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March 26, 2024

TO: Irrigators Association of Minnesota

FR: Vikas Tandon, Ph.D., P.G., Foth Infrastructure & Environment, LLC
Jakob Wartman, P.G., Foth Infrastructure & Environment, LLC
Larry Kramka, Foth Infrastructure & Environment, LLC

RE: Summary of Analysis of Irrigated Lands Across the State of Minnesota Discussion Paper

Foth Infrastructure & Environment, LLC (Foth) performed a review of potential impacts from irrigation withdrawals on groundwater levels and groundwater quality in three different irrigated areas within the state of Minnesota. The results of this review are presented in the attached Discussion Paper. This was a qualitative review that focused on publicly available data over a 30-year time span with data from ~190 wells. The three areas included were:

- the area around Perham,
- Southeast Dakota County, and
- Bonanza Valley.

The groundwater level data was a mix of continuous groundwater level monitors and manual groundwater level measurements. This dataset was robust and allowed Foth to analyze the data for changes to groundwater levels over time. Groundwater quality was also reviewed; however, the publicly available data was not sufficient to make a reasonable conclusion on impacts. In addition to groundwater level and chemistry, this Discussion Paper also reviewed the hydrogeological setting of groundwater in Minnesota and the geology, water supply (precipitation), and general groundwater system of the three areas.

The Discussion Paper provides a qualitative representation of how the groundwater levels are acting in response to irrigation withdrawals in irrigated lands across Minnesota. The data shows that groundwater levels in these irrigated areas have generally remained stable over the last three decades and there is a lack of across-the-board groundwater level declines. The data does not show a net consumptive use of water, which would be shown with groundwater levels decreasing over time across multiple wells. Instead, while there are local changes where the local water table shows declines or increases over time, the net loss from evapotranspiration, baseflow to streams and wetlands, and irrigation related groundwater withdrawals is offset by recharge of the aquifers.

Attachment

Discussion Paper

Missabe Building
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March 26, 2024

Analysis of Groundwater Levels in Select Irrigated Regions of Minnesota

Groundwater from aquifers in Minnesota is critical for supporting a number of uses across the state. These uses include domestic uses (e.g., drinking water supply), industrial uses, agricultural processing, and irrigation.

Foth Infrastructure & Environment, LLC (Foth) was asked to perform a review of groundwater data in various hydrogeologic settings and evaluate changes in water levels over time to determine the magnitude and significance of possible changes to the aquifers from groundwater development. This review assessed the data in three geographic areas in Minnesota that are associated with a high density of agricultural irrigation. While data was generally available over a five-decade period, some of the data records were not continuous or sufficiently long. Therefore, this review, while documenting all available data, focused on evaluating long-term changes at wells with at least three-decades worth of data. This time duration is sufficiently long to ensure that impacts to aquifers due to the increase in groundwater appropriation would be observed. The review focused on water levels as a measure of available water quantity. Impacts to water quality were reviewed, but there was not sufficient data to establish impacts to water quality from increased usage. The results provide a screening level assessment of the potential impacts of water withdrawals in terms of overall groundwater quantity and availability.

Focus Areas and Data Availability

Foth downloaded and reviewed the Cooperative Groundwater Monitoring Program (CGM) data associated with several areas across Minnesota and selected three focus areas. To manage the number of CGM data records analyzed, Foth focused the analysis based on the following factors:

- Data availability and length of records from the wells for water level elevations,
- Number of irrigator wells (data from the Minnesota Department of Health), and
- Data availability from the CGM Program wells for groundwater quality.

Three geographic areas of interest were ultimately selected for this initial review. These include Perham (located in the Otter Tail County in west-central Minnesota), Dakota County (located in east-central part of the state), and Bonanza Valley (located in the central part of the state and mostly in eastern Pope, southwestern Stearns, and northeastern Kandiyohi Counties). These areas have a significant density of irrigation wells as well as monitoring wells for which long-term water level data are available.

Cooperative Groundwater Monitoring Program

The CGM is maintained by the Minnesota Department of Natural Resources (MDNR) in collaboration with the United States Geological Survey. The CGM includes a network of 2,000 wells across Minnesota. As part of this network, MDNR collects static groundwater-level data, along with details of the well construction and geologic setting. The CGM includes wells that are "actively monitored" with use of automated instruments that collect high frequency hourly measurements through the year, while others are classified as being "inactively monitored" with lower frequency of data measurements, typically monthly or quarterly using manual measurements. Both data types were used in our review.

Some of these CGM wells also have water quality data associated with them, however, the water quality data is not collected frequently and was deemed insufficient to make any characterization of long-term change in water quality.

Hydrogeologic Setting

The occurrence and availability of groundwater varies across the state. It is dependent upon the hydrogeologic setting of the area, which in Minnesota is often defined by a combination of the sedimentary deposits (deposited mostly by glaciers at the end of the most recent glacial event, approximately 10,000 to 12,000 years ago) and the underlying bedrock. The sedimentary deposits typically contain fine-grained (e.g., clays and silts) to coarser-grained materials (e.g., sand and gravel) and are unconsolidated (i.e., loosely packed, not cemented). While both the fine-grained materials and coarser-grained materials can contain water, water flows more easily through coarse-grain material. Below the sedimentary deposits the underlying bedrock units are typically consolidated as solid rock. Water cannot easily flow through solid rock but can flow through the fractures, joints, and solution cavities that can exist in the bedrock units.

The following combination of characteristics in the deposits and bedrock that define the water occurrence and availability in various parts of Minnesota include:

- The thickness and the lateral extent of the deposits or bedrock that contain groundwater, i.e., water occurrence, capacity to contain water.
- The properties of these deposits and bedrock that control how water can move through them and how water can be extracted/pumped for use, i.e., water availability for use.

Groundwater formations (aquifers) are recharged from precipitation/rainwater and snowmelt percolating down from land surface. Recharge rates depend upon the amount and intensity of precipitation, soil and vegetation types, geology, topography, and evapotranspiration.

Minnesota has six hydrogeological provinces with a combination of hydrogeologic settings. The settings for the three focus areas are summarized below:

Perham Area – This area lies in the central hydrogeological province. This province is characterized by thick unconsolidated deposits of glacial sediment, with coarse-grained materials like sand and gravel serving as aquifers that supply water to irrigation and other users. These unconsolidated deposits include laterally extensive surficial sandy plains as well as buried sand aquifers underneath the surficial sands. The surficial sands have good water availability and supply potential, while the buried sand aquifers have moderate water availability and supply potential. The deposits are underlain by crystalline bedrock, where water presence and flow are limited to fracture zones. The bedrock in this area typically is a poor source of water and therefore is limited in its ability to function as an aquifer for water supply.

Dakota County Area – This area is primarily located in the east-central hydrogeological province, with the southern part of the county in the karst province. The east-central province is similar to the central province in having surficial and buried sand aquifers. Both of these sandy aquifers have moderate water availability and supply potential. These sandy aquifers are underlain by thick and extensive sandstone and carbonate aquifers, which have good water availability and supply potential. The karst areas of Dakota County have thin, generally less than 50 feet of glacial sediment deposits with limited water availability and supply potential. However, the underlying carbonate and sandstone bedrock often are associated with karst features including fissures, fractures, and sinkholes. These karst features provide a network of inter-connected openings allowing water to flow and be available for pumping. Due to this, the bedrock in the karst areas are a good source of water availability and supply.

Bonanza Valley Area – This area lies in the central hydrogeological province, similar to Perham. Two aquifer systems, both in the unconsolidated sands, serve as sources of water availability and supply. The surficial sandy deposits serve as a water table aquifer, directly connected to the surface and at atmospheric pressure while the underlying buried sandy deposits serve as artesian aquifers, with water under pressure. Groundwater flows between the two sandy aquifers and together they serve as a source of available water and water supply, with the water table sandy aquifer having better water availability and supply potential. The sandy aquifers are in turn underlain by crystalline bedrock, where water presence and flow are limited to fractured rock zones and serve as a limited aquifer for water supply.

Data Analysis – Net Consumptive Use of Water

The focus areas were refined based on the available data and are described in the following sections. The methodology for each area of analysis was repeated and consisted of the following elements:

- The CGM wells and irrigation well locations were overlain on a base map.
- A visual inspection of the plotted points was completed to select an area with reasonable density of CGM and irrigation wells.
- To identify the changes and trends in groundwater levels, Foth plotted the maximum and average water levels over the course of each year for the entire period of well records. The maximum water level would encompass the annual rebound and the annual average encompasses the seasonality.
- Net change criteria and analysis was conducted on the average annual water levels over each of the wells' period of record. Net change criteria was assigned to characterize water levels as exhibiting no change, positive net change (increased water levels), and negative net change (reduced water levels) reviewed based on the following arbitrary thresholds:
  - No change is considered to be the average annual water level at a particular well and did not change by more than 1/10th of a foot over the period of record.

- Positive net change is considered to be at the end of the period of record for a particular well, the average annual water level was higher than at the end of the initial year of monitoring by more than 1/10th of a foot. In other words, water levels increased from the first year the well was developed.
- Negative net change is considered to be at the end of the period of record for a particular well, the average annual water level was lower than at the end of the initial year of monitoring by more than 1/10th of a foot. In other words, water levels decreased from the first year the well was constructed.

Perham Area of Analysis – Figure 1 shows the locations of the CGM wells and irrigation wells. A sub-area, approximately 12 miles x 18 miles, shown within the blue outline on Figure 1 was selected as the area of analysis for detailed evaluation of water level changes over time. This selected area of analysis was determined to have a good density and overlap of irrigation wells as well as CGM wells with available water level data with long record periods (three decades or more).

Data from a total of 29 actively monitored and 52 not-actively monitored CGM wells were processed. The maximum annual water levels were plotted and are shown on Figures 2-A (actively monitored wells) and 2-B (not-actively monitored wells), while the average annual water levels are shown on Figures 3-A (actively monitored wells) and 3-B (not-actively monitored wells). To better look for any trends, trendlines were fitted to both the maximum annual water level (Figures 4-A and 4-B, for actively and not-actively monitored wells, respectively) and the average annual water level data (Figures 5-A and 5-B, for actively and not-actively monitored wells, respectively). When the data and data trends for the wells are reviewed, both the maximum and annual water levels appear to be generally stable over the long term, i.e., there is no apparent systematic or across-the-board long-term depletion (reduction) of water levels in the intensely irrigated areas around Perham.

The lack of long-term depletion of water levels in the area indicates that the volume of water withdrawals (from all uses) does not exceed the volume of water returned to the groundwater aquifer system. The returned water to the groundwater system includes natural and human-caused recharge. Natural recharge originates from precipitation and includes the fraction of rainwater and snowmelt percolating down from land surface, while excluding the fraction that flows overland on the surface to nearby surface water bodies or is removed by evapotranspiration. Human-caused recharge includes the percolation of a part of the irrigation water back into the groundwater underlying the agricultural areas.

The lack of long-term depletion of water levels is interpreted as that there is no net consumptive use in the irrigated areas, and the water levels are able to recover from all uses including irrigation well withdrawals due to a combination of natural and human caused recharge.

As a further validation, Foth reviewed the net change in average annual water levels analysis results. The long-term net changes in water levels, for wells that have at least a three-decade period of record, are shown on Figures 6-A for actively monitored wells and 6-B for not-actively monitored wells. The plotted values show that after the first year of well development the average annual water levels do not represent a systemic decline year over year regardless of the net change being positive or negative. The data confirms that there is lack of across-the-board groundwater level declines resulting in net consumptive use across the entire Perham area as a collective.

Dakota County Area of Analysis – Figure 7 shows the location of CGM wells and irrigation wells within Dakota County. A sub-area, approximately 15 miles x 19 miles, shown within the blue outline on Figure 7 was selected as area of analysis for detailed evaluation of water level changes over time. The area of analysis was determined to have a good density and overlap CGM and irrigation wells with available water level data with long record periods (three decades or more).

Data for a total of 33 actively monitored CGM wells and 28 not-actively monitored CGM wells were processed. Foth calculated and plotted the maximum and average water levels over the course of each year for the entire time period of well records. The maximum annual water levels were plotted and are shown on Figures 8-A (actively monitored wells) and 8-B (not-actively monitored wells), while the average annual water levels are shown on Figures 9-A (actively monitored wells) and 9-B (not-actively monitored wells). Trendlines were fitted to both the maximum annual water level (Figures 10-A and 10-B, for actively and not-actively monitored wells, respectively) and the average annual water level data (Figures 11-A and 11-B, for actively and not-actively monitored wells, respectively). When the data and data trends for the wells are reviewed, both the maximum and annual water levels appear to be generally stable over the long term, i.e., there is no apparent systematic or across-the-board long-term depletion (reduction) of water levels in the intensely irrigated areas around Dakota County.

The consistent lack of long-term depletion of water levels across the wells in the area indicates that there is no system-wide exceedance of the volume of water withdrawn (by all uses) than the volume of water returned to the groundwater aquifer system. The lack of long-term depletion of water levels is interpreted to indicate that there is no net consumptive use in the area of analysis, and the water levels are able to recover from the irrigation and all other withdrawals due to a combination of natural and human caused recharge.

As further validation, Foth reviewed the long-term net changes in average annual water levels. The results of that review are shown on Figures 12-A for actively monitored wells and 12-B for not-actively monitored wells. The plotted values show that after the first year of well development the average annual water levels do not represent a systemic decline year over year regardless of the net change being positive or negative. The data confirms that there is lack of across-the-board groundwater level declines resulting in net consumptive use across the entire Dakota County area as a collective.

Bonanza Valley Area of Analysis – Figure 13 shows the location of CGM wells and irrigation wells within the Bonanza Valley. A sub-area, approximately 28 miles x 9 miles, shown within the blue outline on Figure 13 was selected as area of analysis for detailed evaluation of water level changes over time. The area of analysis was determined to have a good density and overlap of irrigation wells as well as CGM wells with available water level data with long record periods (three decades or more).

Data for a total of 30 actively monitored CGM wells and 26 not-actively monitored CGM wells were processed. Foth calculated and plotted the maximum and average water levels over the course of each year for the entire time period of well records. The maximum annual water levels were plotted and are shown on Figures 14-A (actively monitored wells) and 14-B (not-actively monitored wells), while the average annual water levels are shown on Figures 15-A (actively monitored wells) and 15-B (not-actively monitored wells). Trendlines were fitted to both the maximum annual water level (Figures 16-A and 16-B, for actively and not-actively monitored wells, respectively) and the average annual water level data (Figures 17-A and 17-B, for actively and not-actively monitored wells, respectively). When the data and data trends for the wells are reviewed, both the maximum and annual water levels appear to be generally stable over the long term, i.e., there is no apparent systematic or across-the-board long-term depletion (reduction) of water levels in the intensely irrigated areas around Bonanza Valley.

The consistent lack of long-term depletion of water levels across the wells in the area indicates that there is no system-wide exceedance of the volume of water withdrawn (by all uses) than the volume of water returned to the groundwater aquifer system. The lack of long-term depletion of water levels is interpreted as that there is no net consumptive use in the area of analysis, and the water levels are able to recover from the irrigation and all other water withdrawals due to a combination of natural and human caused recharge.

As further validation, Foth reviewed the long-term net changes in average annual water levels, The results of that review are shown on Figure 18-A for actively monitored wells and Figure 18-B for not-actively monitored wells. The plotted values show that after the first year of well development the average annual water levels do not represent a systemic decline year over year regardless of the net change being positive or negative. The data confirms that there is lack of across-the-board groundwater level declines resulting in net consumptive use across the entire Bonanza area as a collective.

Spatial Patterns of Net Changes Across Focus Areas

The locations of actively and not-actively monitored wells, which were analyzed for long-term net change in water levels in the preceding sections, are displayed on Figure 19 (Perham), Figure 20 (Dakota County), and Figure 21 (Bonanza Valley). The locations were color coded to represent the direction of net change in water level (rising, stable, or declining water) and reviewed in context of the locations of irrigation wells in the areas, which are also displayed on these figures. Across each of the three focus areas, there is a lack of spatial pattern or apparent correlation between the long-term net change in water level and the location of irrigation well clusters. This indicates that the data does not support the existence of an apparent and systematic long-term water level decline associated with the combined water withdrawals from all users or irrigation across the focus areas.

Water Quality Changes

Foth reviewed the publicly available water quality information associated with the CGM monitoring wells. Table 1 shows an inventory of the available water quality data. The number of monitoring locations are limited, with only two locations for the entire Perham area, eight locations for Dakota County – more than half of which only have a single measurement, and six locations in the Bonanza Valley. These limited locations with multiple snapshots in time did not have a long enough data record for a representative of long-term effects of groundwater pumping impacts on the water quality of the aquifers. Considering that each of the three focus areas encompass hundreds of square miles, yet water quality data is available at only a handful of locations over short time durations, it was decided to forgo the evaluation of water quality changes to avoid extrapolation and mischaracterization.

Discussion

Water level trends and net changes were evaluated for three areas across Minnesota where groundwater is used for irrigation. This analysis provides a review of publicly available data. The data includes provisional (not reviewed and qualified) and older data that may not be of the same standard of care. Some of the data plots may show occasional data points that deviate from antecedent and/or succeeding trends. These deviations may be natural or instrumental measurement related and are used as reported in the agency data. However, given the amount of data that was available for water levels in each of the three focus areas (Perham, Dakota County, and Bonanza Valley), the data is sufficient in providing a representative picture of how the groundwater levels are acting in response to irrigation withdrawals in irrigated lands across Minnesota. In addition, the inclusion of deviations from the antecedent/succeeding trends in the analysis provides a conservative analysis of water level changes.

The data shows that groundwater levels have remained generally stable in the three decade or longer period of record that was analyzed, even with increased permitted appropriations and usage, demonstrating that the groundwater system is resilient and water withdrawals are apparently balanced by replenishment through recharge from precipitation and connected surface water resources. The data confirms that there is lack of across-the-board groundwater level declines that if present would have resulted in net consumptive use of water.

This qualitative assessment shows that impacts related to groundwater withdrawals within the area of review are temporary, e.g., annual water levels rebound to average conditions following seasonal agricultural irrigation. While there are local changes where the local water table shows declines or increases over time, the net loss from evapotranspiration, baseflow to streams and wetlands, and groundwater withdrawals from all users is offset by recharge of the aquifers on an across the area basis.

Attachments
- Table
- Figures

Table

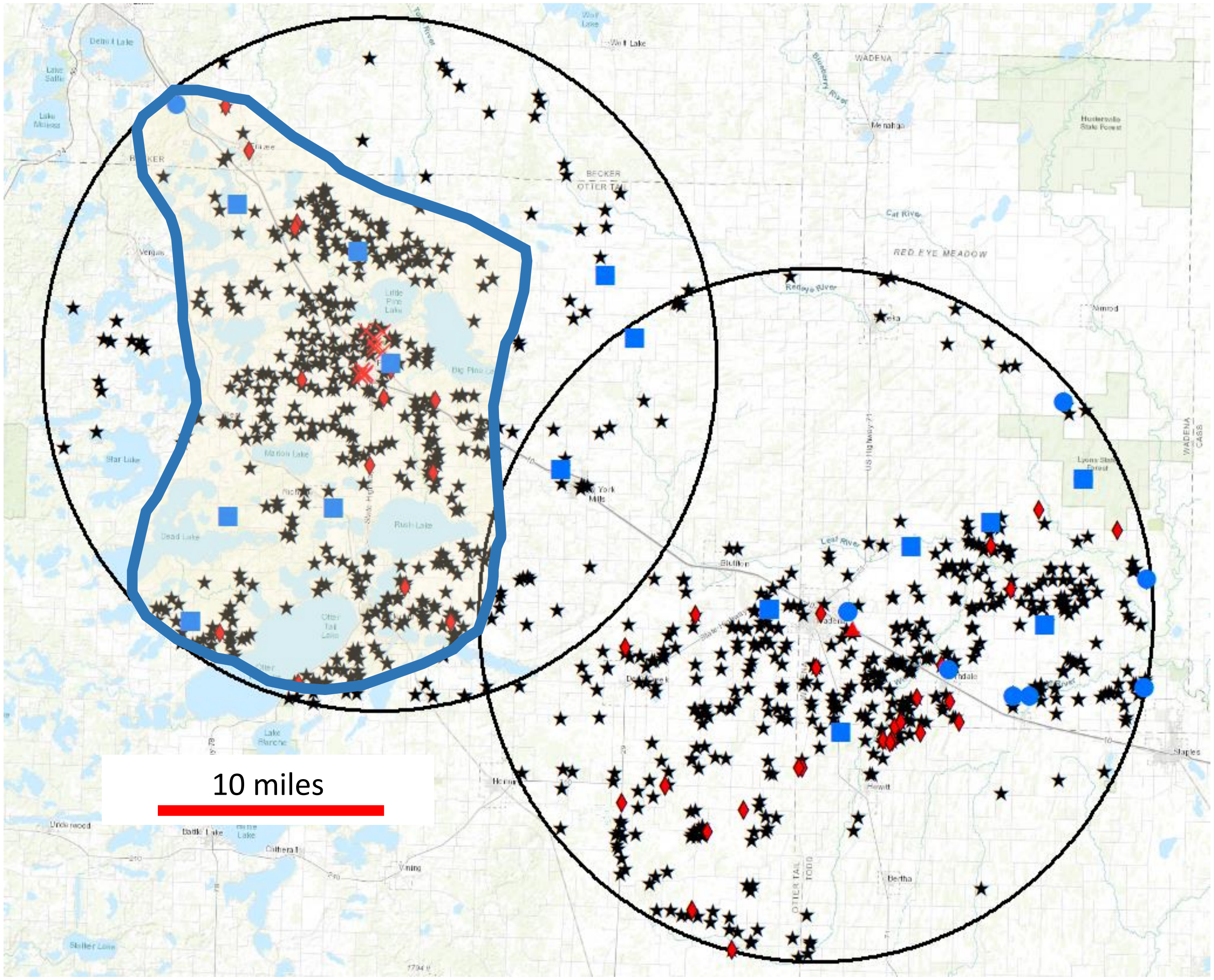
Table 1

Inventory of Available Water Quality Data

Area	Station ID	Days of Available Data	Years of Available Data	Parameter Data Availability			Number of Data Points		
				Nitrates	Pesticide-Related Constituents	Other Parameters	Nitrates	Pesticide Related Constituents	Other Parameters
Perham	244561	multiple years	3	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	3	3	No Data
	244577	multiple years	4	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	5	5	No Data
Dakota County	229948	1	<1	No Data	-	Inorganics; Metals	No Data	No Data	30
	708369	multiple years	12	No Data	Pesticides	Inorganics; Metals; Volatile Organics; Organics, PCBs	No Data	120	1326
	769458	1	<1	No Data	No Data	Inorganics; Metals; Volatile Organics; Organics, etc.	No Data	No Data	105
	779930	1	<1	No Data	No Data	Inorganics; Metals; Volatile Organics; Organics, etc.	No Data	No Data	105
	779931	multiple years	2	No Data	No Data	Inorganics; Metals; Volatile Organics; Organics, etc.	No Data	No Data	223
	779932	multiple years	3	No Data	No Data	Inorganics; Metals; Volatile Organics; Organics, etc.	No Data	No Data	326
	799886	multiple years	<1	No Data	No Data	Inorganics; Metals; Volatile Organics; Organics, etc.	No Data	No Data	30
	799887	1	<1	No Data	No Data	Inorganics; Metals; Volatile Organics; Organics, etc.	No Data	No Data	30
Bonanza Valley	243897	1	<1	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	1	1	No Data
	244288	multiple years	7	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	13	14	No Data
	244313	multiple years	10	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	40	39	No Data
	244483	multiple years	3	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	4	4	No Data
	244490	multiple years	3	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	3	3	No Data
	270262	multiple years	10	Inorganic nitrogen (nitrate and nitrite)	Atrazine	No Data	34	35	No Data

Prepared by: BNK
Checked by: VXT

Figures



NOTES:

LEGEND

- CGM Actively Monitored with Permit Required Monitoring
- CGM Actively Monitored with Water Quality Data
- CCGM Actively Monitored with Only GW Level Data
- CGM Not Actively Monitored with Permit Required Monitoring
- CGM Not Actively Monitored with Water Quality Data
- CGM Not Actively Monitored with Only GW Level Data
- Irrigation Wells

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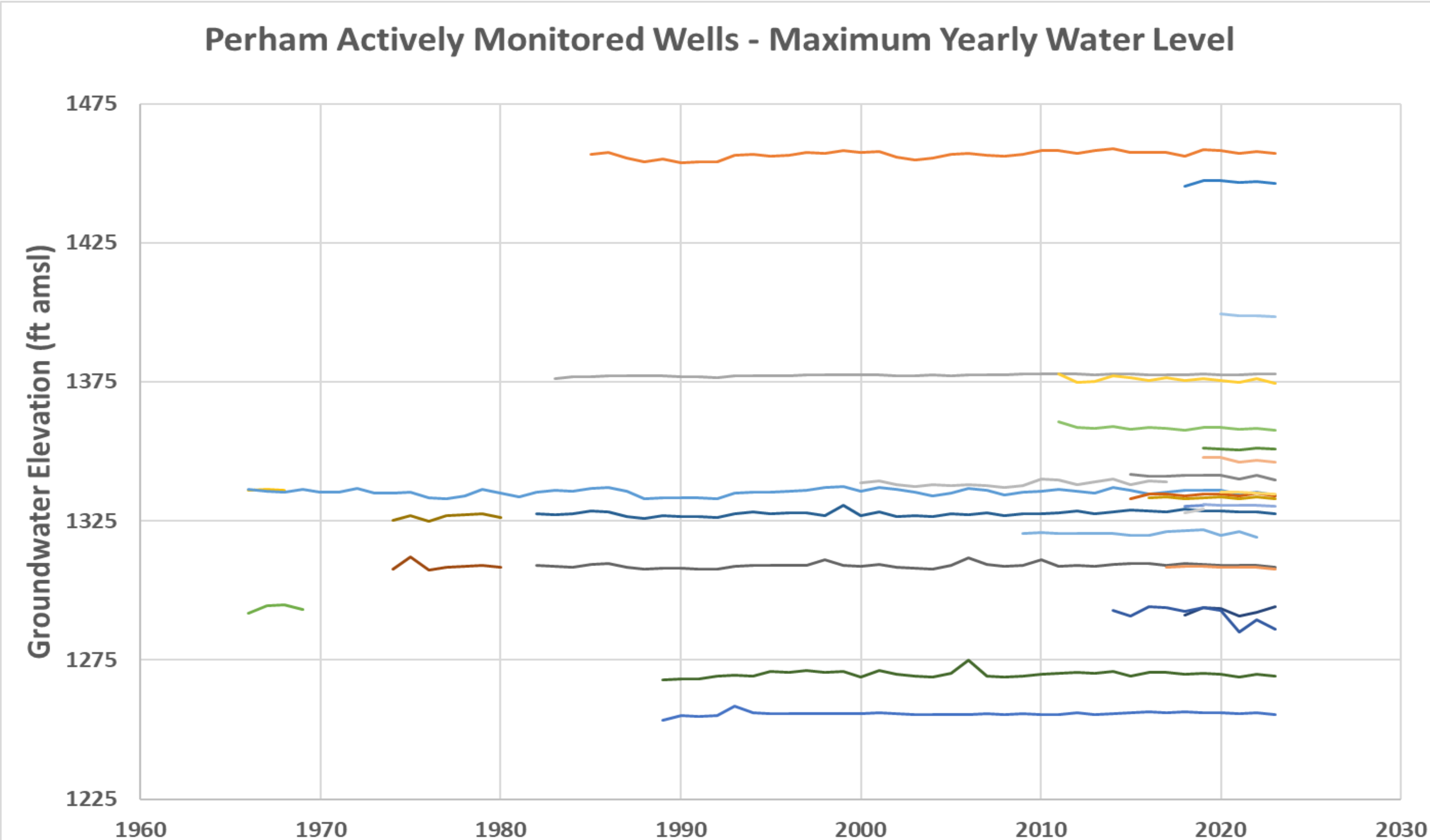
FIGURE 1

GROUNDWATER WELL DATA AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

139193	243596	226168	244561	244568_1	244568_2
244571_1	244571_2	244577_1	244577_2	431180	431181
543620	603814	609556	708374	783228	792507
809289	714934	816902	821232	832492	834152
834154	834156	838529	847288	847289	

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FIGURE 2-A

MAX YEARLY WATER LEVEL AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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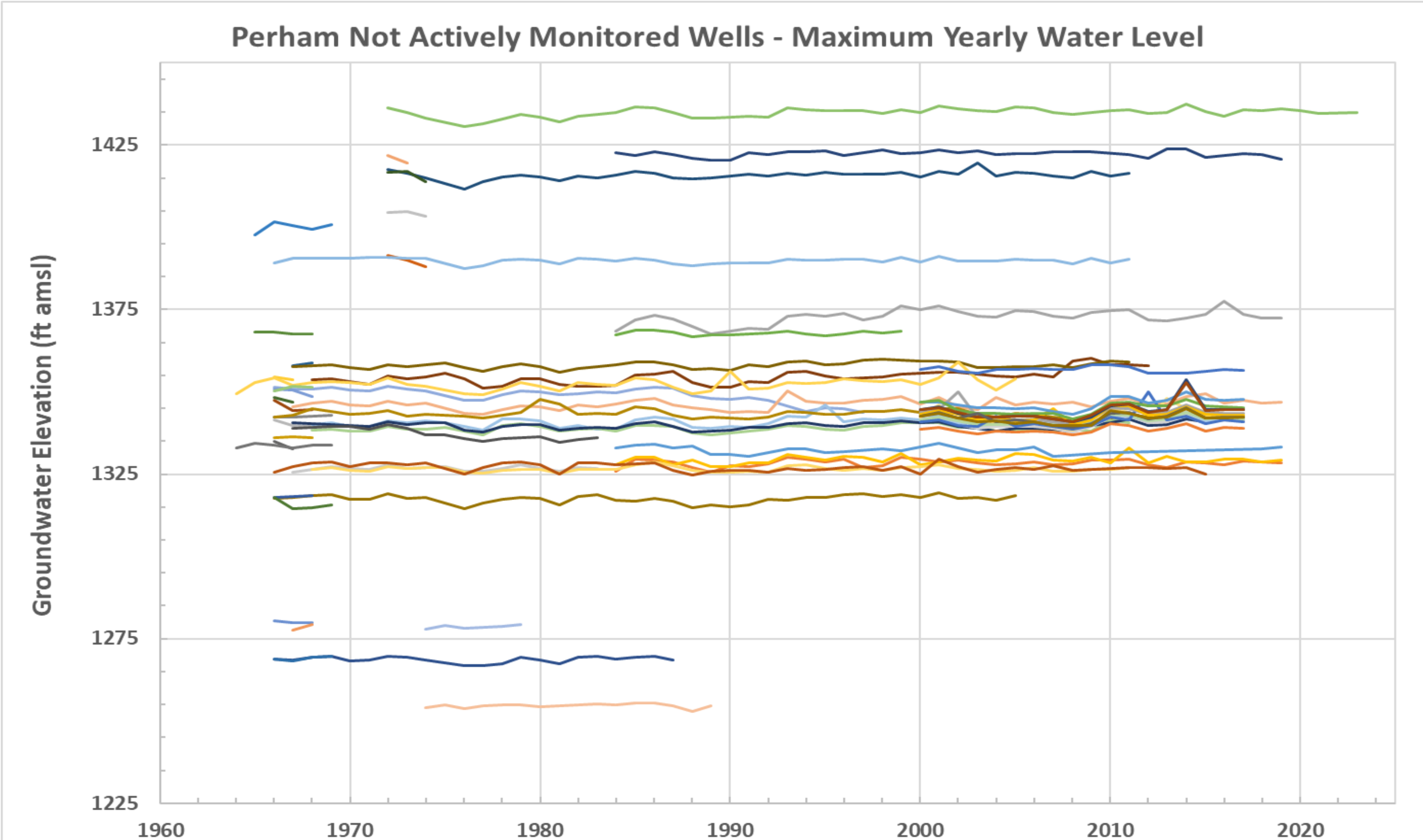
Date: 2/7/2024



NOTES:

LEGEND

103938	105720	129247	165254	175914	214275	214599	214659
214660	214679	214680	214688	214690	214713	214714	215885
215916	220368	226151	226168	243483	243484	244246	244247
244248	244249	244255	244256	244258	244262	244263	244270
244271	244532	244533	244533	244534	244560	244562	244536
244564	244565	244567	244575	244576	609551	609556	609560
609562	609563	609565	609566				

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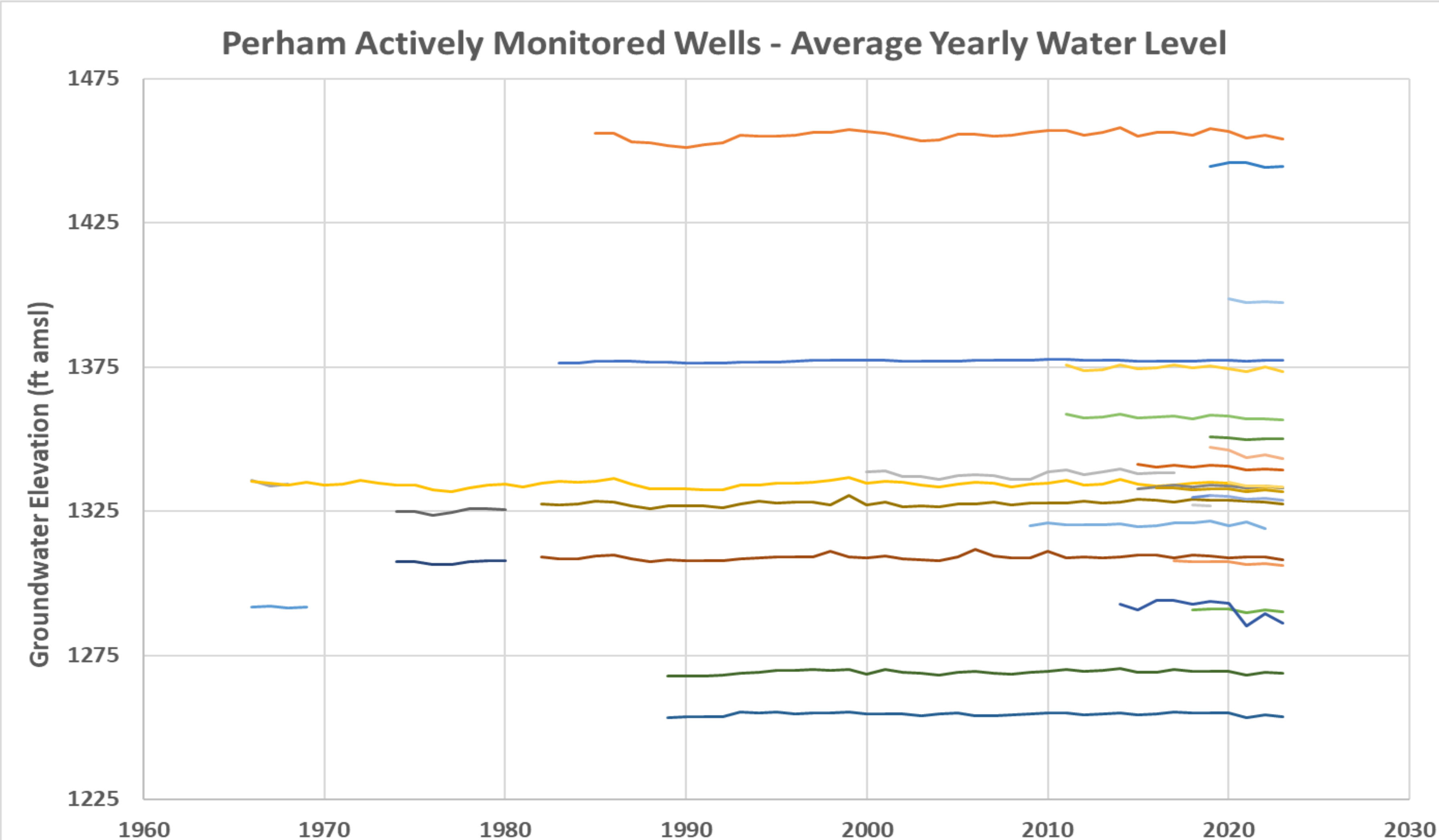
FIGURE 2-B

MAX YEARLY WATER LEVEL AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

139193	226168	243596	244561	244568_1	244568_2
244571_1	244571_2	244577_1	244577_2	431180	431181
543620	603814	609556	708374	714934	783228
792507	809289	816902	821232	832492	834152
834154	834156	838529	847288	847289	

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FIGURE 3-A

AVG YEARLY WATER LEVEL AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
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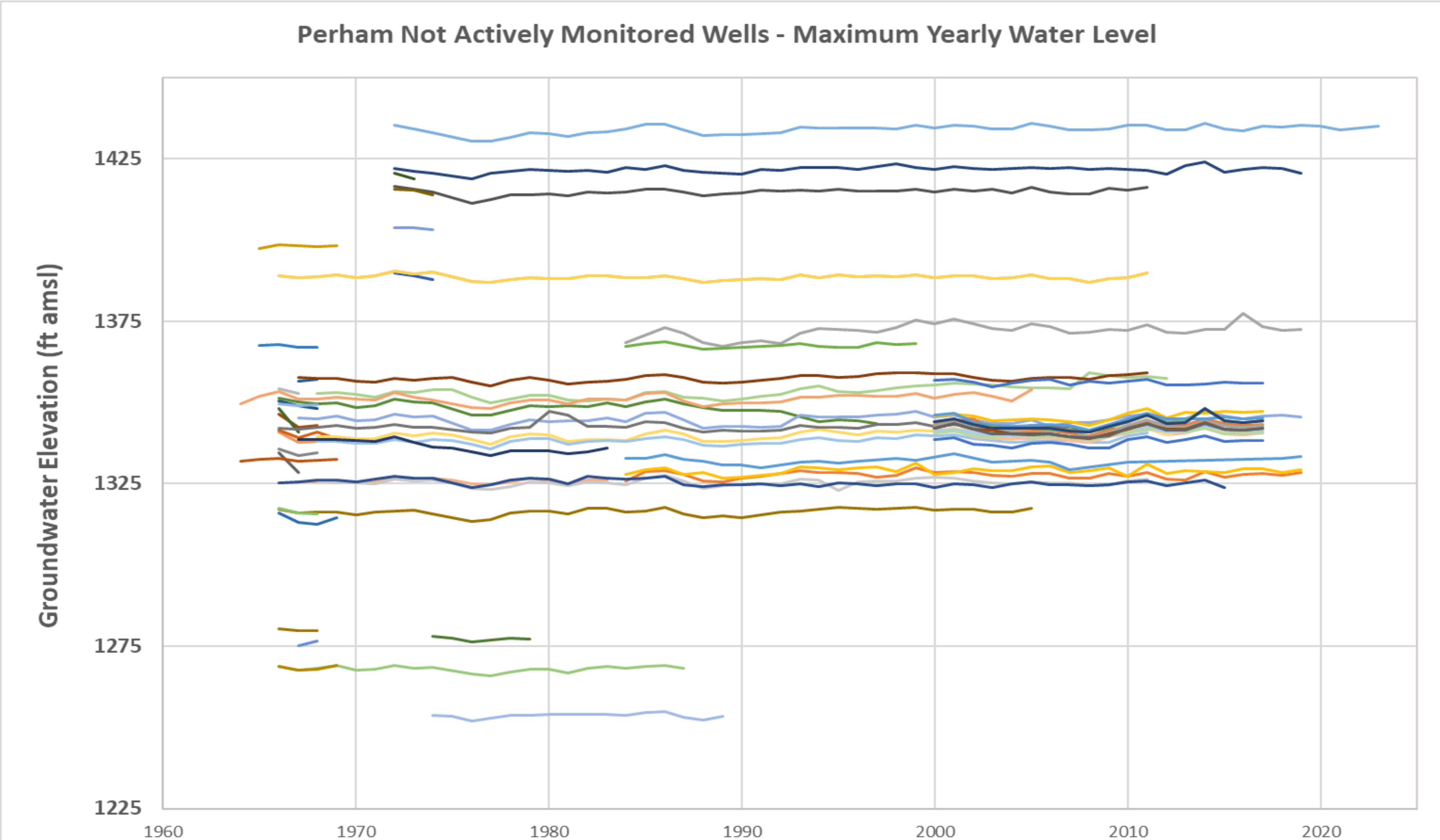

NOTES:

LEGEND

103938	105720	129247	165254	175914	214275	214599	214659
214660	214679	214680	214688	214690	214713	214714	215885
215916	220368	226151	226168	243483	243484	244246	244247
244248	244249	244255	244256	244258	244262	244263	244270
244271	244532	244533	244533	244534	244560	244562	244536
244564	244565	244567	244575	244576	609551	609556	609560
609562	609563	609565	609566				

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FIGURE 3-B AVG YEARLY WATER LEVEL AROUND PERHAM 2024 IRRIGATED AREAS ANALYSIS NOT-ACTIVELY MONITORED WELLS		
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Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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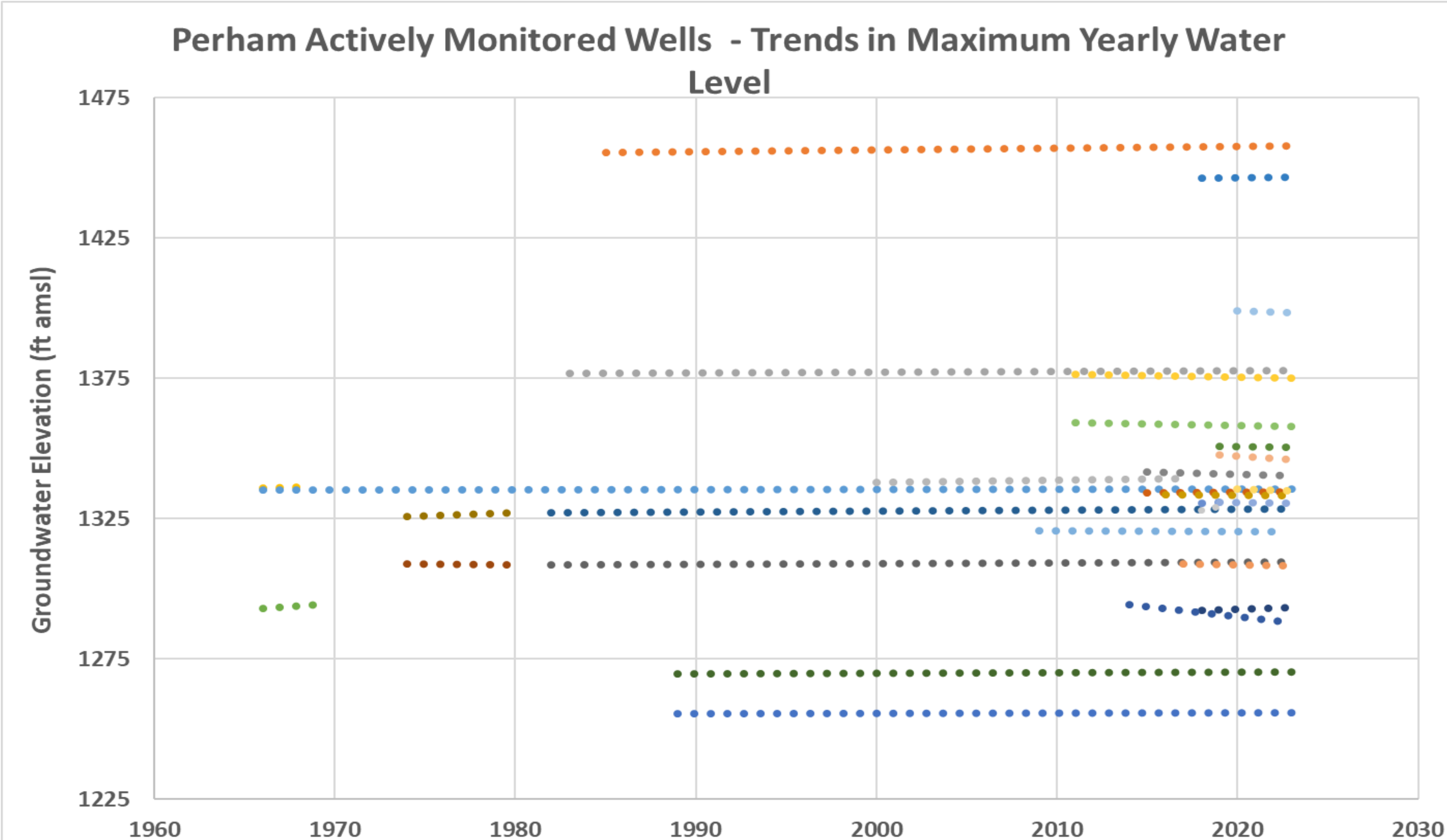
Date: 2/7/2024



NOTES:

LEGEND

Linear (139193)	Linear (243596)	Linear (226168)	Linear (244561)
Linear (244568_1)	Linear (244568_2)	Linear (244571_1)	Linear (244571_2)
Linear (244577_1)	Linear (244577_2)	Linear (431180)	Linear (431181)
Linear (543620)	Linear (603814)	Linear (609556)	Linear (708374)
Linear (783228)	Linear (792507)	Linear (809289)	Linear (714934)
Linear (816902)	Linear (821232)	Linear (832492)	Linear (834152)
Linear (834154)	Linear (834156)	Linear (838529)	Linear (847288)
Linear (847289)			

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FIGURE 4-A

TRENDS IN MAX YEARLY WATER LEVEL AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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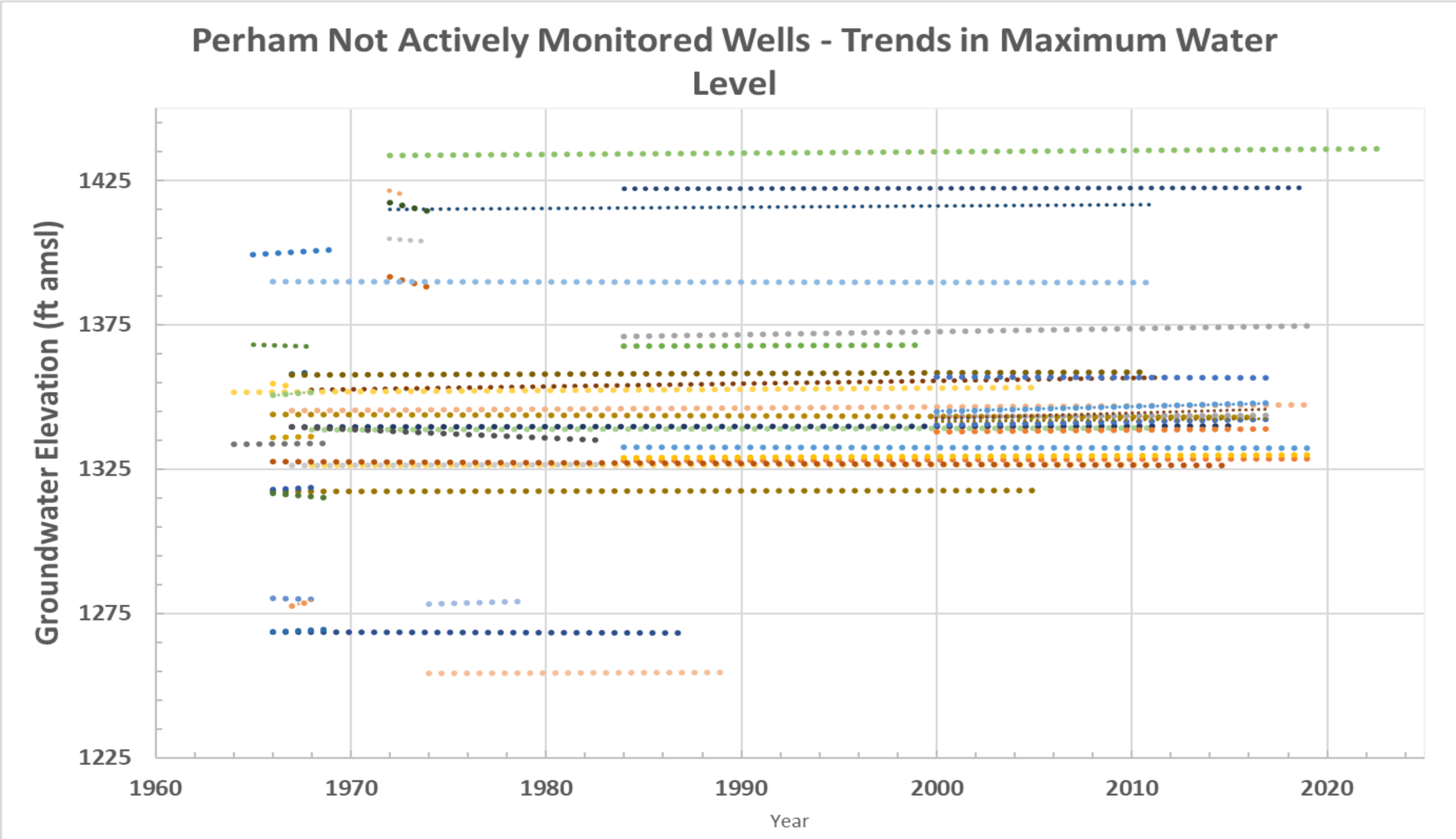


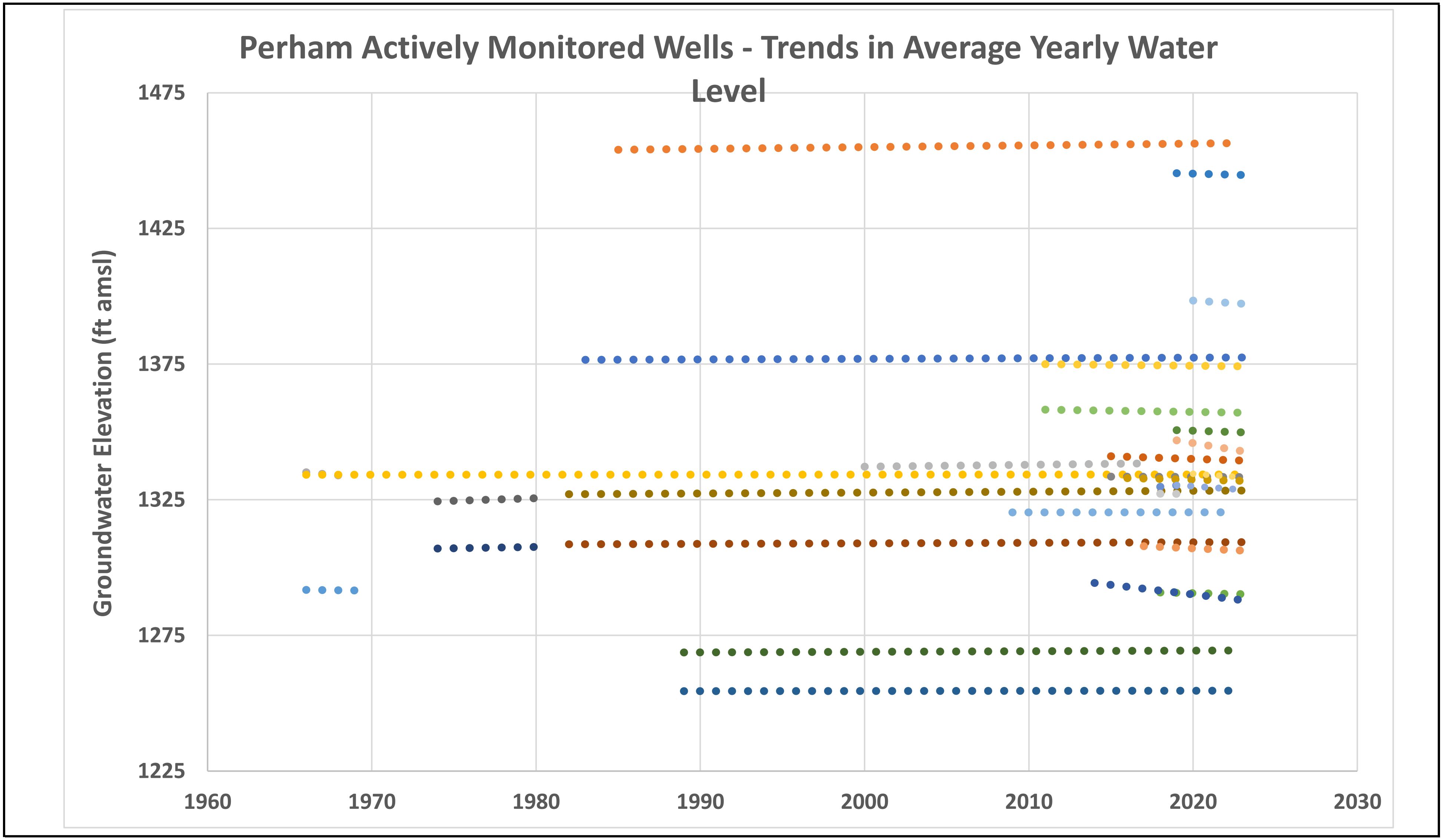
NOTES:

LEGEND

Linear (103938)	Linear (105720)	Linear (129247)	Linear (165254)	Linear (175914)	Linear (214275)
Linear (214599)	Linear (214659)	Linear (214660)	Linear (214679)	Linear (214680)	Linear (214688)
Linear (214690)	Linear (214713)	Linear (214714)	Linear (215885)	Linear (215916)	Linear (220368)
Linear (226151)	Linear (226168)	Linear (243483)	Linear (243484)	Linear (244246)	Linear (244247)
Linear (244248)	Linear (244249)	Linear (244255)	Linear (244256)	Linear (244258)	Linear (244262)
Linear (244263)	Linear (244270)	Linear (244271)	Linear (244532)	Linear (244533)	Linear (244533)
Linear (244534)	Linear (244560)	Linear (244562)	Linear (244536)	Linear (244564)	Linear (244564)
Linear (244565)	Linear (244567)	Linear (244575)	Linear (244576)	Linear (609556)	Linear (609560)
Linear (609562)	Linear (609563)	Linear (609565)	Linear (609566)		

Foth

IRRIGATORS ASSOCIATION OF MINNESOTA		
FIGURE 4-B TRENDS IN MAX YEARLY WATER LEVEL AROUND PERHAM 2024 IRRIGATED AREAS ANALYSIS NOT-ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

Linear (139193)	Linear (226168)	Linear (243596)	Linear (244561)	Linear (244568_1)
Linear (244568_2)	Linear (244571_1)	Linear (244571_2)	Linear (244577_1)	Linear (244577_2)
Linear (431180)	Linear (431181)	Linear (543620)	Linear (603814)	Linear (609556)
Linear (708374)	Linear (714934)	Linear (783228)	Linear (792507)	Linear (809289)
Linear (816902)	Linear (821232)	Linear (832492)	Linear (834152)	Linear (834154)
Linear (834156)	Linear (838529)	Linear (847288)	Linear (847289)	

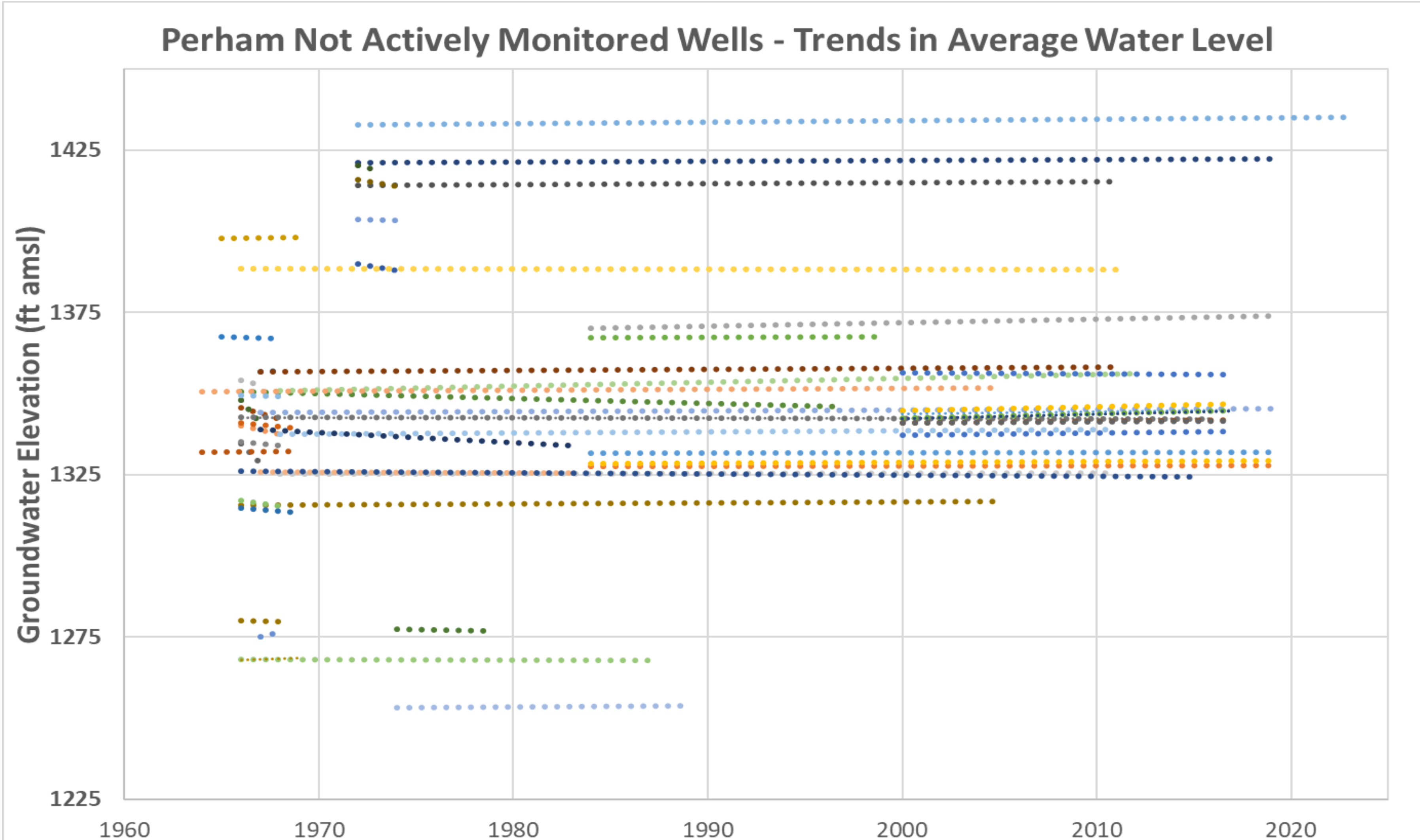
Foth

IRRIGATORS ASSOCIATION OF MINNESOTA

FIGURE 5-A

TRENDS IN AVG YEARLY WATER LEVEL AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

Linear (103938)	Linear (105720)	Linear (129247)	Linear (165254)	Linear (175914)	Linear (214275)
Linear (214599)	Linear (214659)	Linear (214660)	Linear (214679)	Linear (214680)	Linear (214688)
Linear (214690)	Linear (214713)	Linear (214714)	Linear (215885)	Linear (215916)	Linear (220368)
Linear (226151)	Linear (226168)	Linear (243483)	Linear (243484)	Linear (244246)	Linear (244247)
Linear (244248)	Linear (244249)	Linear (244255)	Linear (244256)	Linear (244258)	Linear (244262)
Linear (244263)	Linear (244270)	Linear (244271)	Linear (244532)	Linear (244533)	Linear (244533)
Linear (244534)	Linear (244560)	Linear (244562)	Linear (244536)	Linear (244564)	Linear (244564)
Linear (244565)	Linear (244567)	Linear (244575)	Linear (244576)	Linear (609556)	Linear (609560)
Linear (609562)	Linear (609563)	Linear (609565)	Linear (609566)		

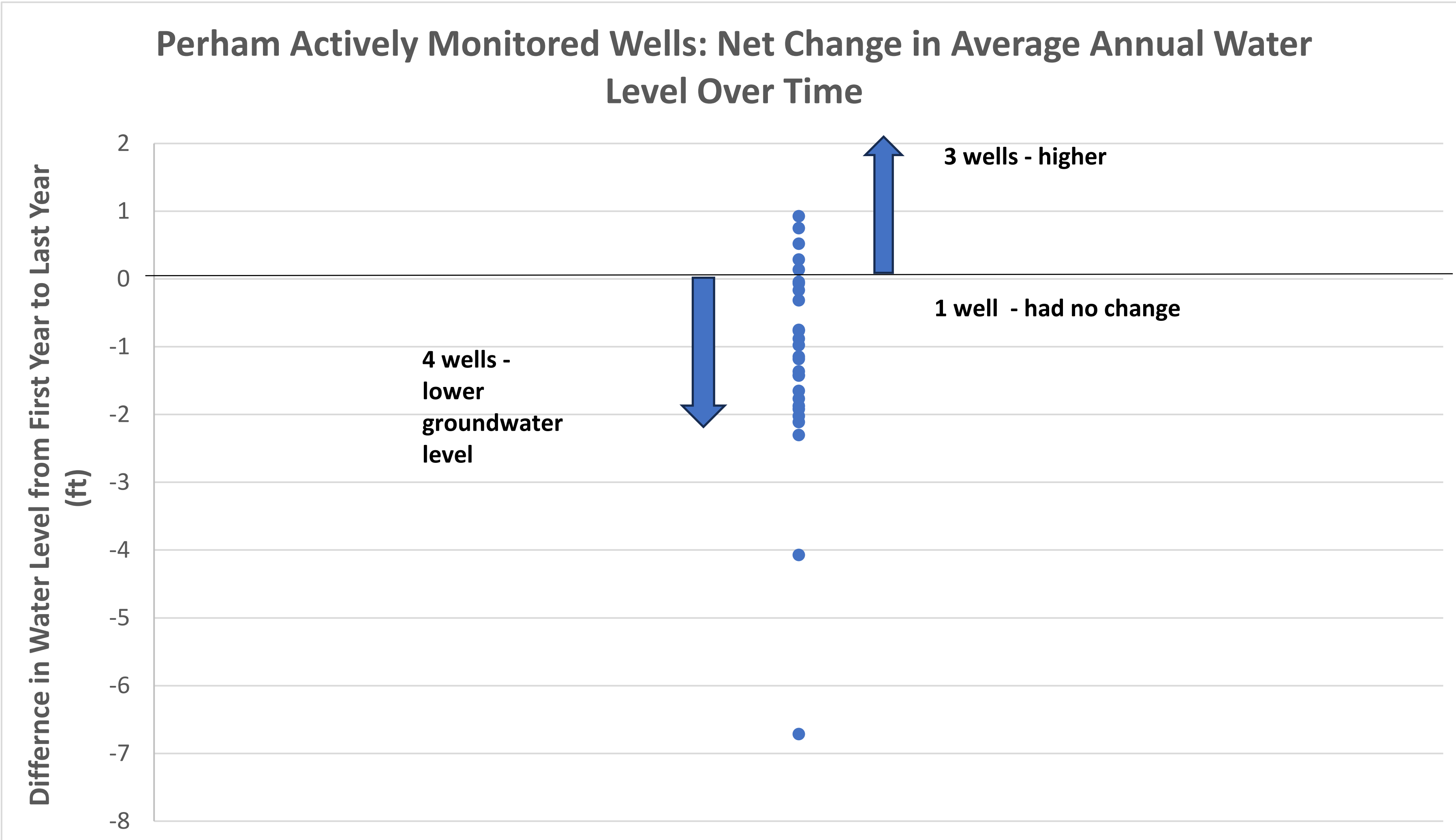
Foth

IRRIGATORS ASSOCIATION OF MINNESOTA

FIGURE 5-B

TRENDS IN AVG YEARLY WATER LEVEL AROUND PERHAM
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

Only wells with at least 30 year period of record were used for establishing long term water level change.

LEGEND

IRRIGATORS ASSOCIATION OF MINNESOTA		
FIGURE 6-A NET CHANGE IN WATER LEVEL AROUND PERHAM 2024 IRRIGATED AREAS ANALYSIS ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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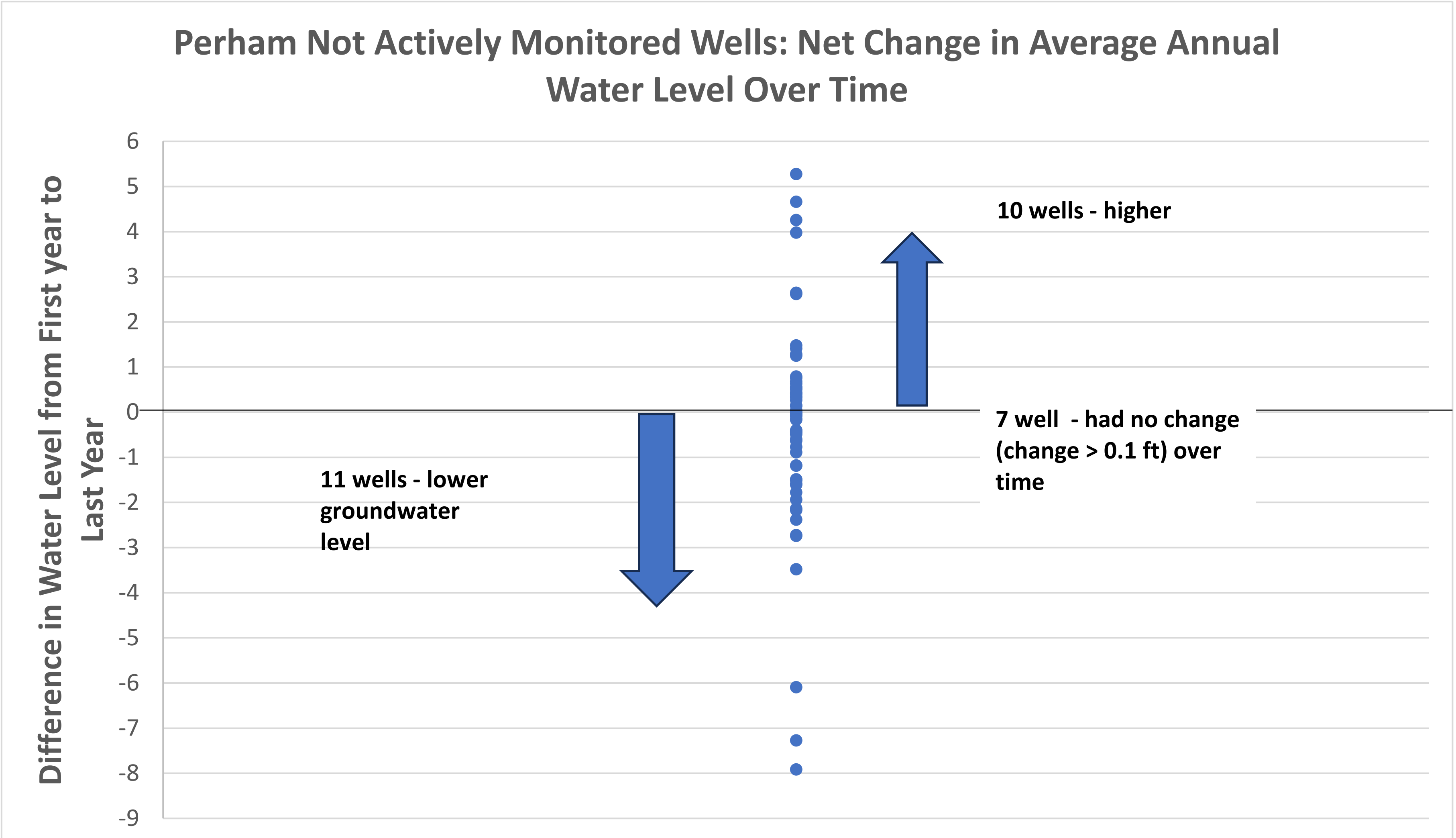
Date: 2/7/2024



NOTES:

Only wells with at least 30 year period of record were used for establishing long term water level change.

LEGEND

IRRIGATORS ASSOCIATION OF MINNESOTA		
FIGURE 6-B NET CHANGE IN WATER LEVEL AROUND PERHAM 2024 IRRIGATED AREAS ANALYSIS NOT-ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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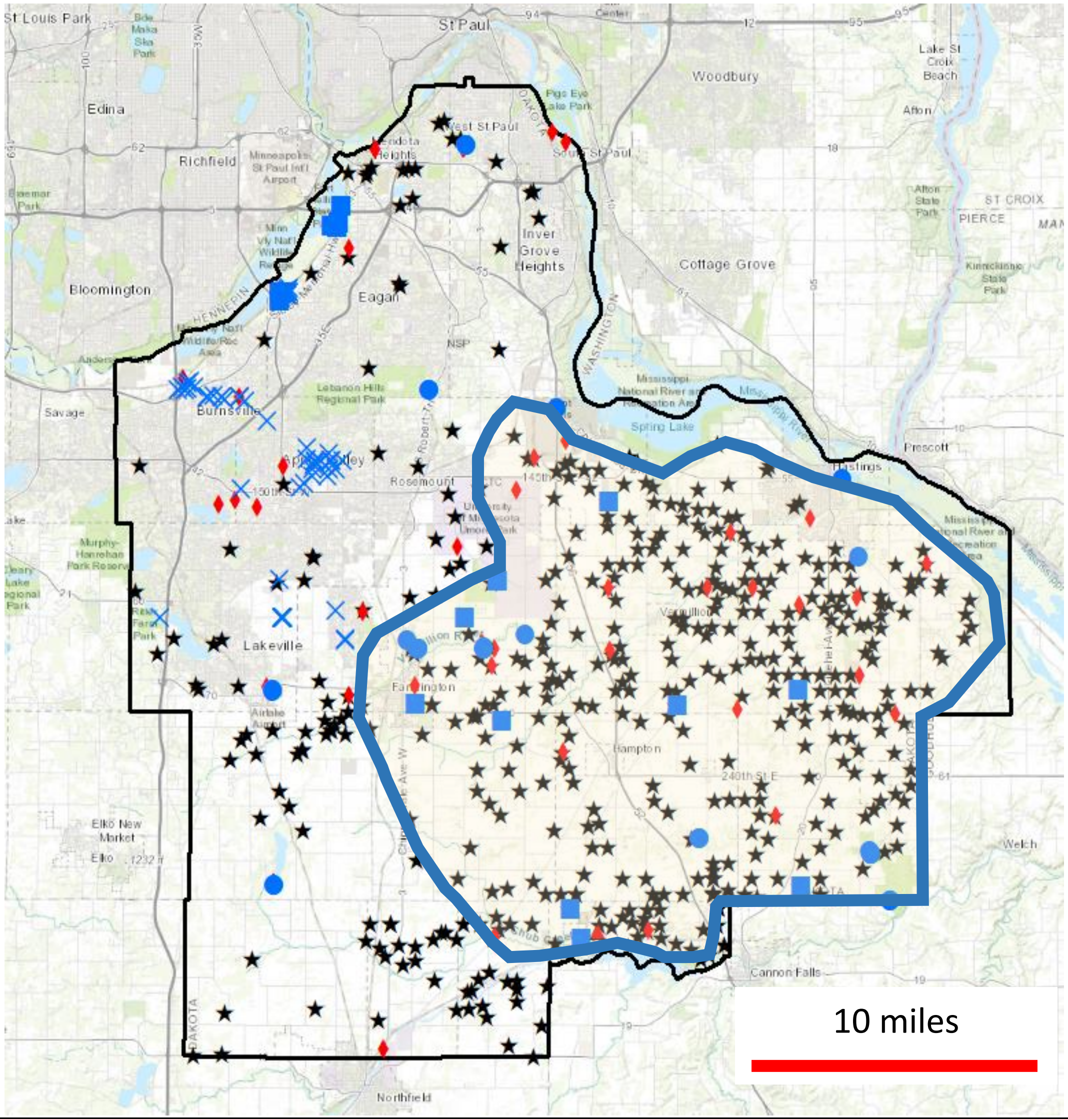
Date: 2/7/2024



NOTES:

LEGEND

- CGM Actively Monitored with Permit Required Monitoring
- CGM Actively Monitored with Water Quality Data
- CCGM Actively Monitored with Only GW Level Data
- CGM Not Actively Monitored with Permit Required Monitoring
- CGM Not Actively Monitored with Water Quality Data
- CGM Not Actively Monitored with Only GW Level Data
- Irrigation Wells

Foth

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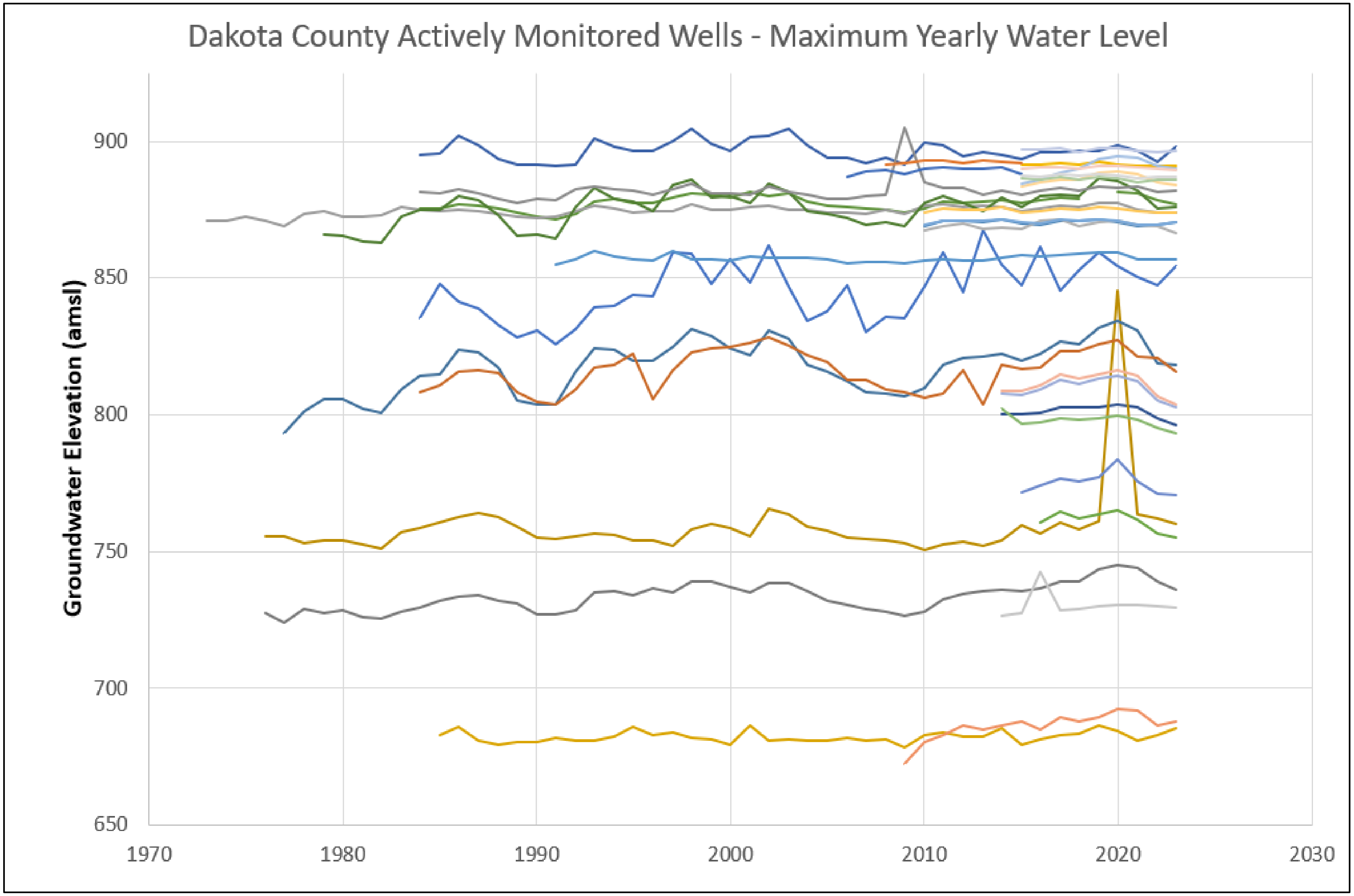
FIGURE 7

GROUNDWATER LEVEL DATA AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

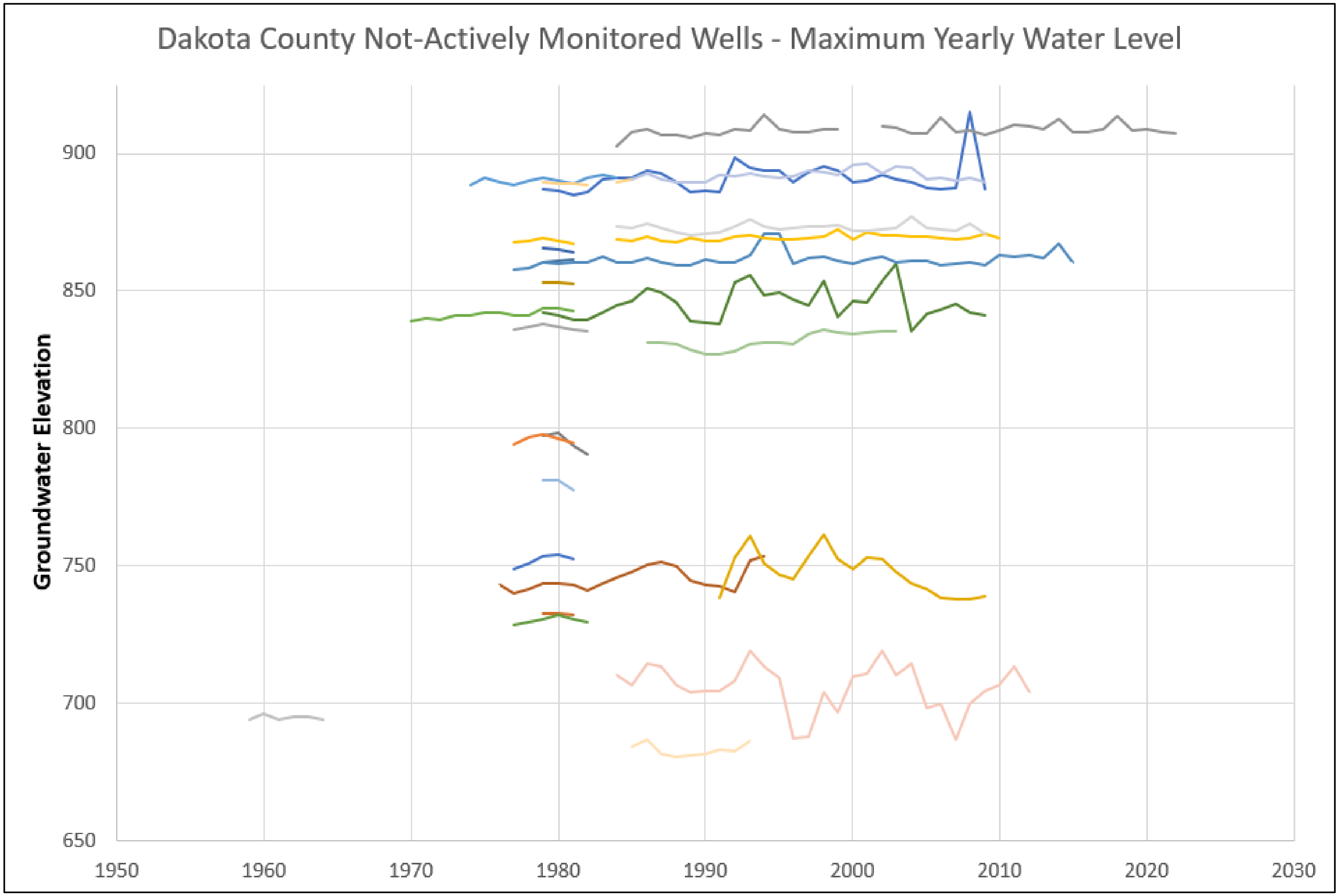
120158	170885	207650	216228	227972	229948	243739	243746	243754
243769	243772	243774	243775	243778	708369	731135	759589	767144
767145	769458	779930	779931	779932	799885	799886	799887	800955
806093	806094	809288	812238	812241	813731			

IRRIGATORS ASSOCIATION OF MINNESOTA

FIGURE 8-A

MAX YEARLY WATER LEVEL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

101062, 104319, 120168, 121806, 121846, 129239, 132216, 136465, 175910, 227975, 243738, 243740, 243741, 243742, 243743, 243744, 243745, 243747, 243748, 243749, 243750, 243765, 243768, 243770, 243771, 243773, 243776, 243779

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FIGURE 8-B

MAX YEARLY WATER LEVEL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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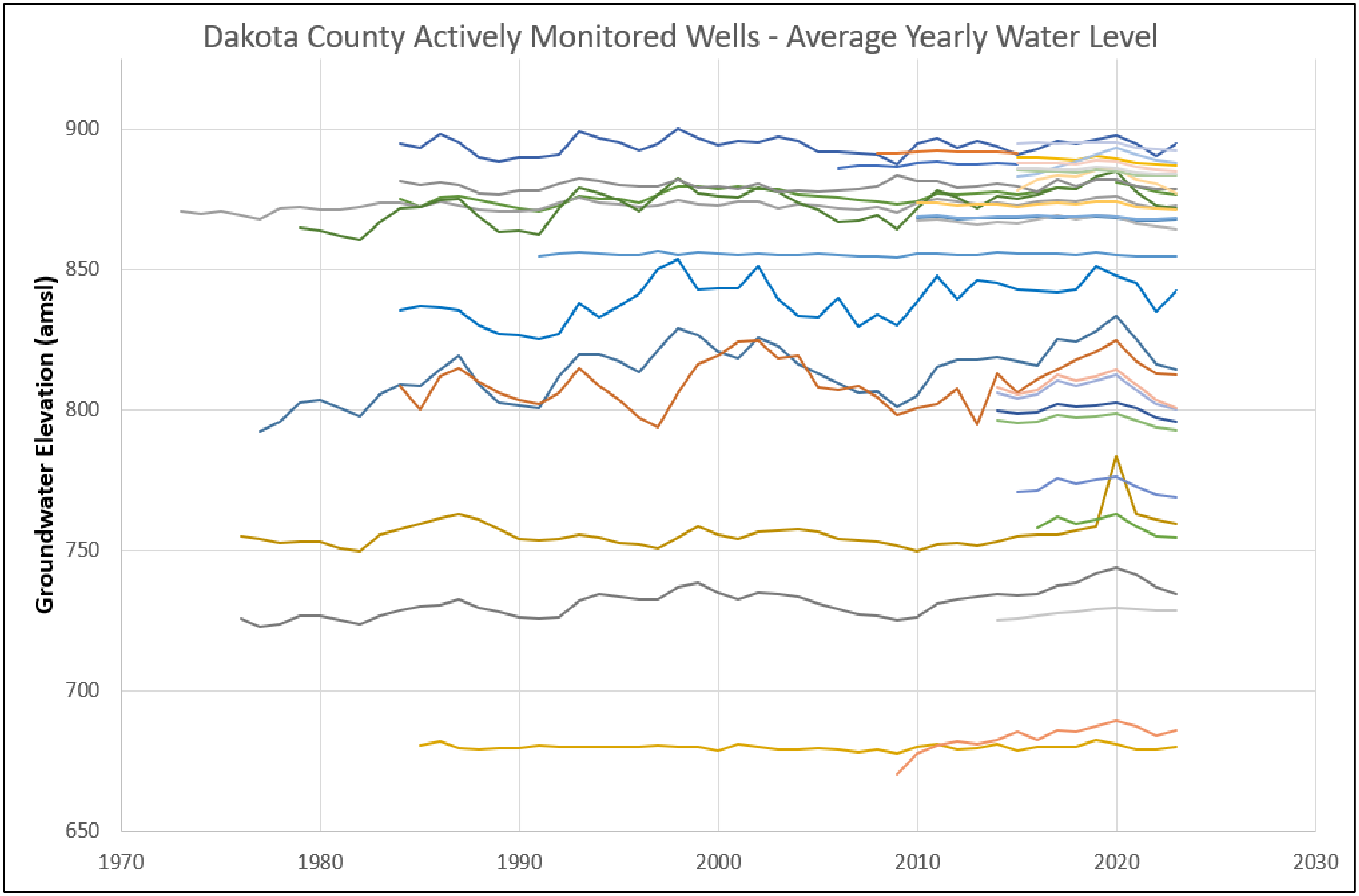
Date: 2/7/2024



NOTES:

LEGEND

120158	170885	207650	216228	227972	229948	243739	243746	243754
243769	243772	243774	243775	243778	708369	731135	759589	767144
767145	769458	779930	779931	779932	799885	799886	799887	800955
806093	806094	809288	812238	812241	813731			

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FIGURE 9-A

AVG YEARLY WATER LEVEL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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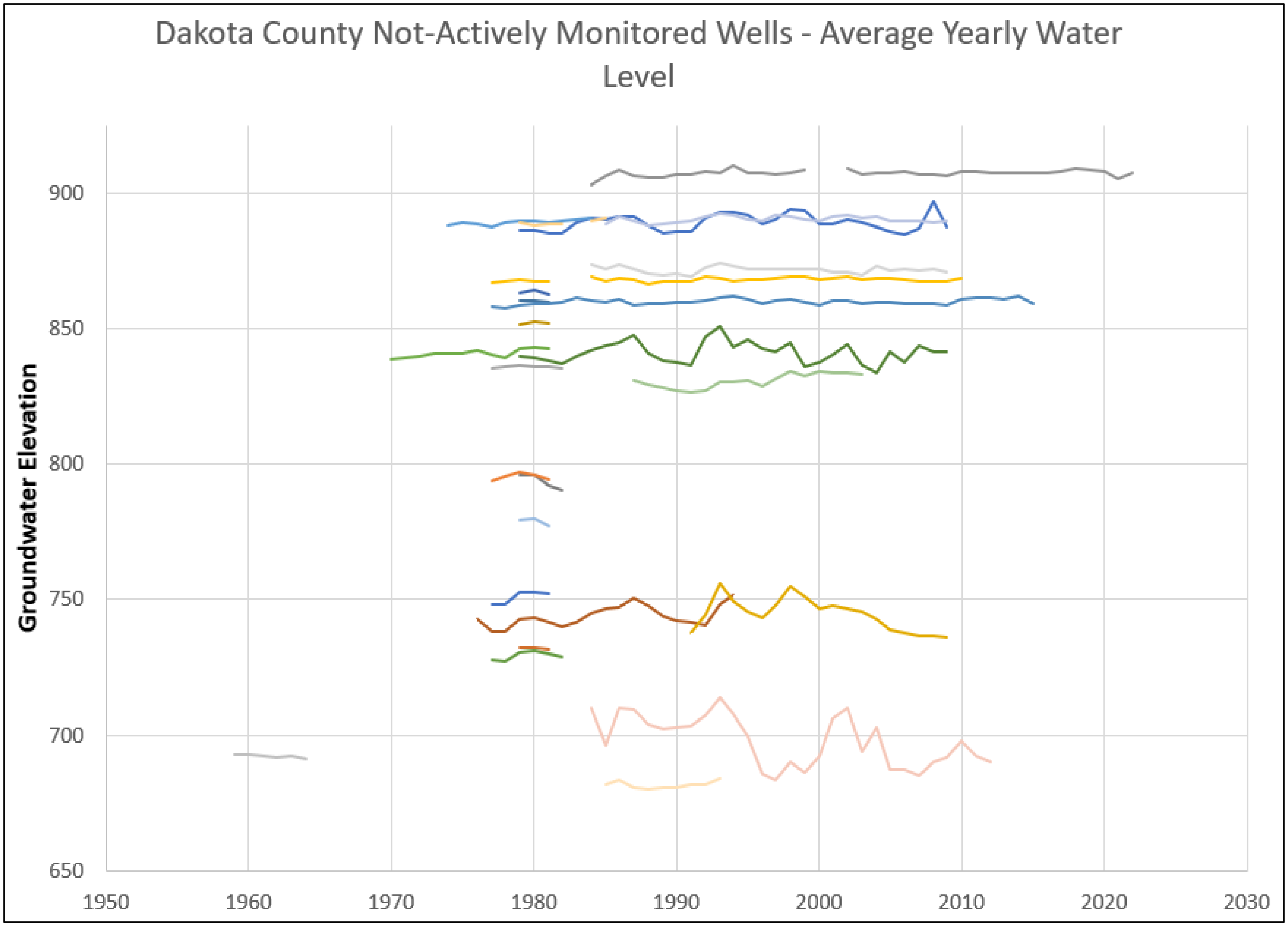
Date: 2/7/2024



NOTES:

LEGEND

101062	104319	120168	121806	121846	129239	132216	136465	175910	227975
243738	243740	243741	243742	243743	243744	243745	243747	243748	243749
243750	243765	243768	243770	243771	243773	243776	243779		

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FIGURE 9-B

AVG YEARLY WATER LEVEL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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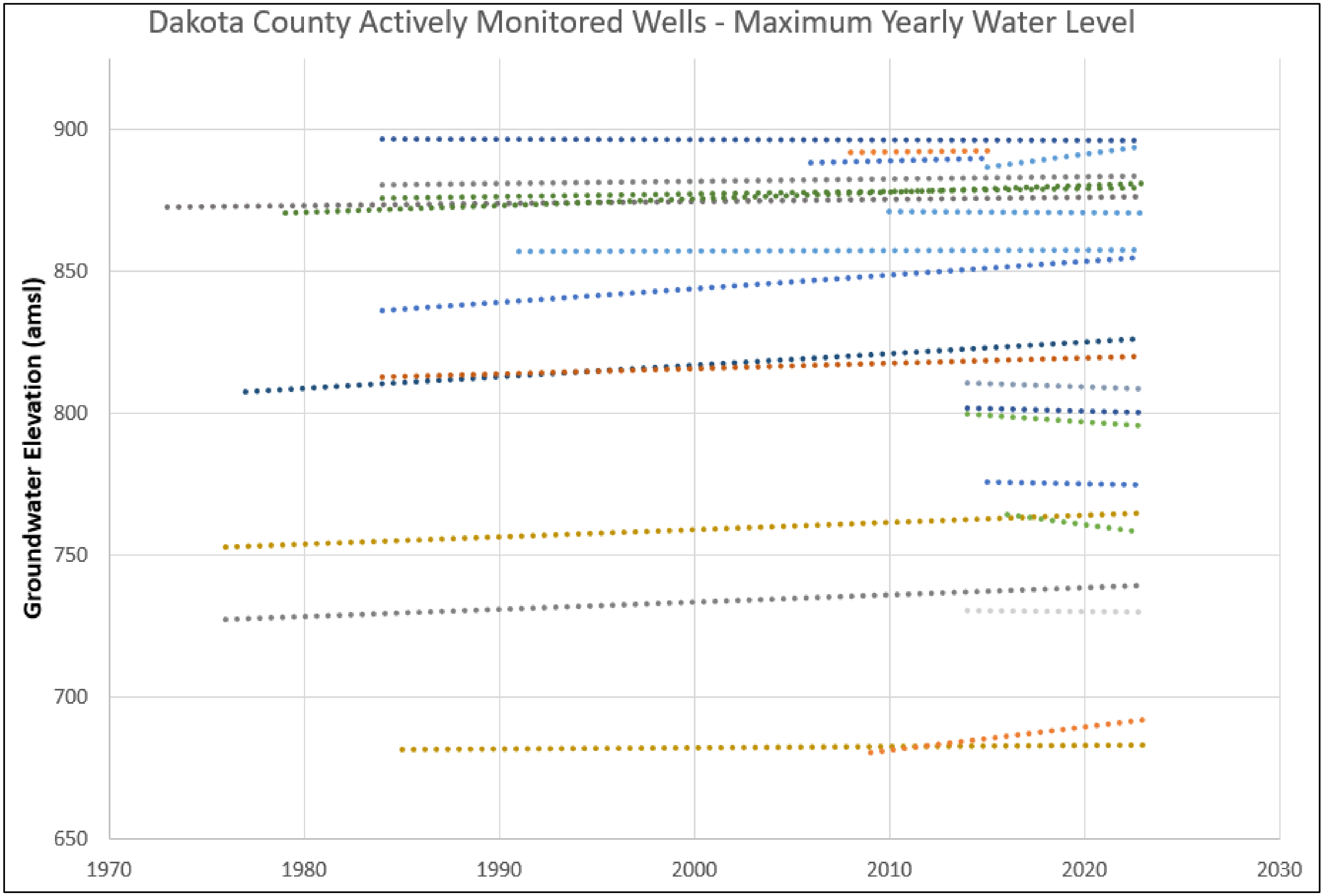
Date: 2/7/2024



NOTES:

LEGEND

Linear (120158) · Linear (170885) · Linear (207650) · Linear (227972) · Linear (229948) · Linear (243739)
Linear (243746) · Linear (243754) · Linear (243769) · Linear (243772) · Linear (243774) · Linear (243775)
Linear (243778) · Linear (731135) · Linear (759589) · Linear (767144) · Linear (767145) · Linear (769458)
Linear (779932) · Linear (799885) · Linear (799886) · Linear (800955) · Linear (806094)

Foth

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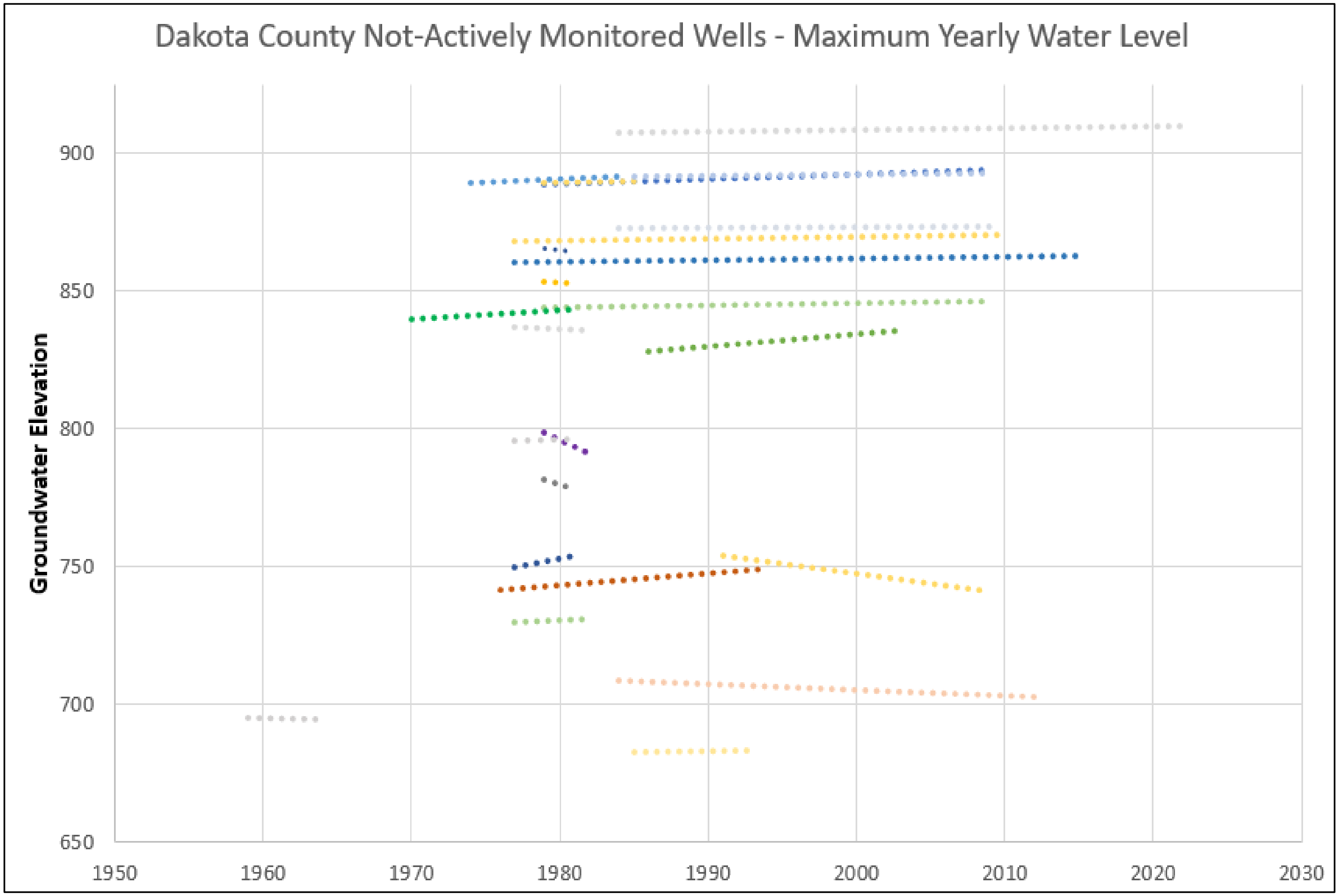
FIGURE 10-A

TRENDS IN MAX YEARLY WL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

Path: pw:\\foth-pw.bentley.com:foth-pw-01\Documents\Clients\Irrigators Association of MN\0023I038.00\10300 Reports Date: 2/7/2024



NOTES:

-

LEGEND

Linear (101062) Linear (104319) Linear (120168) Linear (121806) Linear (129239) Linear (132216)
Linear (175910) Linear (227975) Linear (243738) Linear (243740) Linear (243741) Linear (243742)
Linear (243743) Linear (243744) Linear (243745) Linear (243747) Linear (243748) Linear (243749)
Linear (243750) Linear (243765) Linear (243768) Linear (243770) Linear (243771) Linear (243773)
Linear (243776) Linear (243779)

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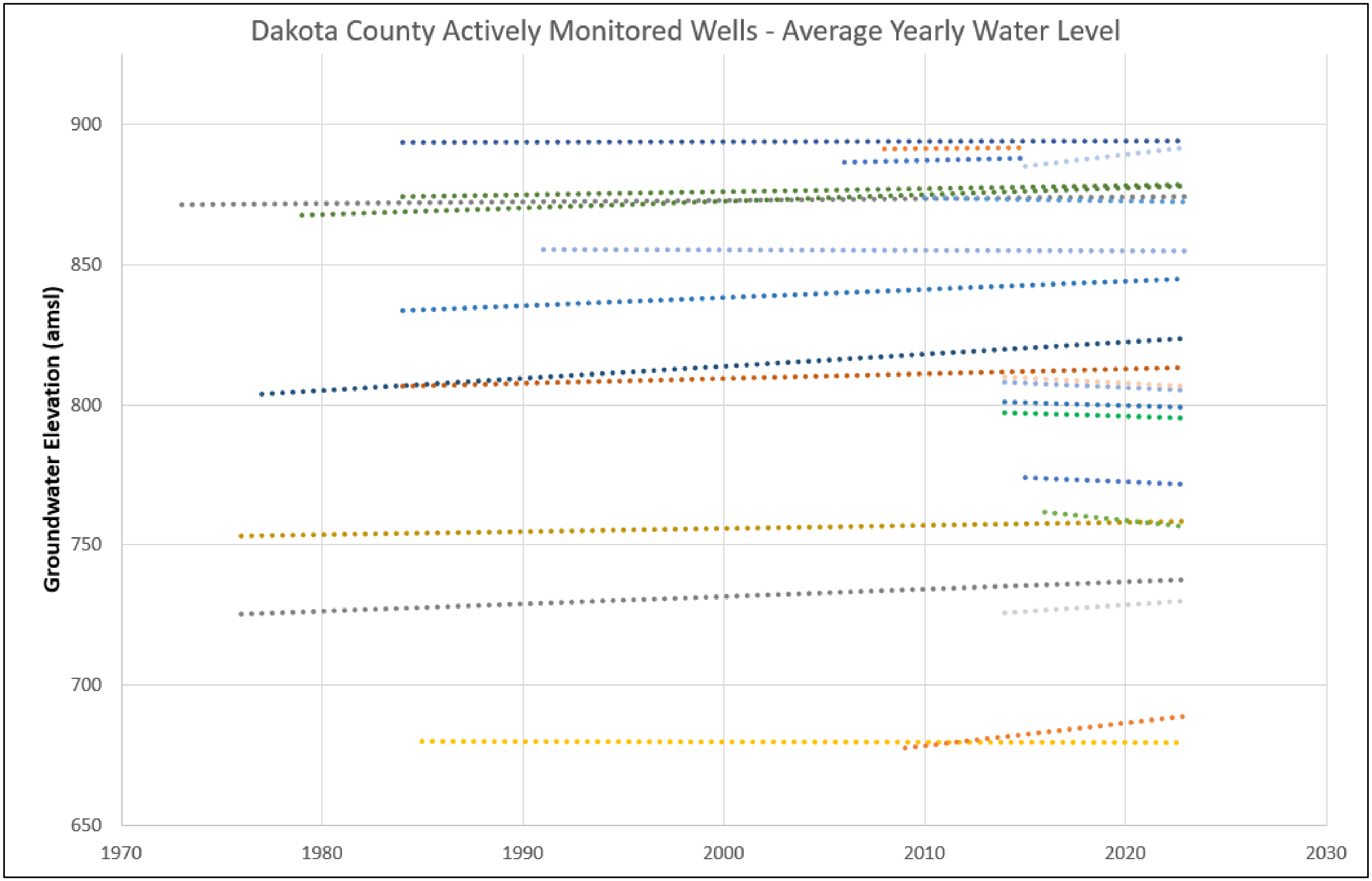
FIGURE 10-B

TRENDS IN MAX YEARLY WL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

Linear (120158)	Linear (170885)	Linear (207650)	Linear (227972)	Linear (229948)	Linear (243739)
Linear (243746)	Linear (243754)	Linear (243769)	Linear (243772)	Linear (243774)	Linear (243778)
Linear (731135)	Linear (759589)	Linear (767144)	Linear (767145)	Linear (769458)	Linear (779931)
Linear (799885)	Linear (799886)	Linear (799887)	Linear (800955)	Linear (806094)	

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FIGURE 11-A

TRENDS IN AVG YEARLY WL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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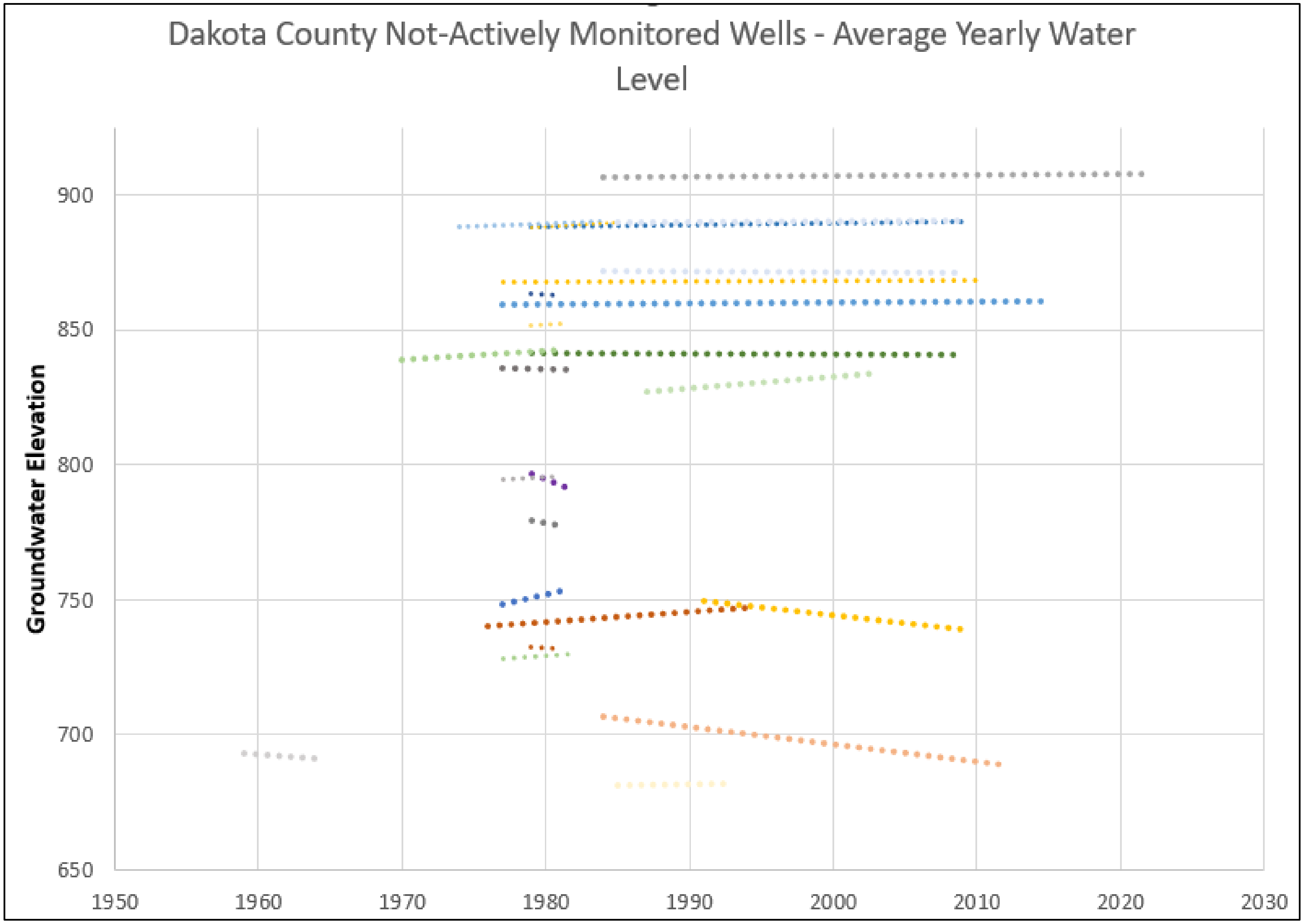

NOTES:

LEGEND

Linear (101062), Linear (104319), Linear (120168), Linear (121806), Linear (129239), Linear (132216), Linear (136465), Linear (175910), Linear (227975), Linear (243738), Linear (243740), Linear (243741), Linear (243742), Linear (243743), Linear (243744), Linear (243745), Linear (243747), Linear (243748), Linear (243749), Linear (243750), Linear (243765), Linear (243768), Linear (243770), Linear (243771), Linear (243773), Linear (243776), Linear (243779)

IRRIGATORS ASSOCIATION OF MINNESOTA

FIGURE 11-B

TRENDS IN AVG YEARLY WL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:
Drawn By: BNK	Checked By: VXT / Project: 0023I038.00

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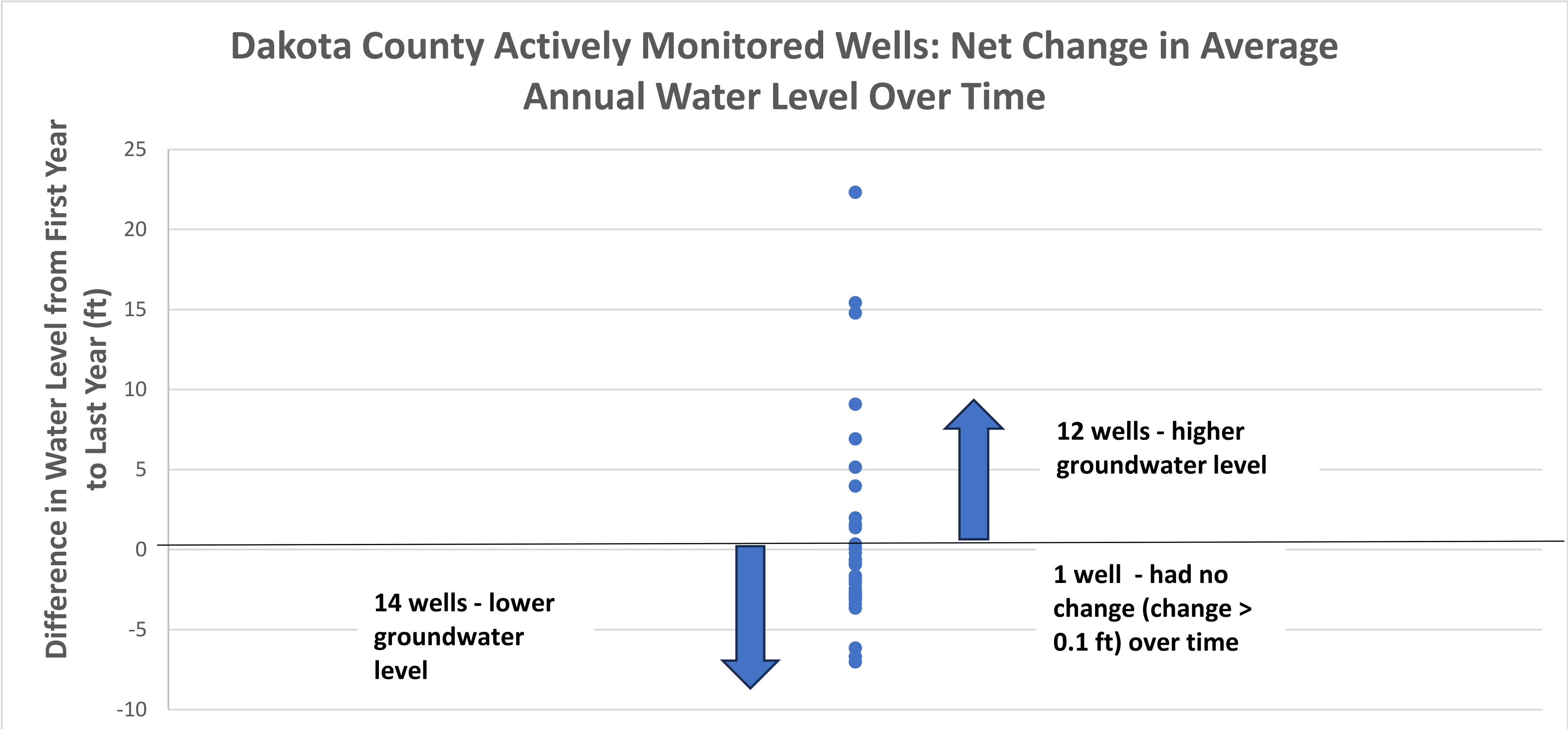

NOTES:

Only wells with at least 30 year period of record were used for establishing long term water level change.

LEGEND

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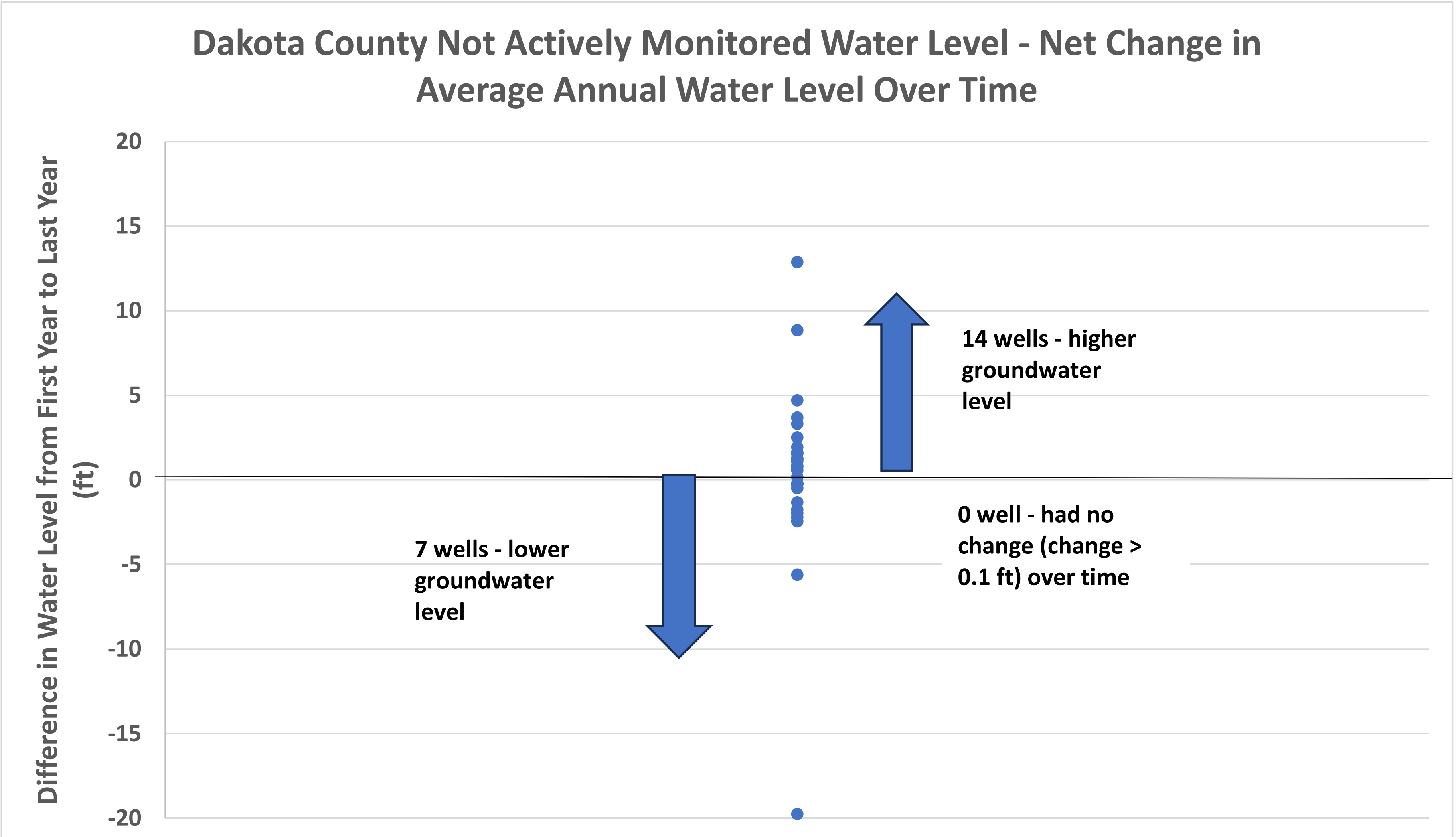
FIGURE 12-A

NET CHANGE IN WATER LEVEL AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

Path: pw:\\foth-pw.bentley.com:foth-pw-01\Documents\Clients\Irrigators Association of MN\0023I038.00\10300 Reports Date: 2/7/2024



NOTES:

Only wells with at least 30 year period of record were used for establishing long term water level change.

LEGEND

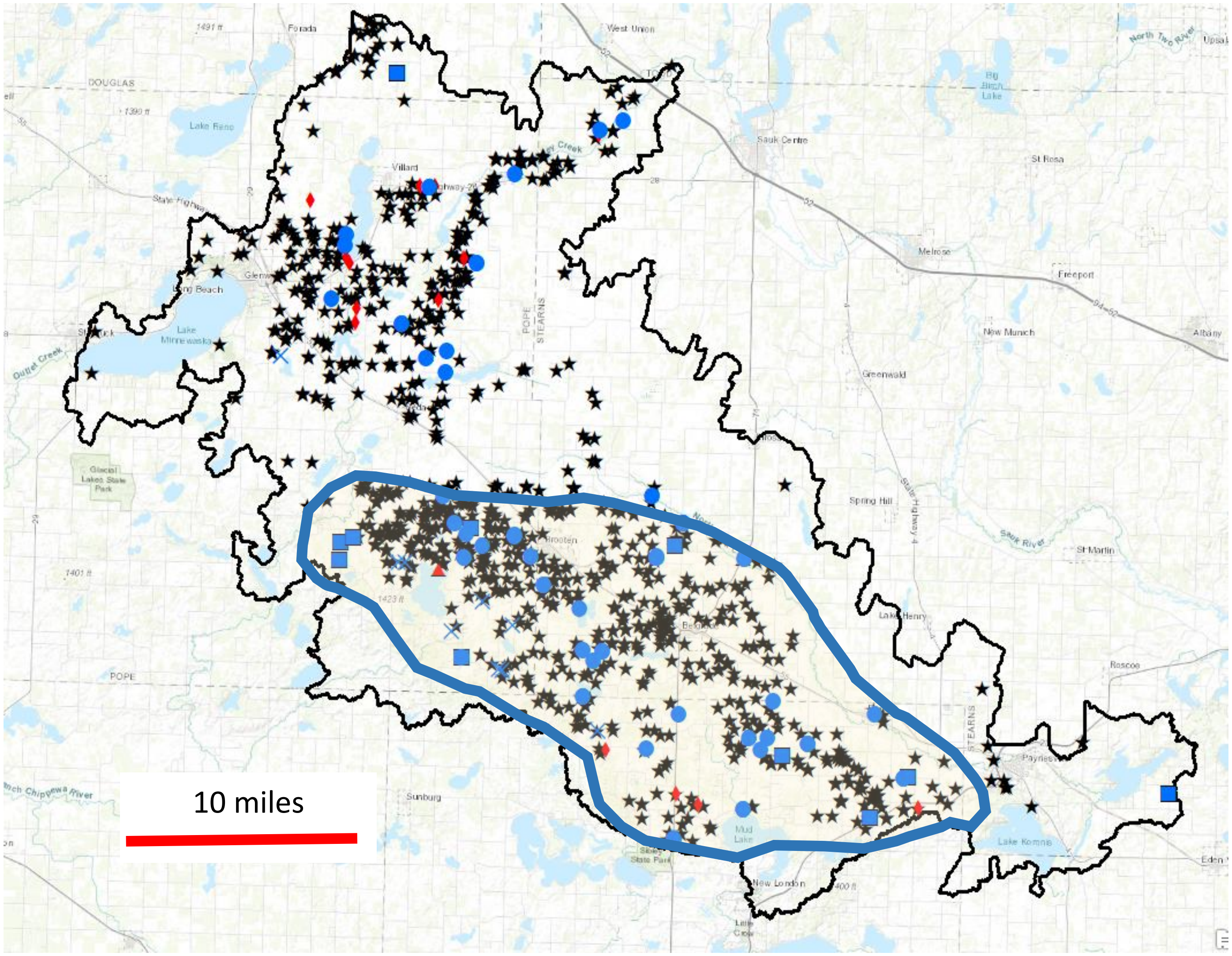
IRRIGATORS ASSOCIATION OF MINNESOTA

FIGURE 12-B

NET CHANGE IN WATER LEVEL AROUND
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Foth

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

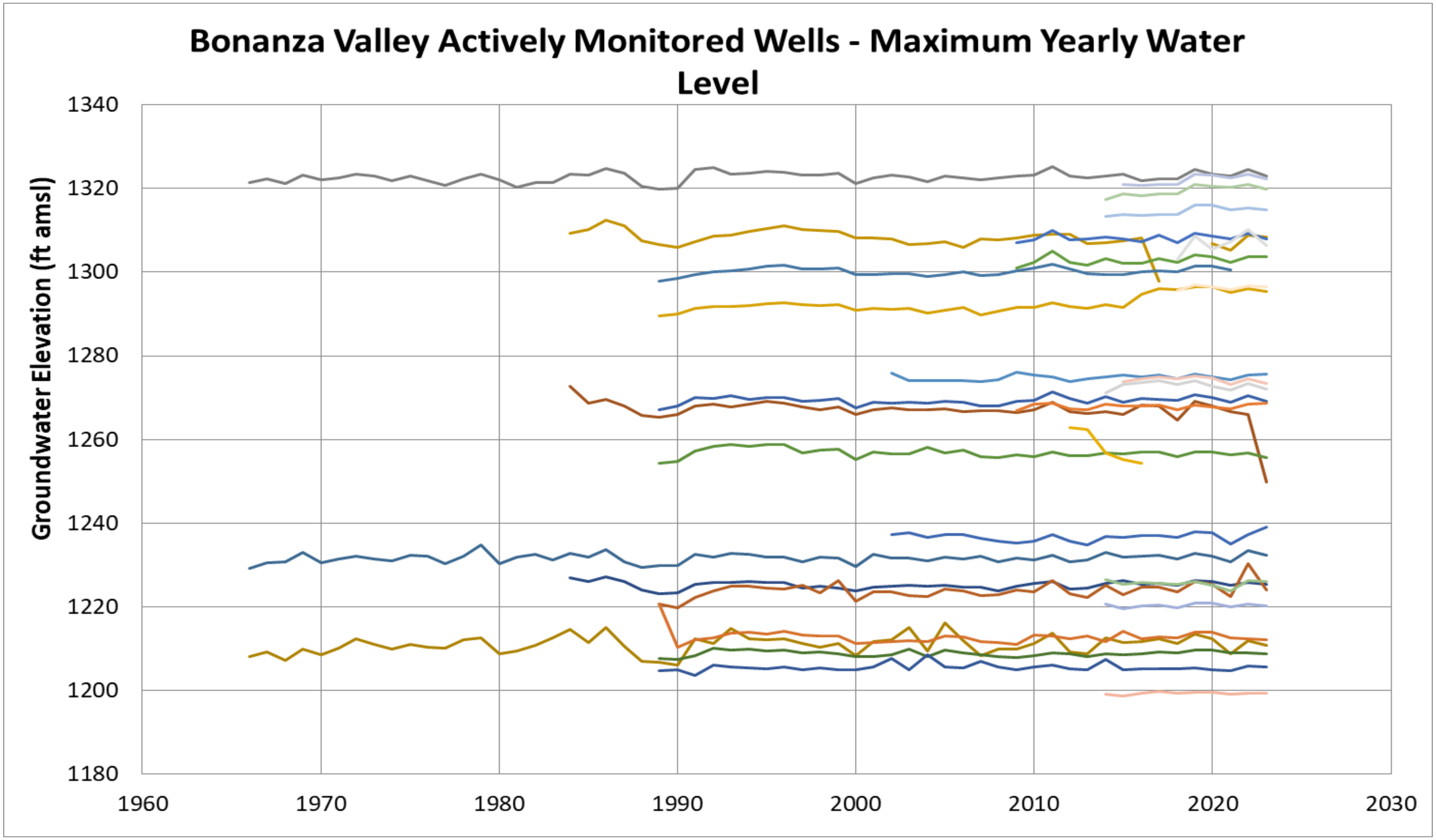
- CGM Actively Monitored with Permit Required Monitoring
- CGM Actively Monitored with Water Quality Data
- CCGM Actively Monitored with Only GW Level Data
- CGM Not Actively Monitored with Permit Required Monitoring
- CGM Not Actively Monitored with Water Quality Data
- CGM Not Actively Monitored with Only GW Level Data
- Irrigation Wells

IRRIGATORS ASSOCIATION OF MINNESOTA

FIGURE 13

GROUNDWATER LEVEL DATA AROUND BONANZA VALLEY
2024 IRRIGATED AREAS ANALYSIS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

152112	178559	243897	243898	243941	243942
243944	244288	244294	244321	244482	244485
244489	270262	411237	611215	623060	689964
689976	689977	802957	802958	804937	809277
809278	809279	809280	809281	816948	816949

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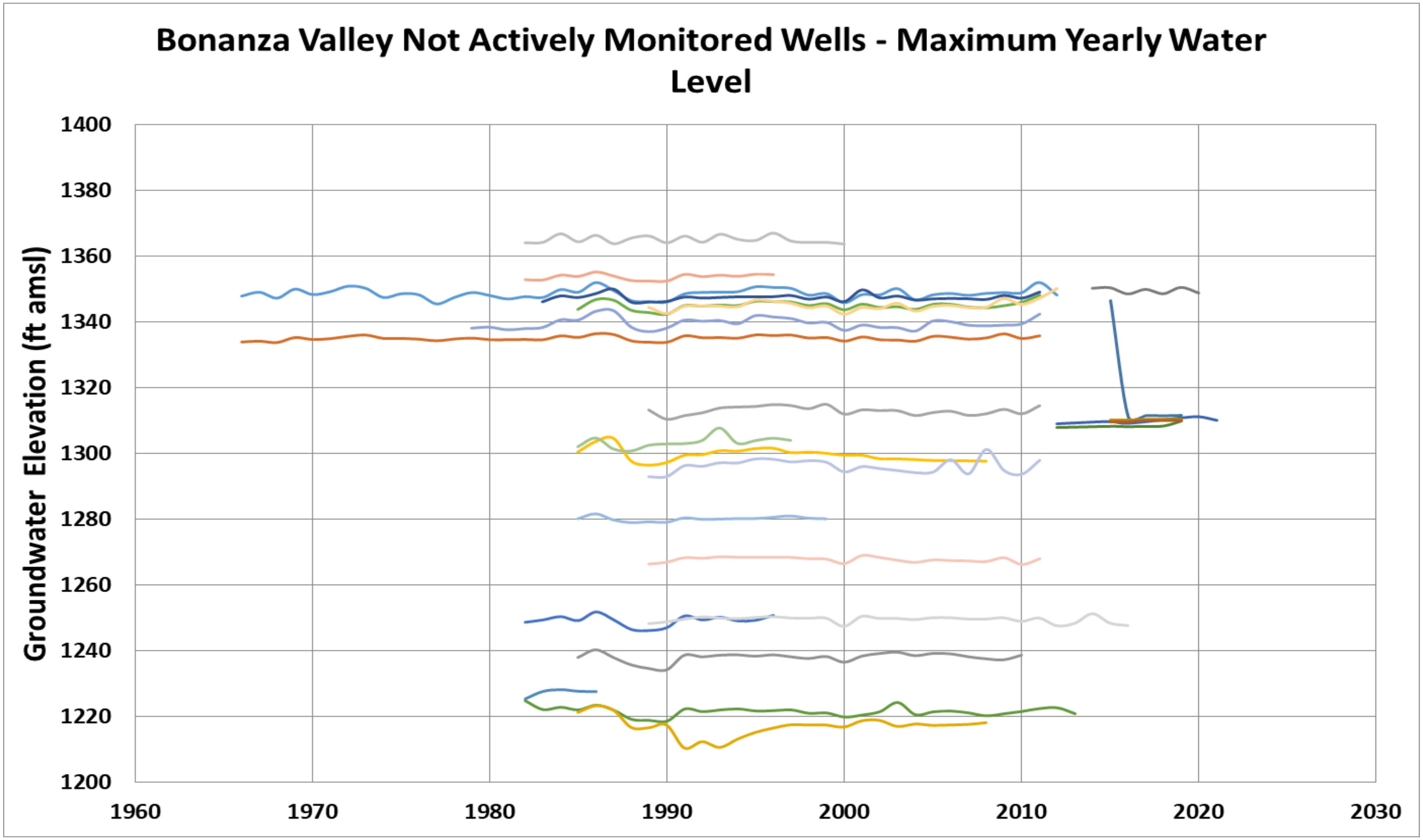
IRRIGATORS ASSOCIATION OF MINNESOTA		
FIGURE 14-A MAX YEARLY WATER LEVEL AROUND BONANZA VALLEY 2024 IRRIGATED AREAS ANALYSIS ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

211160	229558	243938	243939	244290	244291
244299	244309	244311	244312	244314	244318
244320	244323	244480	244481	244486	244488
244490	788418	798642	802549	802550	805216
811460	243940				

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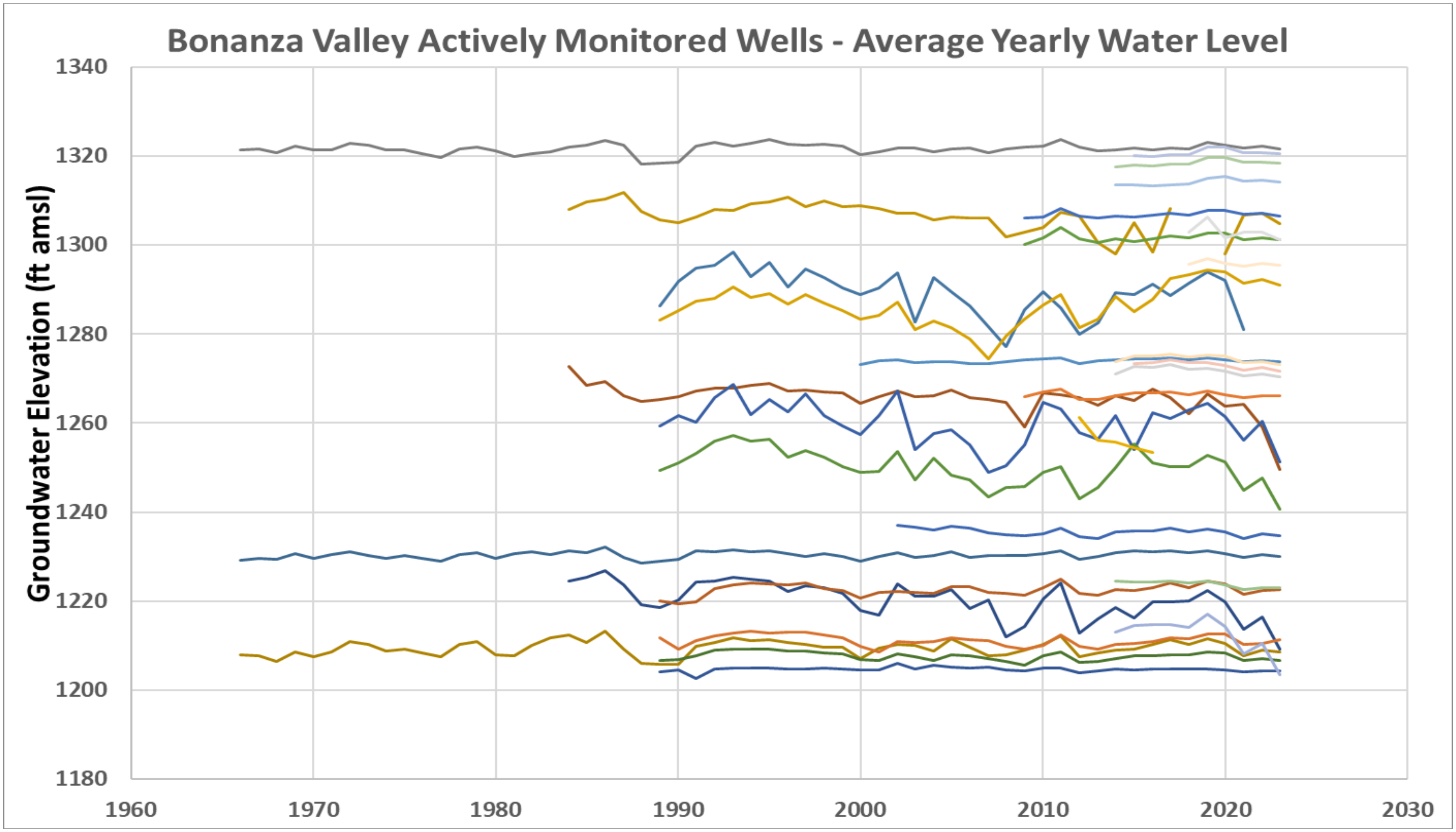
FIGURE 14-B

MAX YEARLY WATER LEVEL AROUND BONANZA VALLEY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

152112	178559	243897	243898	243941	243942
243944	244288	244294	244321	244482	244485
244489	270262	411237	611215	623060	689964
689976	689977	802957	802958	809277	809278
809279	809280	809281	809282	816948	816949

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FIGURE 15-A AVG YEARLY WATER LEVEL AROUND BONANZA VALLEY 2024 IRRIGATED AREAS ANALYSIS ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

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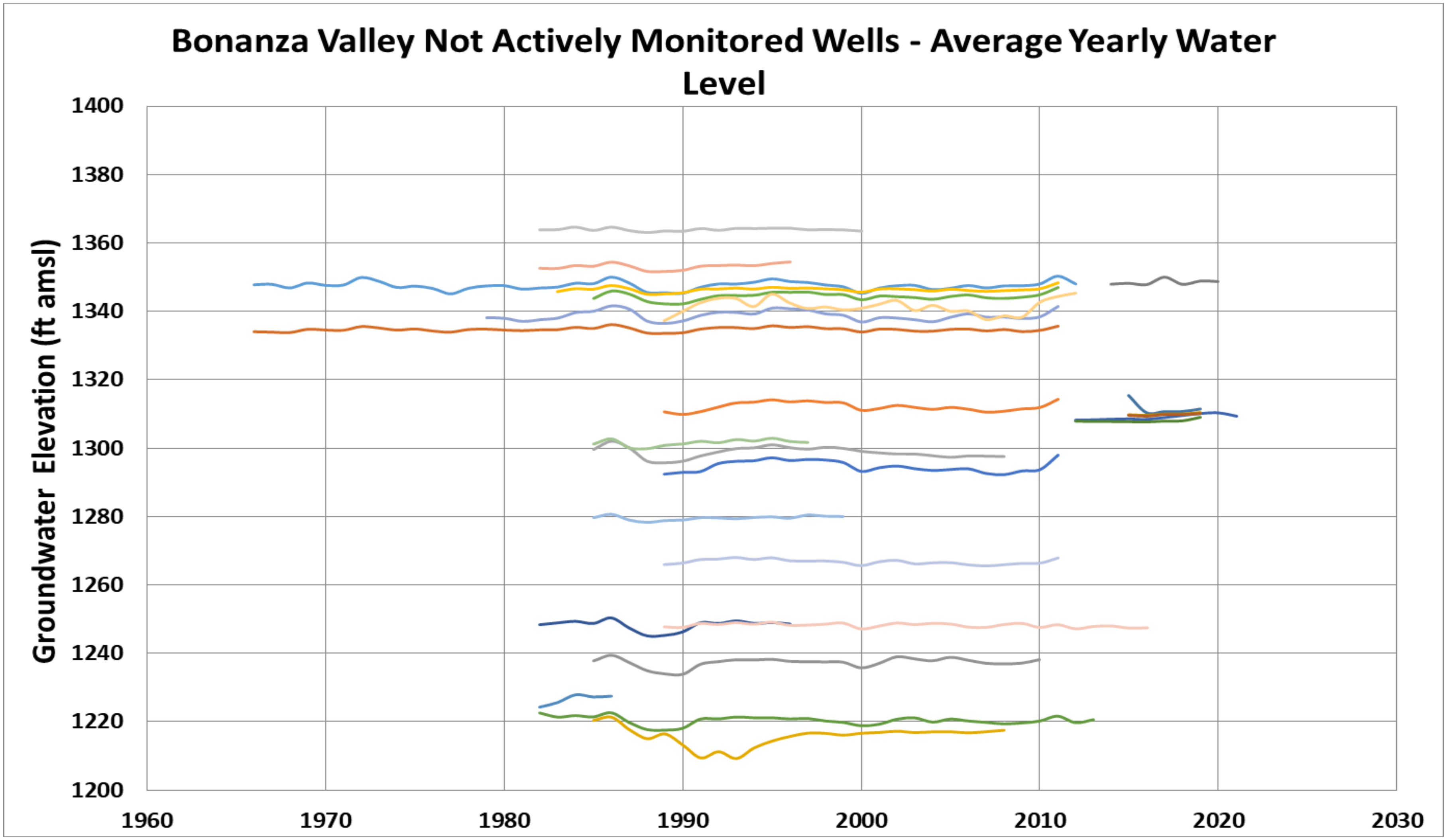

NOTES:

LEGEND

211160	229558	243938	243939	244290	244291	244299
244309	244311	244312	244314	244318	244320	244323
244480	244481	244486	244488	244490	788418	798642
802549	802550	805216	811460	243940		

Foth

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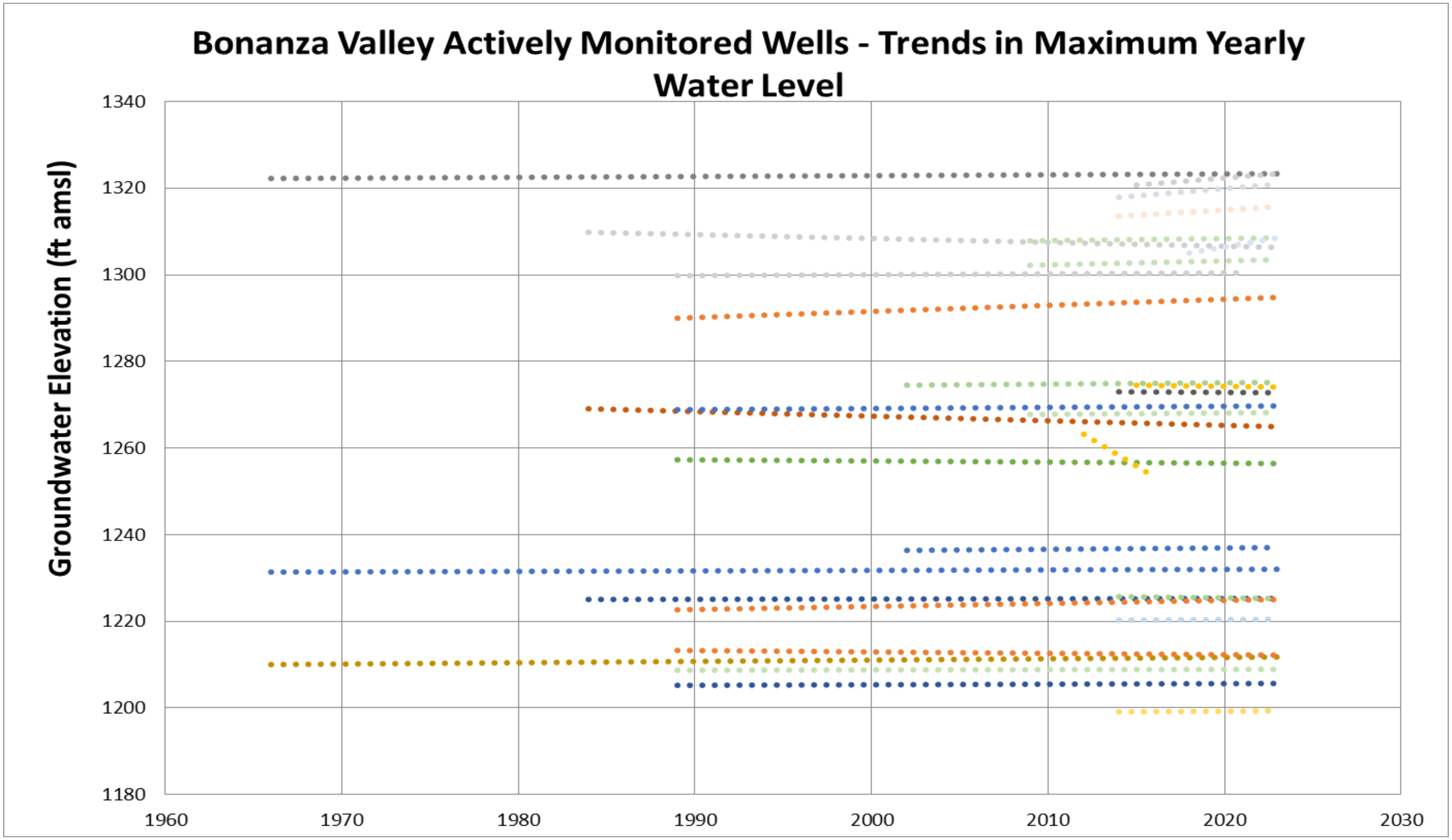
FIGURE 15-B

AVG YEARLY WATER LEVEL AROUND BONANZA VALLEY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

Linear (152112)	Linear (178559)	Linear (243897)	Linear (243898)
Linear (243941)	Linear (243942)	Linear (243944)	Linear (244288)
Linear (244294)	Linear (244321)	Linear (244482)	Linear (244485)
Linear (244489)	Linear (270262)	Linear (411237)	Linear (611215)
Linear (623060)	Linear (689964)	Linear (689976)	Linear (689977)
Linear (802957)	Linear (802958)	Linear (804937)	Linear (809277)
Linear (809277)	Linear (809278)	Linear (809279)	Linear (809280)
Linear (809281)	Linear (816948)		

Foth

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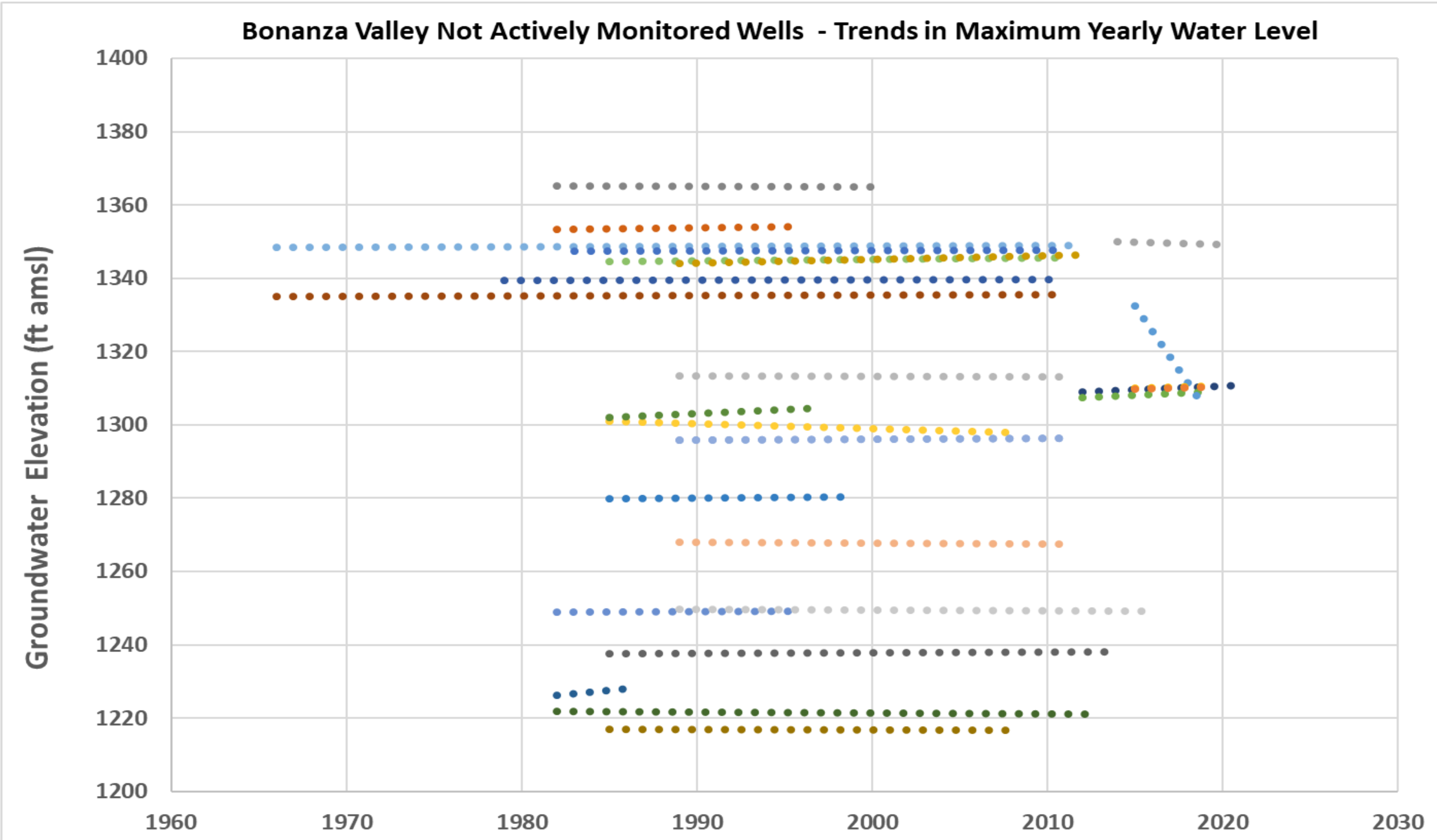
FIGURE 16-A

TRENDS IN MAX YEARLY WL AROUND BONANZA VALLEY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

Linear (211160)	Linear (229558)	Linear (243938)	Linear (243939)
Linear (243940)	Linear (244290)	Linear (244291)	Linear (244299)
Linear (244309)	Linear (244311)	Linear (244312)	Linear (244314)
Linear (244318)	Linear (244320)	Linear (244323)	Linear (244480)
Linear (244481)	Linear (244486)	Linear (244488)	Linear (244490)
Linear (788418)	Linear (798642)	Linear (802549)	Linear (805216)
Linear (811460)	Linear (811460)		

Foth

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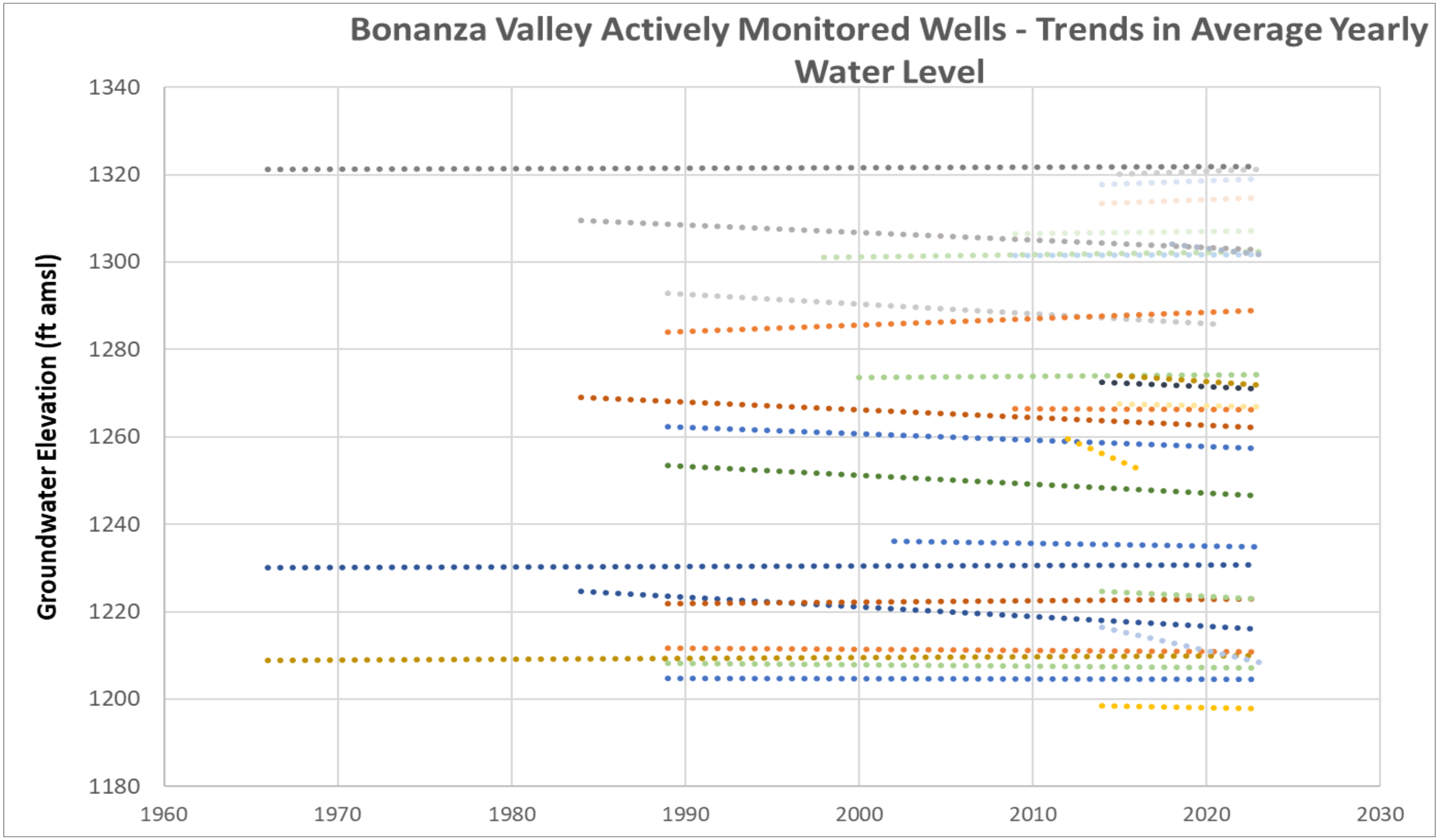
FIGURE 16-B

TRENDS IN MAX YEARLY WL AROUND BONANZA VALLEY
2024 IRRIGATED AREAS ANALYSIS
NOT-ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

LEGEND

Linear (152112) Linear (178559) Linear (243897) Linear (243898)
Linear (243941) Linear (243942) Linear (243944) Linear (244288)
Linear (244294) Linear (244321) Linear (244482) Linear (244483)
Linear (244483) Linear (270262) Linear (270262) Linear (591779)
Linear (611215) Linear (623060) Linear (689964) Linear (689977)
Linear (802957) Linear (802958) Linear (804937) Linear (809277)
Linear (809278) Linear (809279) Linear (809280) Linear (809281)
Linear (812217) Linear (816948)

Foth

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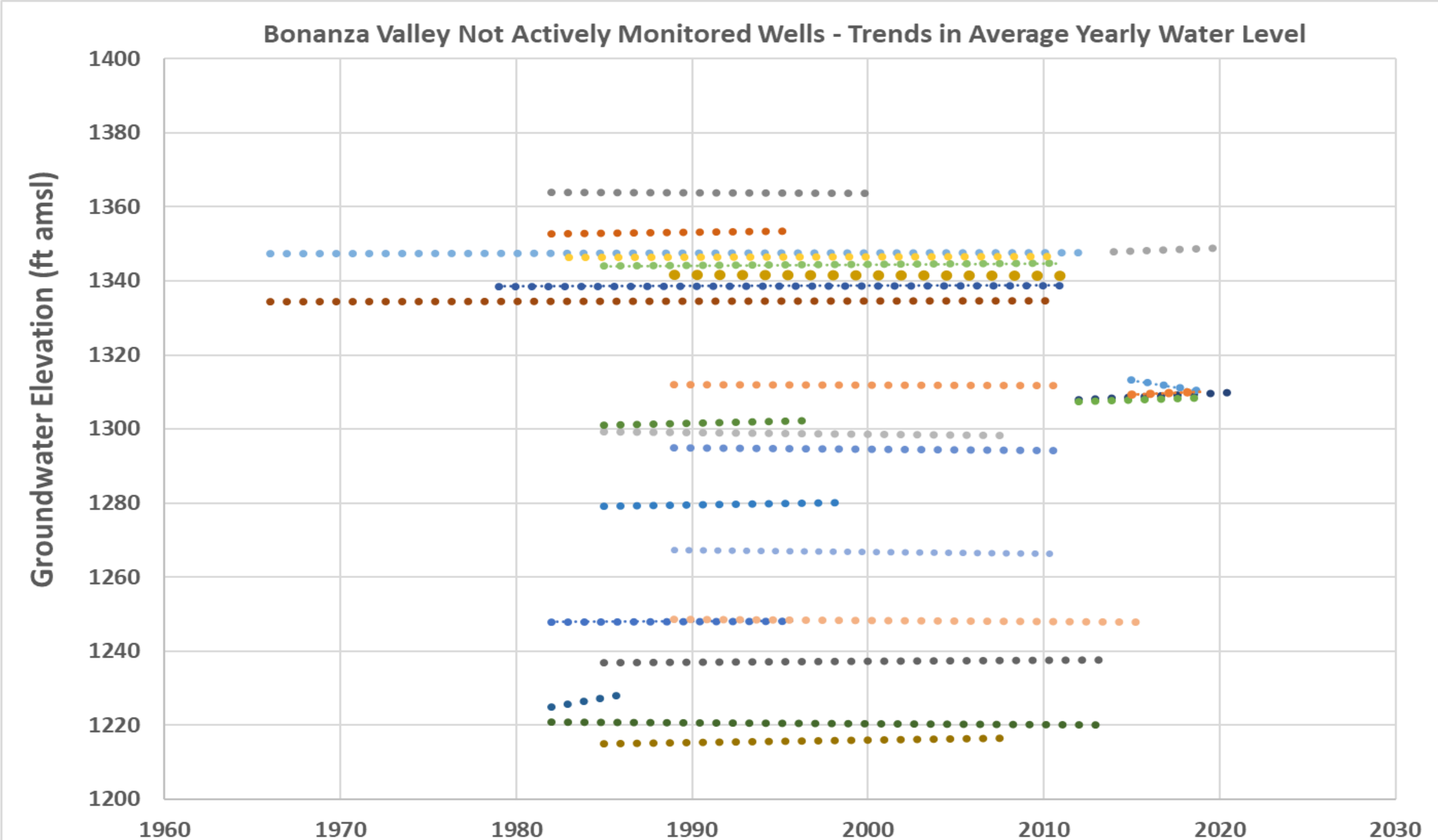
FIGURE 17-A

TRENDS IN AVG YEARLY WL AROUND BONANZA VALLEY
2024 IRRIGATED AREAS ANALYSIS
ACTIVELY MONITORED WELLS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

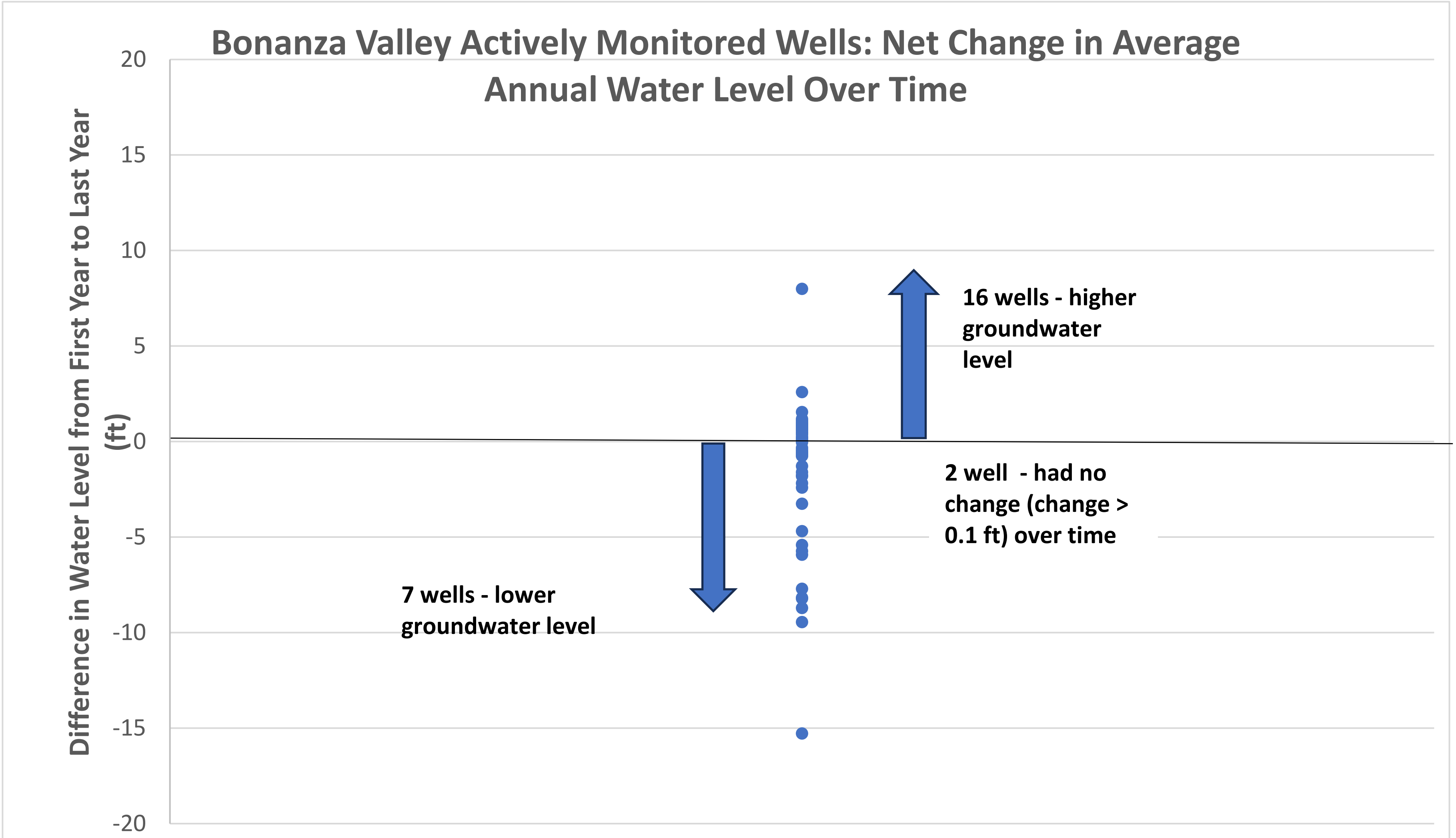
LEGEND

Linear (211160)	Linear (229558)	Linear (243938)	Linear (243939)
Linear (243940)	Linear (244290)	Linear (244291)	Linear (244299)
Linear (244309)	Linear (244311)	Linear (244312)	Linear (244314)
Linear (244318)	Linear (244320)	Linear (244323)	Linear (244480)
Linear (244481)	Linear (244486)	Linear (244488)	Linear (244490)
Linear (788418)	Linear (798642)	Linear (802549)	Linear (805216)
Linear (811460)	Linear (811460)		

Foth

IRRIGATORS ASSOCIATION OF MINNESOTA		
FIGURE 17-B TRENDS IN AVG YEARLY WL AROUND BONANZA VALLEY 2024 IRRIGATED AREAS ANALYSIS NOT-ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

Path: pw:\\foth-pw.bentley.com:foth-pw-01\Documents\Clients\Irrigators Association of MN\0023I038.00\10300 Reports Date: 2/7/2024



NOTES:

Only wells with at least 30 year period of record were used for establishing long term water level change.

LEGEND

Foth

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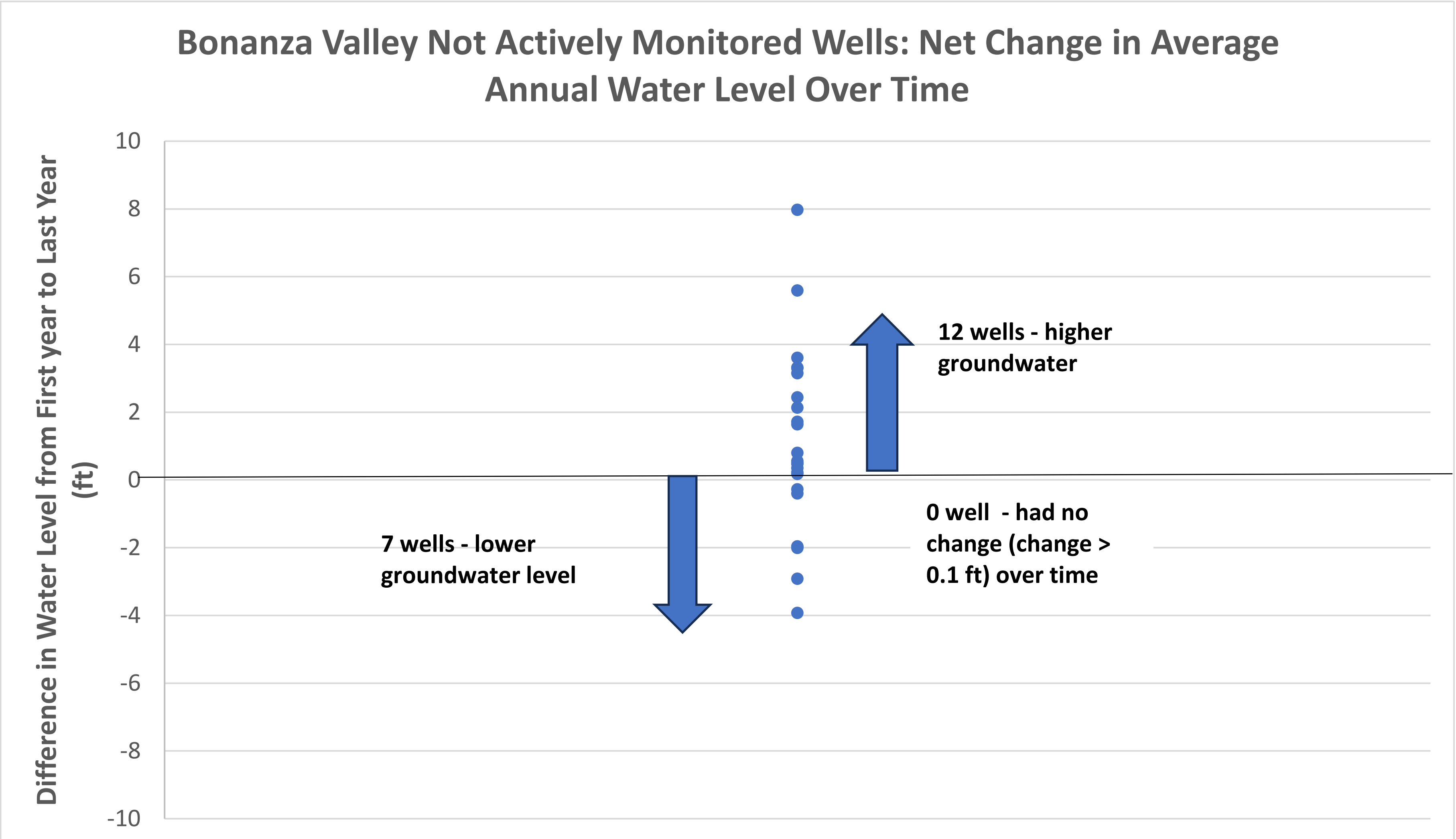
FIGURE 18-A NET CHANGE IN WATER LEVEL AROUND BONANZA VALLEY 2024 IRRIGATED AREAS ANALYSIS ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00



NOTES:

Only wells with at least 30 year period of record were used for establishing long term water level change.

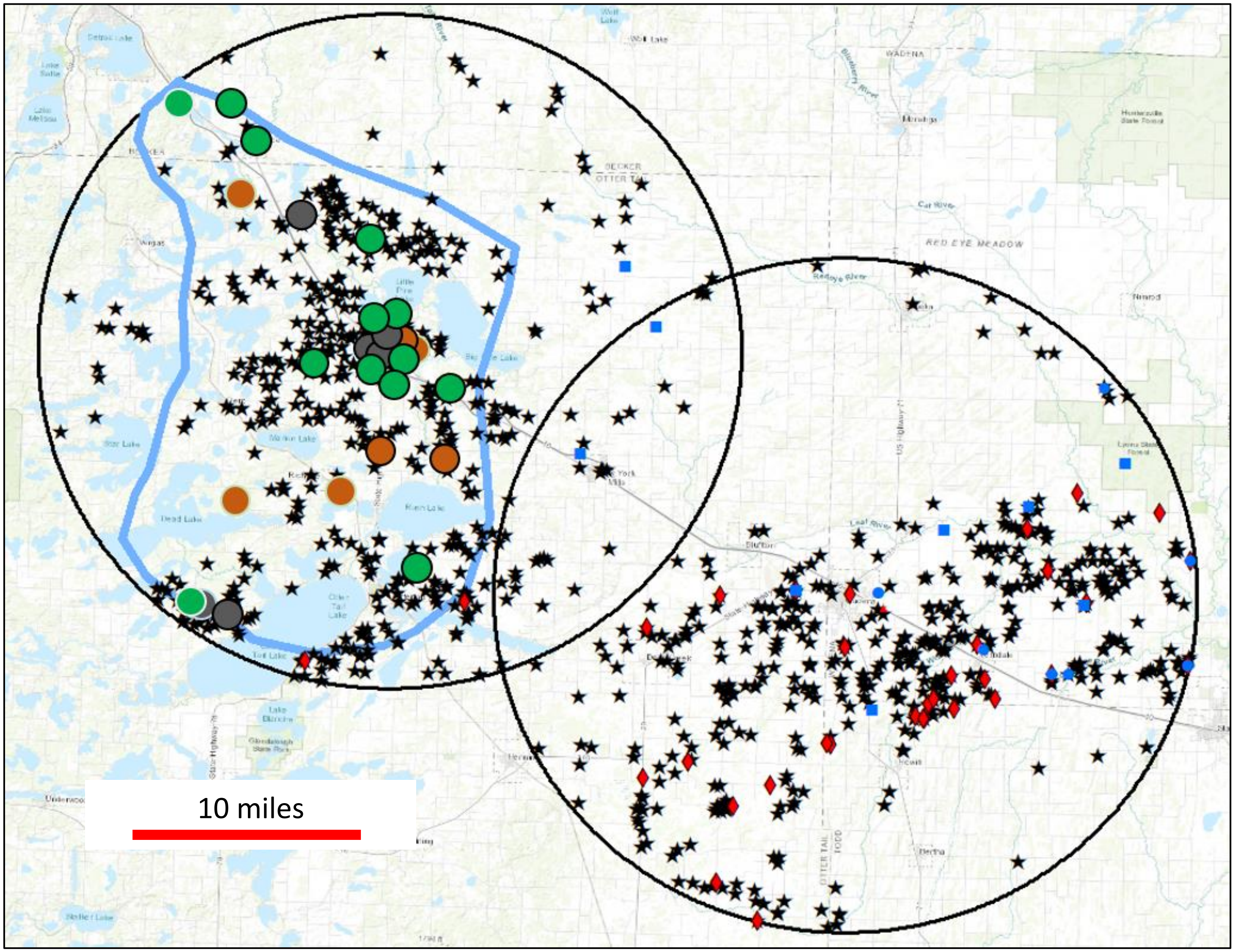
LEGEND

Foth

IRRIGATORS ASSOCIATION OF MINNESOTA		
FIGURE 18-B NET CHANGE IN WATER LEVEL AROUND BONANZA VALLEY 2024 IRRIGATED AREAS ANALYSIS NOT-ACTIVELY MONITORED WELLS		
Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

Path: pw:\\foth-pw.bentley.com:foth-pw-01\Documents\Clients\Irrigators Association of MN\0023I038.00\10300 Reports

Date: 2/7/2024



NOTES:

*Not all wells may show due to clustering

LEGEND

- Actively Monitored Well with Rising Water Level
- Actively Monitored Well with Static Water Level
- Actively Monitored Well with Falling Water Level
- Not Actively Monitored Well with Rising Water Level
- Not Actively Monitored Well with Static Water Level
- Not Actively Monitored Well with Falling Water Level

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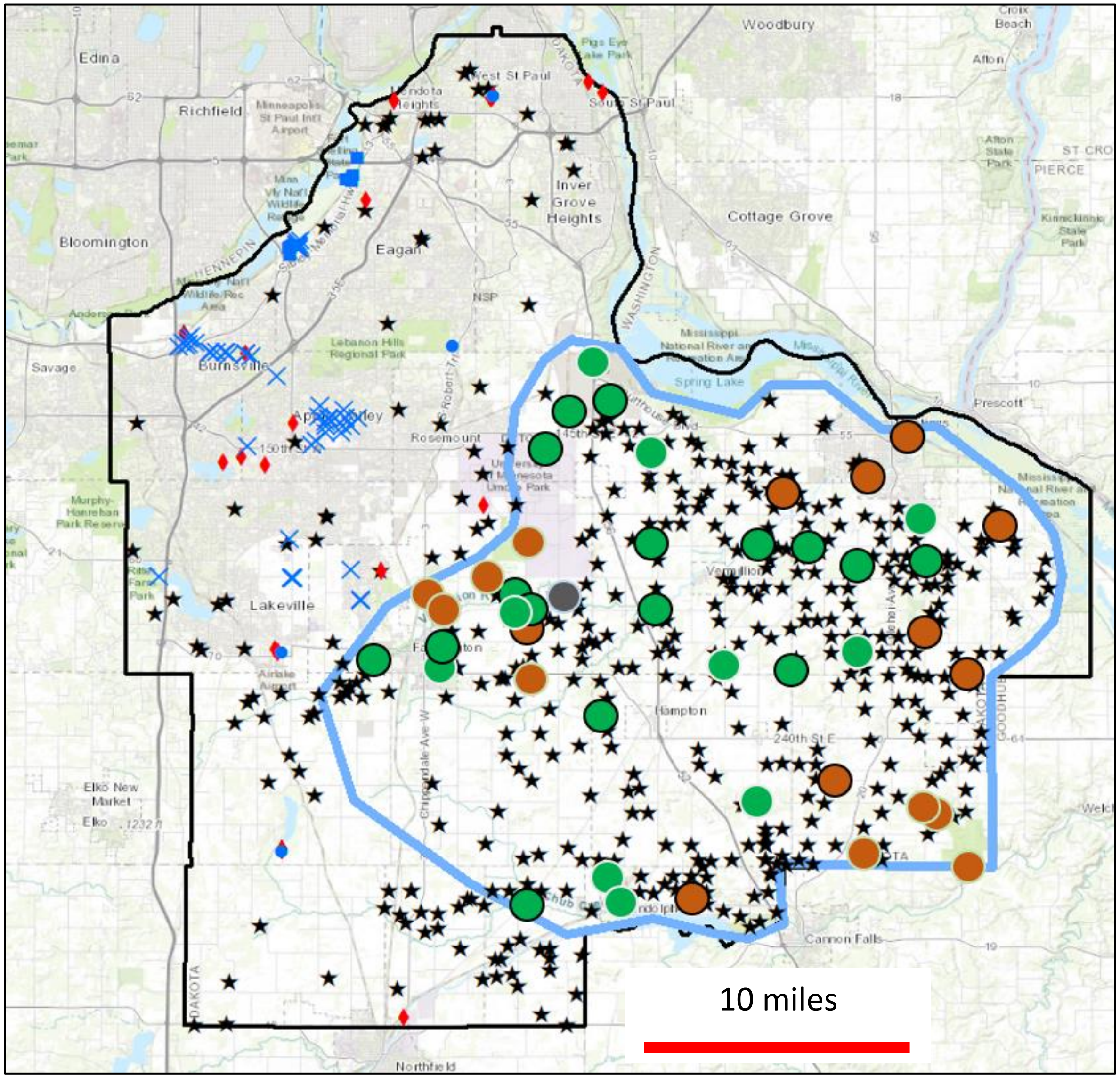
FIGURE 19

CHANGE IN WATER LEVELS AROUND PERHAM

2024 IRRIGATED AREAS ANALYSIS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

Path: pw:\\foth-pw.bentley.com:foth-pw-01\Documents\Clients\Irrigators Association of MN\0023I038.00\10300 Reports   Date: 2/8/2024



NOTES:

*Not all wells may show due to clustering

LEGEND

- Actively Monitored Well with Rising Water Level
- Actively Monitored Well with Static Water Level
- Actively Monitored Well with Falling Water Level
- Not Actively Monitored Well with Rising Water Level
- Not Actively Monitored Well with Static Water Level
- Not Actively Monitored Well with Falling Water Level

Foth

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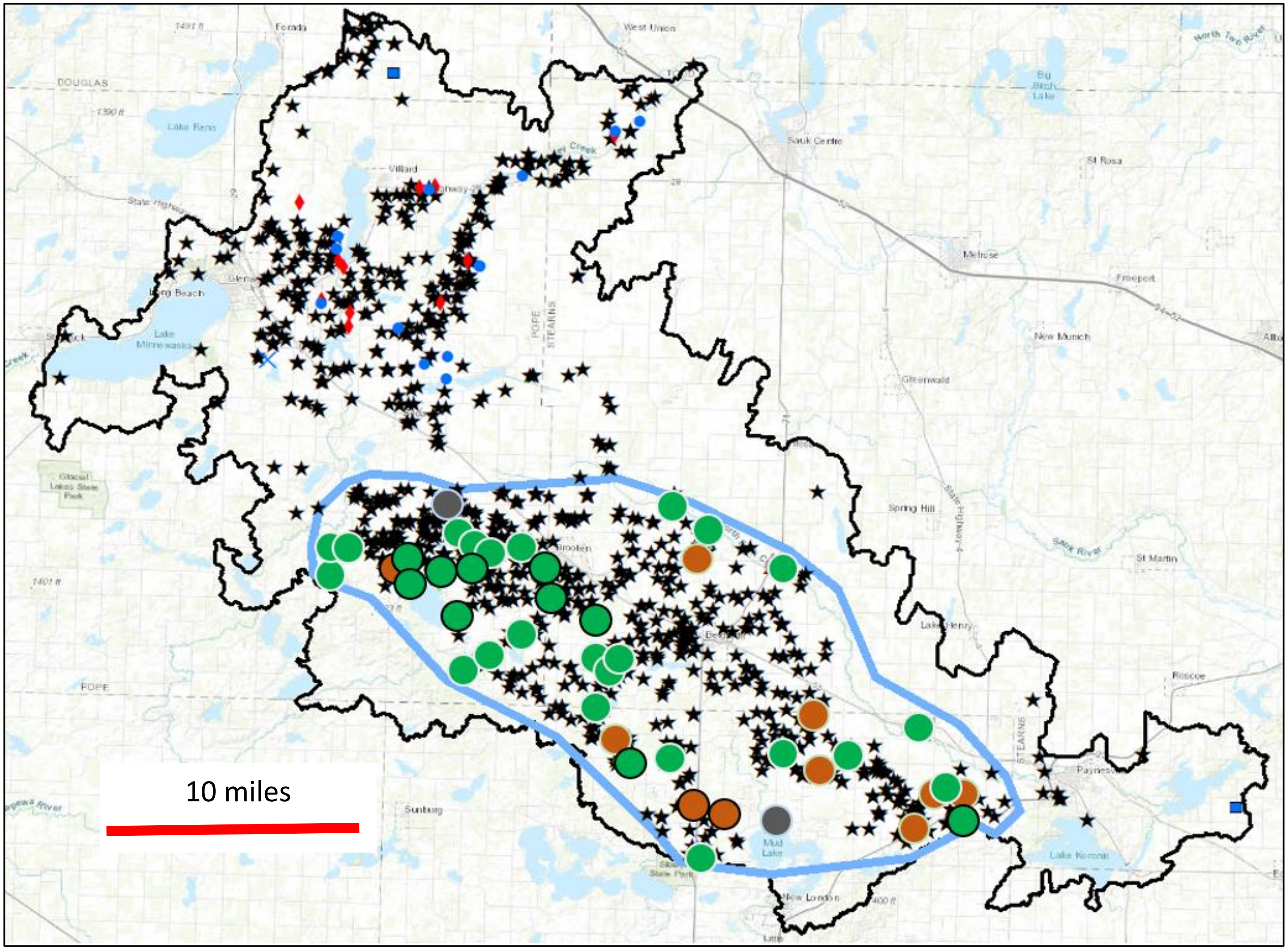
FIGURE 20

CHANGE IN WATER LEVELS AROUND DAKOTA COUNTY
2024 IRRIGATED AREAS ANALYSIS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00

Path: pw:\\foth-pw.bentley.com:foth-pw-01\Documents\Clients\Irrigators Association of MN\0023I038.00\10300 Reports Date: 2/8/2024



NOTES:

*Not all wells may show due to clustering

LEGEND

- Actively Monitored Well with Rising Water Level
- Actively Monitored Well with Static Water Level
- Actively Monitored Well with Falling Water Level
- Not Actively Monitored Well with Rising Water Level
- Not Actively Monitored Well with Static Water Level
- Not Actively Monitored Well with Falling Water Level

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FIGURE 21

CHANGE IN WATER LEVELS AROUND BONANZA VALLEY

2024 IRRIGATED AREAS ANALYSIS

Date: JANUARY 2024	Revision Date:	
Drawn By: BNK	Checked By: VXT	Project: 0023I038.00