EXPERT REPORT: Case No. 18 WATER 14014

for

Daniel Clement, Burns & McDonnell

a) Consulted for: Equus Beds aquifer water usage and sustainable yield, recharge mechanisms and accounting, water resource conditions, and technical tools and models
b) The grounds for Daniel Clement's opinions are knowledge of pertinent information presented in City of Wichita's Response to Production Request of Equus Beds Groundwater Management District No.2 and City of Wichita's Responses to Intervener's Production Requests, as referenced in the summaries of the respective opinions below, and in several cases, excerpted and attached for convenience of reference.
c) Daniel Clement's factual observations and opinions, as presented in the Proposal documents and summarized herein, include:
    i. Expert opinions based on factual observations:
    ii. Expert opinions based on scientific analyses:
        - 2.4.1 Stress Period (SP) Development
            - The PDSI values from 1933 to 1940 were compared to more recent years to find and develop a complete hydrologic data set for simulating the duration and intensity of the 1% drought.
            - Conditions exhibited in the years 2011 and 2012 were selected to repeat four times, for a total of eight years, to simulate a 1% drought.
            - Proposal Section 2.4.1 has been provided as Attachment A-1.
            - PDSI information for recent calendar years for South Central Kansas was obtained from NOAA. The data was presented as Attachment F of the Proposal and is provided as Attachment A-2.
        - Table 2-4: PDSI values for South-Central Kansas
            - The 12-month annual PDSI data shows the 2011-2012 drought to be less severe than the 1930's drought.
            - The 6-month seasonal PDSI data shows the 2011-2012 drought exhibited drier summer months than the 1930's drought.
            - Proposal Table 2-4 has been provided as Attachment B.
        - Table 2-5: Water Variables and Inputs to the EBGWM by Stress Period
            - Using both ASR credits and reductions of demand, Cheney Reservoir will not be depleted in the modeled 1% drought.

    - Proposal Table 2-5 has been provided as Attachment C.
- 2.4.3 Groundwater Pumping - Agricultural Irrigation, Industrial Use, Other Municipal Users
    - For the drought and drought recovery simulation, the model utilizes the matching DWR reported pumping values from calendar years 2010, 2011, and 2012.
    - Some portion of agricultural irrigation the applied water returns to the aquifer as infiltration. The DWR reported quantity for model years of 2010, 2011, and 2012 were adjusted to account for this infiltration.
    - Proposal Section 2.4.3 has been provided as Attachment D-1.
    - Pumping values for industrial and other non-Wichita municipal pumping were utilized to develop the pumping inputs for the model, as described in excerpts of Proposal Attachment E, provided as Attachment D-2.
- Table 2-6: Net Irrigation Use in the 1% Drought Model
    - The net irrigation use modeled in the CWSA during the drought is less than authorized quantity.
    - Proposal Table 2-6 has been provided as Attachment E.
- 2.4.4 Groundwater Pumping - City of Wichita
    - The total simulated City of Wichita groundwater pumping from the EBWF for drought years 1 through 8 is based on the MODSIM-DSS 1% drought modeling work completed by the City.
    - City well pumping was distributed based on the actual water rights allocation for each well as a percentage of total authorized EBWF water rights.
    - Proposal Section 2.4.4 has been provided as Attachment F.Attachment G of the Proposal provides streamflow hydrographs and flow percentile classification for calendar years 2010 through 2012 as implemented in the EBGWM. Attachment G is provided as Attachment G of this report.

- 2.4.6 Precipitation & Natural Aquifer Recharge
  - The 1% drought model was constructed using precipitation and distributed natural recharge consistent with the original model documentation
  - Proposal Section 2.4.6 has been provided as Attachment H-1.

  Natural recharge was implemented as described in excerpts of Proposal Attachment E, provided as Attachment H-2.
- 2.5 Groundwater Modeling Results - 1% Drought Simulation
  - Review of the constructed hydrographs at Index Wells indicates that groundwater levels within the EBWF are projected to fall below the current ASR minimum index levels during the simulated drought.
  - Hydrographs, tables, and maps presenting when and where the January 1993 conditions are encountered were provided as Attachment I to the Proposal, and are presented as Attachment I to this Report.
- Figure 9 - 1993 Groundwater Levels as a Percentage of Predevelopment Saturated Aquifer Thickness
  - Figures 2, 3, and 4 of Proposal Attachment H - USGS SIR 2013-5170, Revised 1993 Groundwater Levels, were utilized to calculate saturated aquifer thickness. Figure 9 of the Proposal presents 1993 conditions as a percentage of predevelopment conditions. Figure 9 is provided as Attachment J.
- Table 2-9: Groundwater Modeling Results for 1% Drought Simulation
  - This Table presents average modeled water level changes within the model at annual intervals.
  - At the end of the 8-year simulated drought, the average remaining saturated thickness as a percentage of predevelopment saturated thickness was 86% for model cells in the CWSA.
  - Table 2-9 of the Proposal has been provided as Attachment K.

- 2.6 Proposed Modifications to ASR Minimum Index Water Levels
  - The results of the EBGWM 1% drought simulation were utilized to calculate the lowest groundwater elevation for each IW site throughout the eight-year simulated drought.
  - To account for variability in actual drought conditions, an additional contingency was subtracted from the calculated lowest groundwater elevations encountered during the groundwater modeling simulation for each IW site.
  - The City is requesting that the proposed minimum index levels be applied to all existing ASR Phase II infrastructure.
  - Modifications to the minimum index level on permits covering ASR Phase I infrastructure are not being requested at this time.
  - Proposal Section 2.6 has been provided as Attachment L.
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- Table 2-10: Development of Proposed ASR Minimum Index Levels
  - The lowest water level, modeled or exhibited in 1993, was used as a basis for the proposed level, which reflects a proposed contingency.
  - Proposal Table 2-10 has been provided as Attachment M.
- Table 2-11: Proposed ASR Minimum Index Levels
  - Average remaining saturated thickness within CWSA Index Cells at Proposed levels exceeds 79% of predevelopment conditions.
  - Within the CWSA, the minimum remaining percentage of predevelopment conditions is 72%.
  - Proposal Table 2-11 has been provided as Attachment N.
- Figure 11 - Average Aquifer Conditions by Index Cell at Proposed Minimum Levels
  - Figure 11 illustrates the average remaining aquifer saturated thickness for each Index Cell under the proposed levels as a percentage of predevelopment aquifer thickness.
  - Figure 11 of the Proposal has been presented as Attachment O.
- 2.7 Summary
  - To address the concern of recharge credits becoming unavailable during drought the proposed ASR minimum index water level elevations illustrated in Table 2-11 have been submitted for consideration.

  - Proposal Section 2.7 has been provided as Attachment P.

- 3.5 ASR Physical Recharge & ASR Operations Plan
  - The operations plan will utilize groundwater level monitoring and the calculated recharge capacity of the ASR recharge well network to determine the quantity and eligibility to accumulate AMCs.
  - To determine the physical recharge capacity of the ASR recharge well network, the City proposing the implementation of an annual water level monitoring program in conjunction with a recharge capacity calculation table.
  - Proposal Section 3.5 has been provided as Attachment Q.
- Figure 14 - AMC Operations Table 2016 Example
  - Section 3.5 erroneously refers to Figure 13, when Figure 14 is intended, to present an operations table as a guide to estimate the amount available physical recharge capacity available in the ASR recharge well network.
  - Figure 14 is provided as Attachment R.
- Review and critique of the technical expert report submitted by Carl E Nuzman P.E., P.Hg
  - This document is provided as Attachment S.

d) Daniel Clement is a Burns & McDonnell employee; the Contracts provided in the City's Production of Documents disclose a Fee Schedule for each class of employee.

e) Daniel Clement's qualifications are as presented in the City of Wichita's Preliminary Expert Disclosure.

f) Daniel Clement's factual observations and opinions are as presented above in this Expert Report, ASR Permit Modification Proposal, cover letter, and supporting appendices.

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Daniel Clement, Burns & McDonnell

Details of the USGS Equus Beds Groundwater Flow Model (EBGWM), including information regarding the model setup, calibration, sensitivity analysis and results are contained in the public document "*Simulation of Groundwater Flow, Effects of Artificial Recharge, and Storage Volume Changes in the Equus Beds Aquifer near the City of Wichita, Kansas Well Field, 1935-2008,*" USGS Scientific Investigations Report 2013-5042 (Kelly, et al, 2013) which has been included as Attachment E. The model captures the areal extent of the City's ASR BSA, and is currently approved for use as the method for accounting and tracking of ASR credits (Figure 3).

The EBGWM is currently the best forward analysis and prediction tool available for simulating the total combined effects of a 1% drought on the local and regional water levels surrounding the City's ASR project. The EBGWM provides a method to simulate the effects of a 1% drought on the aquifer water levels by the input of simulated drought variables including increased agricultural irrigation pumping, additional City pumping, reduced aquifer recharge, reduced streamflow, and increased evapotranspiration. When developed by the USGS, the EBGWM was calibrated to groundwater flow and water level changes from 1935 through 2008. Since publication of the model, BMcD has updated the model inputs to include the years 2009 through 2015 to generate the ASR annual accounting report. BMcD used a pre- and post-processing software package (Groundwater Vistas) to facilitate import of modeling files and analysis of results. Groundwater Vistas utilizes the same calculation packages used by the original EBGWM (MODFLOW-2000), and no changes were made to the original construction or hydrogeologic properties of the model. The performance of the model remains identical to the original transient calibrations performed and published by the USGS. The EBGWM model was modified for the purposes of simulating the effects of a 1% drought adding stress periods to include the years 2009 through 2015 and the necessary data for those calendar years to be simulated in a forward analysis. Model parameters such as boundary conditions, surface elevation, bedrock elevation, aquifer hydraulic conductivity, storativity, and hydrologic unit groups are as originally established by the USGS.

2.4.1 Stress Period (SP) Development

The MODSIM-DSS model performs simple reservoir accounting based on the inputs of one inflow source and local hydrologic variables for the reservoir. The EBGWM is a complex regional scale tool that requires more detailed information from multiple stream gages and weather stations to create stress periods as prescribed by the original USGS EBGWM documentation. Hydrologic data was collected from the NOAA, USGS, and other sources and examined for the 1% drought occurrence years of 1933-1940. The availability of detailed hydrologic data for this period was found to be limited for the groundwater model area in both density and completeness for evapotranspiration, stream flows, and precipitation. The sporadic hydrologic data for the groundwater model area during 1933-1940 would make generation of model inputs for annual stress periods using the methods prescribed by the original groundwater model documentation problematic. Data from the 1930's would also require additional consideration and potential adjustment for variables such as stream gage elevations, incising of stream beds, and stream base flow. Rather than attempt interpolation from incomplete hydrologic data, the PDSI values from 1933 to 1940 were compared to more recent years to find and develop a complete hydrologic data set for simulating the duration and intensity of the 1% drought. The data provided in Attachment C indicates that a 1% drought should extend for a total of approximately eight years and exhibit a cumulative PDSI of roughly -22.4 with a mean PDSI of -2.80. PDSI information for recent calendar years for South Central Kansas was obtained from NOAA for comparison to the PDSI from 1933 to 1940 (Attachment F). The annual (12 Month) and seasonal (6 Month) intensities from this data set were compared to the PDSI statistics of the target years of 1933 through 1940. The recent calendar years that best compare to the target years were 1991, 2002, 2006, 2011, and 2012. Based on this comparison, the years 2011 and 2012 were selected to repeat four times, for a total of eight years, to simulate a 1% drought. This approach results in a total seasonal cumulative PDSI of -23.45 with a mean PDSI of -2.93 (Table 2-4).

Table 2-4: *PDSI values for South-Central Kansas*

Drought Year	12 Month Annual PDSI Calculated NOAA South Central KS	6 Month Seasonal PDSI Calculated NOAA South Central KS
1934	-4.26	-4.78
1936	-2.71	-3.98
1933	-2.58	-3.96
2011	-1.99	-3.68
1937	-3.13	-2.90
1940	-3.10	-2.63
1939	-1.63	-2.55
2012	-1.92	-2.18
1935	-2.60	-1.48
1938	-1.08	0.69
1933-1940 AVG	-2.64	-2.70
2011-2012 AVG	-1.96	-2.93
1933-1940 Cumulative	-21.09	-21.58
2011-2012 Simulated 8 Year Cumulative	-15.64	-23.45

DWR and GMD2 also requested that in addition to simulating a 1% drought, two years of aquifer recovery conditions be included in the modeling scenario. After examining the recent historic record of PDSI information, the year 2010 was chosen as a wet calendar year to simulate aquifer recoveries based on a NOAA reported annual PDSI of +2.5 and a six-month seasonal PDSI of +1.56. The groundwater modeling inputs utilized for each stress period of the simulated 1% drought are summarized in Table 2-5 and described below.

2.4.2 Starting Groundwater Model Elevations

To establish the starting groundwater elevations for the 1% drought simulation, BMcD and City staff reviewed historic, current, and future water resource management and ASR strategies. To select initial head conditions for the 1% drought scenario, the simulated transient water levels provided by USGS in the original model report for 1990-2008 were compared against the designed recharge capacity of existing ASR infrastructure. This comparison indicated that the simulated groundwater levels representing the end of the 1998 period were the best match for representing the minimum groundwater levels required to maintain 30 MGD of physical ASR recharge capacity. These initial water levels represent an average of 91% full conditions across model cells inside the USGS Central Wellfield Study Area (CWSA) and 94% full conditions for the BSA as a percentage of predevelopment saturated thickness (see Figure 3 for boundaries of the active groundwater model, CWSA and BSA). The starting groundwater elevations represent the lower anticipated groundwater elevation range considerate of ASR recharge capacity, re-occurrence of drought, and the aquifer management strategies currently available to the City.

2.4.3 Groundwater Pumping – Agricultural Irrigation, Industrial Use, Other Municipal Users

The withdrawal of groundwater is regulated and tracked through a statewide metering and reporting program managed by the DWR. For the drought and drought recovery simulation, the model utilizes the matching DWR reported pumping values from calendar years 2010, 2011, and 2012. The DWR metered pumping values for industrial and other non-Wichita municipal pumping were utilized to develop the pumping inputs for the model.

During agricultural irrigation, some portion of the applied water returns to the aquifer as infiltration. To account for this infiltration, the DWR reported quantity for the target model years of 2010, 2011, and 2012 were adjusted as documented in the original groundwater model documentation (Attachment E - *USGS Scientific Investigations Report 2013-5042*). Net irrigation use within the CWSA is shown in Table 2-6. The total calculated currently authorized quantity for irrigation use when considering all irrigation water rights within the CWSA is approximately 13,400 AF.

ATTACHMENT F
Historic NOAA PDSI Values for South-Central Kansas

Annual and Seasonal Total PDSI Comparison
South Central Kansas
from
http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp
Annual: 12 month total; Seasonal: 6 month growing season

South Central KS PDSI

Year	PDSI Date	Annual	Seasonal	Rank
1901	10/01/1901	-11.42	-10.51	27
1902	10/01/1902	-6.07	11.07	79
1903	10/01/1903	9.08	0.51	52
1904	10/01/1904	10.84	12.82	84
1905	10/01/1905	-2.07	2.33	57
1906	10/01/1906	1.88	5.43	69
1907	10/01/1907	31.04	14.43	88
1908	10/01/1908	31.72	17.49	101
1909	10/01/1909	0.42	-2.88	45
1910	10/01/1910	-2.68	-12.86	23
1911	10/01/1911	-32.23	-15.05	19
1912	10/01/1912	6.09	5.9	70
1913	10/01/1913	-21.38	-18.06	11
1914	10/01/1914	-16.79	-8.3	33
1915	10/01/1915	16.52	24.99	113
1916	10/01/1916	33.66	3.93	63
1917	10/01/1917	-21.66	-12.6	24
1918	10/01/1918	-25.84	-8.39	32
1919	10/01/1919	15.94	0.93	53
1920	10/01/1920	-17.25	-3.33	44
1921	10/01/1921	7.62	0.98	54
1922	10/01/1922	3.64	4.76	65
1923	10/01/1923	3.21	12.62	83
1924	10/01/1924	19.62	-4.25	41
1925	10/01/1925	-24.24	-15.98	15
1926	10/01/1926	-19.67	-6.62	35
1927	10/01/1927	20.43	14.7	90
1928	10/01/1928	29.81	16.26	97
1929	10/01/1929	34.48	16.8	100
1930	10/01/1930	-4.03	-5.58	38
1931	10/01/1931	-0.64	-3.84	43
1932	10/01/1932	1.59	0.28	51
1933	10/01/1933	-30.98	-23.76	7
1934	10/01/1934	-51.12	-28.65	3
1935	10/01/1935	-31.22	-8.85	29
1936	10/01/1936	-32.46	-23.9	6
1937	10/01/1937	-37.5	-17.38	12
1938	10/01/1938	-13	4.15	64
1939	10/01/1939	-19.56	-15.27	18
1940	10/01/1940	-37.18	-15.8	16
1941	10/01/1941	11.97	12.36	82
1942	10/01/1942	36.66	18.96	102
1943	10/01/1943	4.9	-6.06	37
1944	10/01/1944	15.88	15.4	92
1945	10/01/1945	38.71	15.73	95
1946	10/01/1946	-16.75	-11.65	25
1947	10/01/1947	16.61	4.98	67
1948	10/01/1948	9.34	10.98	78
1949	10/01/1949	43.07	21.45	107
1950	10/01/1950	-8.23	-1.81	48
1951	10/01/1951	15.79	24.26	112
1952	10/01/1952	17.74	-13.28	21
1953	10/01/1953	-43.52	-26.01	4
1954	10/01/1954	-51.82	-29.92	2
1955	10/01/1955	-60.51	-25.6	5
1956	10/01/1956	-59.2	-37.8	1
1957	10/01/1957	-12.15	22.04	108
1958	10/01/1958	43.22	22.98	110
1959	10/01/1959	24.17	10.26	76
1960	10/01/1960	32.79	14.66	89
1961	10/01/1961	25.54	16.45	98
1962	10/01/1962	36.51	11.75	81
1963	10/01/1963	-19.97	-16.03	14
1964	10/01/1964	-39.35	-23.14	8
1965	10/01/1965	17.74	15.94	96
1966	10/01/1966	0.6	-14.77	20
1967	10/01/1967	-40.68	-17.15	13
1968	10/01/1968	-22.06	-5.03	40
1969	10/01/1969	23.54	15.47	93
1970	10/01/1970	-4.93	-5.44	39
1971	10/01/1971	-16	-6.85	34
1972	10/01/1972	1.21	0.24	50
1973	10/01/1973	31.25	19.28	103
1974	10/01/1974	42.67	13.96	86
1975	10/01/1975	19.04	2.2	56
1976	10/01/1976	-7.17	-1.42	49
1977	10/01/1977	-4.21	4.89	66
1978	10/01/1978	-3.62	-2.45	47
1979	10/01/1979	-0.3	3.6	61
1980	10/01/1980	4.65	-8.53	30
1981	10/01/1981	-18.43	2.34	58
1982	10/01/1982	15.04	5	68
1983	10/01/1983	1.89	1.95	55
1984	10/01/1984	-2.85	-6.15	36
1985	10/01/1985	23.1	14.4	87
1986	10/01/1986	32.84	15.13	91
1987	10/01/1987	49.16	27.03	115
1988	10/01/1988	15.71	-8.52	31
1989	10/01/1989	-11.11	8.04	71
1990	10/01/1990	-2.27	-4.21	42
1991	10/01/1991	-30.85	-21.19	10
1992	10/01/1992	5.03	10.19	75
1993	10/01/1993	49.15	22.36	109
1994	10/01/1994	-13	-8.88	28
1995	10/01/1995	18.33	15.58	94
1996	10/01/1996	-9.62	2.56	59
1997	10/01/1997	40.74	25.03	114
1998	10/01/1998	46.39	13.33	85
1999	10/01/1999	43.75	24.22	111
2000	10/01/2000	33.25	16.62	99
2001	10/01/2001	14.9	-2.59	46
2002	10/01/2002	-28.5	-11.21	26
2003	10/01/2003	16.77	2.73	60
2004	10/01/2004	6.66	8.11	72
2005	10/01/2005	26.18	9.19	73
2006	10/01/2006	-23.46	-15.41	17
2007	10/01/2007	17.68	19.57	104
2008	10/01/2008	30.75	20.35	105
2009	10/01/2009	44.76	21.4	106
2010	10/01/2010	31	9.37	74
2011	10/01/2011	-23.89	-22.09	9
2012	10/01/2012	-23.04	-13.08	22
2013	10/01/2013	-3	11.37	80
2014	10/01/2014	5.74	3.79	62
2015	10/01/2015	6.97	10.45	77

precipitation. The sporadic hydrologic data for the groundwater model area during 1933-1940 would make generation of model inputs for annual stress periods using the methods prescribed by the original groundwater model documentation problematic. Data from the 1930's would also require additional consideration and potential adjustment for variables such as stream gage elevations, incising of stream beds, and stream base flow. Rather than attempt interpolation from incomplete hydrologic data, the PDSI values from 1933 to 1940 were compared to more recent years to find and develop a complete hydrologic data set for simulating the duration and intensity of the 1% drought. The data provided in Attachment C indicates that a 1% drought should extend for a total of approximately eight years and exhibit a cumulative PDSI of roughly -22.4 with a mean PDSI of -2.80. PDSI information for recent calendar years for South Central Kansas was obtained from NOAA for comparison to the PDSI from 1933 to 1940 (Attachment F). The annual (12 Month) and seasonal (6 Month) intensities from this data set were compared to the PDSI statistics of the target years of 1933 through 1940. The recent calendar years that best compare to the target years were 1991, 2002, 2006, 2011, and 2012. Based on this comparison, the years 2011 and 2012 were selected to repeat four times, for a total of eight years, to simulate a 1% drought. This approach results in a total seasonal cumulative PDSI of -23.45 with a mean PDSI of -2.93 (Table 2-4).

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2011-2012 Simulated 8 Year Cumulative	-15.64	-23.45

DWR and GMD2 also requested that in addition to simulating a 1% drought, two years of aquifer recovery conditions be included in the modeling scenario. After examining the recent historic record of PDSI information, the year 2010 was chosen as a wet calendar year to simulate aquifer recoveries based

Table 2-5: *Water Resource Variables and Inputs to the EBGWM by Stress Period*

Model Variable or Assumption	Model Stress Period 1	2	3	4	5	6	7	8	9	10
Future Demand Planning Year	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069
Simulated Hydrologic Year	2011	2012	2011	2012	2011	2012	2011	2012	2010	2010
Streamflows	2011	2012	2011	2012	2011	2012	2011	2012	2010	2010
Precipitation & Recharge	2011	2012	2011	2012	2011	2012	2011	2012	2010	2010
Evapotranspiration	2011	2012	2011	2012	2011	2012	2011	2012	2010	2010
Irrigation, Industrial, Other Well Pumping	2011 DWR Reported	2012 DWR Reported	2011 DWR Reported	2012 DWR Reported	2011 DWR Reported	2012 DWR Reported	2011 DWR Reported	2012 DWR Reported	2010 DWR Reported	2010 DWR Reported
Total EBWF & ASR (AF)	34,202	45,651	59,907	46,732	56,579	41,980	39,308	39,491	20,067	20,067
City of Wichita ASR Credit Pumping (AF)	0	5,651	19,907	6,732	15,552	1,980	0	0	0	0
Cheney Reservoir Pumping (AF)	47,060	26,841	11,209	25,158	14,233	28,831	31,808	31,173	Not Simulated	Not Simulated
City of Wichita Drought Conservation Stage	Normal	Stage 1	Stage 1	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Not Simulated	Not Simulated
Cheney % of Conservation Pool 12 Month Simulated AVG at Beginning of Year	110%	92%	62%	59%	62%	53%	53%	63%	Not Simulated	Not Simulated
Total City of Wichita Demand EBWF + Cheney (AF)	81,262	72,492	71,116	71,890	70,812	70,811	71,116	70,664	Not Simulated	Not Simulated

on a NOAA reported annual PDSI of +2.5 and a six-month seasonal PDSI of +1.56. The groundwater modeling inputs utilized for each stress period of the simulated 1% drought are summarized in Table 2-5 and described below.

2.4.2 Starting Groundwater Model Elevations

To establish the starting groundwater elevations for the 1% drought simulation, BMcD and City staff reviewed historic, current, and future water resource management and ASR strategies. To select initial head conditions for the 1% drought scenario, the simulated transient water levels provided by USGS in the original model report for 1990-2008 were compared against the designed recharge capacity of existing ASR infrastructure. This comparison indicated that the simulated groundwater levels representing the end of the 1998 period were the best match for representing the minimum groundwater levels required to maintain 30 MGD of physical ASR recharge capacity. These initial water levels represent an average of 91% full conditions across model cells inside the USGS Central Wellfield Study Area (CWSA) and 94% full conditions for the BSA as a percentage of predevelopment saturated thickness (see Figure 3 for boundaries of the active groundwater model, CWSA and BSA). The starting groundwater elevations represent the lower anticipated groundwater elevation range considerate of ASR recharge capacity, re-occurrence of drought, and the aquifer management strategies currently available to the City.

2.4.3 Groundwater Pumping – Agricultural Irrigation, Industrial Use, Other Municipal Users

The withdrawal of groundwater is regulated and tracked through a statewide metering and reporting program managed by the DWR. For the drought and drought recovery simulation, the model utilizes the matching DWR reported pumping values from calendar years 2010, 2011, and 2012. The DWR metered pumping values for industrial and other non-Wichita municipal pumping were utilized to develop the pumping inputs for the model.

During agricultural irrigation, some portion of the applied water returns to the aquifer as infiltration. To account for this infiltration, the DWR reported quantity for the target model years of 2010, 2011, and 2012 were adjusted as documented in the original groundwater model documentation (Attachment E - *USGS Scientific Investigations Report 2013-5042*). Net irrigation use within the CWSA is shown in Table 2-6. The total calculated currently authorized quantity for irrigation use when considering all irrigation water rights within the CWSA is approximately 13,400 AF.

Streambed thicknesses are unknown and were assigned an arbitrary value of 1 ft. Initial streambed conductances for drains were altered during calibration to more closely match observed and simulated flow from the aquifer to the drains. Simulated rivers and drains are shown in figure 28.

Wells

Pumping wells are internal boundaries of the model where water was removed at a specified rate equal to the discharge of each well. The total volume of water withdrawn annually from the aquifer by pumping from irrigation, production, and industrial wells was obtained from each water supplier when available or from the KDA-DWR Water Rights Information System database (Kansas Department of Agriculture–Division of Water Resources, unpub. data, 2009). The depth of each pumping well was based on the screened interval, when known, or the depth of the well. The Multinode Well Package was used to simulate all industrial, irrigation and production well pumping (Harbaugh and others, 2000). The MultiNode Well Package vertically distributes pumping between model layers from each well based on the top and bottom altitudes of the screened interval and the hydraulic properties of each model layer.

Groundwater pumpage data for 1935 to 1979 were obtained from Spinazola and others (1985) and Myers and others (1996). Groundwater pumpage for the stress periods from 1935 through 1979 was distributed in the model based on the spatial and temporal distribution of pumping in Spinazola and others (1985). The model cells from Spinazola and others (1985) are 1 mile on each side and pumping was assigned to the center of each cell. Pumping wells were placed in the current model to coincide with the center of each cell in the model from Spinazola and others (1985). Pumping was distributed vertically across all model layers by using the MultiNode Well Package. Locations of simulated pumping wells for 1935 through 1979 are shown in figure 29.

Annual groundwater pumpage data for industrial, irrigation, and production wells in the study area for 1988 through 2008 were obtained from the KDA-DWR (Kelly Emmons, Kansas Department of Agriculture, Division of Water Resources, written commun., June 5, 2009, and August 31, 2009). Groundwater pumpage for the stress period from 1980 through 1989 was distributed in the model using well locations and pumping rates from 1989. Groundwater pumpage for the stress periods from 1990 through 2008 was distributed in the model using well locations and average annual pumping rates.

Monthly pumpage data for Wichita's production wells for 1990 through 1993 and 1995 through 2008 (Megan Schmeltz, city of Wichita, written commun., September 25, 2009) and monthly artificial recharge data for phase I ASR sites for 2007 through 2008 were obtained from the city of Wichita (U.S. Geological Survey, 2011). Monthly pumping rates were used to calculate an annual rate used for the Wichita wells. The city of Wichita also provided annual artificial-recharge data for 2002 through 2005 for the *Equus* Beds Groundwater Recharge Demonstration sites (U.S. Geological Survey, 2011). Locations for Wichita's production wells and the phase I ASR artificial-recharge wells were provided by KDA-DWR. Locations of the *Equus* Beds Artificial-recharge Demonstration Project recharge sites were those previously determined by the USGS.

The pumping wells and artificial-recharge sites were assigned to the model-grid cell they plotted within based on decimal-degree locations provided by KDA-DWR. Each well was evaluated individually to determine the altitude of the bottom of the well and the screened interval. The top and bottom altitudes were used in the MultiNode Well Package to vertically distribute well pumping across model layers for each well.

The depth of each well was determined using one of the following methods. Where data were available, the altitude of the bottom of the screened interval was used. For unknown screened intervals, the altitude of the bottom of the well was used. If the altitude of the bottom of the screened interval or depth of the well were unknown, and aquifer information provided by KDA-DWR indicated the well was in the *Equus* Beds aquifer, well depth was assigned as the depth of the lowest model layer in the cell that contained the well. If the well was not in the *Equus* Beds aquifer, it was excluded from use.

The top of the screened interval for each well was determined using one of the following methods. If the screened interval was known, the top altitude was used. If the screened interval was unknown, the top of the screened interval was arbitrarily set at 20 ft below land surface. For shallow pumping wells located in model layer 1, the top of the screened interval was arbitrarily set at 10 ft below land surface. Locations of simulated pumping wells for 1980 through 2008 are shown in figure 30.

Industrial pumpage was assumed to be at a constant rate throughout the year. The annual volume of pumpage divided by the number of days in the year was used to calculate a pumpage rate in cubic feet per day.

Two modifications were made to the annual irrigation pumpage data obtained from KDA-DWR. Irrigation pumpage that was unmetered (pumpage reported as the number of hours the pump ran multiplied by a pump rate) was considered over-reported and was reduced by varying annual percentages. Comparisons of pumpage at selected wells before and after metering indicated that unmetered pumpage was over-reported by about 20 percent before 1990 (Andy Lyon, Kansas Department of Agriculture, Division of Water Resources, written commun., July 2010). The KWO estimates the percentage by which the annual reported unmetered irrigation water is greater than actual irrigation (Kansas Water Office and Kansas State Board of Agriculture, Division of Water Resources, 1989) using the following equation:

$$\text{Percent of unmetered irrigation over-reported} = 100x[((Viu/Aiu) - (Vim/Aim))xAiu]/Viu \quad (4)$$

where

Viu = volume of unmetered irrigation water,

Aiu = area irrigated by unmetered irrigation water,

Vim = volume of metered irrigation water, and

Aim = area irrigated by metered irrigation water.

Using this method for the years 1989 through 2008, the amount by which the unmetered irrigation pumpage was estimated to be over-reported within the model area is listed in table 4.

Table 4. Estimated over-reporting of unmetered irrigation pumpage by year.

Year	Estimated overreporting of unmetered irrigation pumpage, in percent	Year	Estimated overreporting of unmetered irrigation pumpage, in percent
1989	17.17	1999	17.18
1990	1.33	2000	3.52
1991	5.19	2001	1.90
1992	24.20	2002	6.01
1993	22.71	2003	0
1994	6.96	2004	18.31
1995	11.03	2005	8.81
1996	17.55	2006	0.34
1997	27.29	2007	16.73
1998	11.27	2008	19.72

For the multiyear stress periods simulating 1935 through 1979, the amount of irrigation water that was over-reported was estimated at 20 percent. For the stress period from 1980 through 1989, the 1989 value (17.17 percent) was used.

Irrigation return flow is the part of the applied irrigation pumpage that is not consumed and recharges the aquifer. For the preparation of data for the model, the amount of irrigation return flow was considered to vary by the type of irrigation system used. Estimated return flow by system type is the same as that estimated by the KGS and used by KDA-DWR for the Middle Arkansas River Basin model (Andrew Lyon, Kansas Department of Agriculture, Division of Water Resources, written commun., July 2010). These percentages are similar to those reported in the Irrigation Guide for Kansas (National Resources Conservation Service, 2006). The irrigation system types used by KDA-DWR were grouped into the return-flow groups and are listed in table 5.

Since 1991, the percent of irrigation in the model area that was assigned to flood, center pivot-impact, and center pivot-LDN (low-impact drop nozzle) was estimated using a modification of a method used by KDA-DWR for their Middle Arkansas River Basin model (Andrew Lyon, Kansas Department of Agriculture, Division of Water Resources, written commun., July 2010). This method used data from a study done by Kansas State University that estimated the percentage of acres irrigated by gravity (flood), sprinkler, and microirrigation (drip) methods for the years 1970 through 2000 (Lamm and Brown, 2004). A ratio of the acres irrigated using sprinkler methods divided by the acres irrigated using gravity methods was computed for each year for the entire State of Kansas. The acres irrigated using drip methods during 1970 through 2000 were negligible (less than 1 percent in 2000). Using the data from KDA-DWR, the ratio of the acres irrigated using methods other than flood to the acres irrigated using the flood method for 1991 through 2008 for the model area was calculated and a relation between the state-wide ratio and the model area ratio was developed from the 10 years of overlap (1991 through 2000) between the datasets. In general, the ratio of center pivot to flood irrigation was lower for the whole State of Kansas than for the active part of the study area, probably in part because of the lack of large surface-water irrigation districts in the area. For the Middle Arkansas River Basin model, the state-wide ratio of center pivot to flood irrigation was multiplied by 2.5 to estimate the ratio of center pivot to flood irrigation was in their model area. A multiplier of 1.5 gave a better fit for the data for the active model area of this study. The 1.5 multiplier was applied to the state-wide ratio of center pivot to flood irrigation for 1970 through 1990 to estimate the ratio for the active model area. From this ratio, the percentage of acres irrigated by flood and nonflood methods in the active model area was estimated for 1970 through 1990. For the years before 1970, the ratio in 1970 was reduced by 0.03 each year through 1967 and by 0.02 each year for 1955 through 1966 to account for changes in irrigation methods with time. For the Middle Arkansas River Basin model, all irrigation before 1955 was assumed to use flood methods (Andrew Lyon, Kansas Department of Agriculture, Division of Water Resources, written commun., July 2010). This assumption also was used for the *Equus* Beds aquifer model. For the multiyear stress periods before 1990, the average percentage of acres estimated as irrigated by flood and nonflood methods was used to estimate the amount of irrigation return flow. Irrigation return flow calculated for each well was then subtracted from that well's pumping to obtain the net amount of groundwater pumpage. Although irrigation pumpage was assumed to occur only in May through August, annual irrigation pumping rates were calculated and used in the simulation.

Municipal pumpage was assumed to occur throughout the year. Monthly data, when available (for the city of Wichita municipal wells for 1990 through 1993 and 1995 through 2008), were used to determine annual pumping rates instead of using the annual rates from KDA-DWR. The changes made to the production pumpage data supplied by the city of Wichita are summarized in table 6, located at the back of the report. Average annual pumping rates were used for all other production wells.

Table 5. Estimated return flow from irrigation by irrigation system types.

[KDA-DWR, Kansas Department of Agriculture–Division of Water Resources]

Return-flow system type	Estimated return flow (percent)	KDA-DWR irrigation system type
Flood	25	Flood
Center-pivot high-impact nozzle	9	Unreported
		Center pivot-standard
		Sprinkler other
		Other
Center-pivot low-impact drop nozzle	7	Drip
		Center-pivot low-impact drop nozzle
		Drip and other
Combination	12.2	Center pivot and flood (assumed 80-percent center-pivot-standard and 20-percent flood)

Some of the Wichita production wells were redrilled, causing substantial changes in screen and well depths. Information from NWIS and Wichita (Rich Robinson, city of Wichita, written commun., December 2009) about the well and screen depths, and information available from KDA-DWR was used to more accurately assign well and screen depth for each well in each stress period.

Annual volumes of artificial recharge in gallons for the *Equus* Beds Demonstration Recharge sites and at each of the phase I ASR sites (U.S. Geolgoical Survey, 2011) were available. These volumes were converted to cubic feet and then divided by the total number of days in the year to get the artificial-recharge rate in cubic feet per day as used in the model.

Some of the *Equus* Beds Recharge Demonstration and phase I ASR project's artificial-recharge sites that are not wells (for example, basins or trenches; fig. 3) cover parts of adjacent model-grid cells; however, all of the artificial recharge for these sites was assigned to the cell that contained the point location previously used as the location of the site. The error associated with assigning artificial recharge to one cell instead of all the cells that intersect the recharge basins is assumed to be small because the recharge basins do not extend more than one cell from the point location previously used as the location of the site. Because the model treats sites where water is pumped into or out of the aquifer as wells, the artificial recharge was distributed to the entire cell. If recharge wells were drilled into a recharge basin (for example, at the Recharge Demonstration basins at Halstead) and the amount of recharge at each well was unavailable, the total amount was divided equally among them.

Head-Dependent Boundaries

The *Equus* Beds aquifer extends beyond the model boundary in several areas, and thus the model boundary does not represent the actual physical or groundwater flow boundaries of the aquifer. These boundaries were simulated in the model as general head boundaries, a form of the head-dependent flux boundary that allows groundwater to enter or exit the model proportional to the difference between the water level in the model and the water level assigned to the boundary multiplied by a conductance term that limits the rate of flow (McDonald and Harbaugh, 1988). These boundaries were located as far as practical from the Wichita well field to limit boundary effects on model results. Water levels along the boundary were assigned to each general head boundary cell based on an assumed water table value located 20 miles outside the model. General head boundary conductances were calculated by multiplying the hydraulic conductivity of each general head boundary cell by the length and width of the cell divided by the distance to the location of the assumed water-table value (20 miles). General head boundaries are shown in figure 31.

Head and Streamflow Gain and Loss Observations

Groundwater-level observations and streamflow gain and loss observations were compared to simulated groundwater levels and streamflow gains and losses using the Head Observation Package and the River Observation Package (Harbaugh and others, 2000) for the steady-state and transient groundwater calibration simulations. Groundwater-level observation data, including groundwater level altitude, well location within the model, and time of observation, were calculated and entered into the Head Observation Package.

Groundwater-level data and associated well-construction and aquifer information available from the USGS NWIS database (U.S. Geological Survey, 2009a; U.S. Geological Survey, unpub. data, 2009) and the Kansas Geological Survey's WIZARD database (Kansas Geological Survey, 2009) were compiled for wells in the study area. Groundwater levels commonly are recorded as depth below land surface. To convert them to groundwater altitudes, they were subtracted from the land-surface altitude determined for the well. If a land-surface altitude was not determined for the well, one was estimated

Table 2-6: *Net Irrigation Use in the 1% Drought Model*

Model Stress Period	Water Use Data Year	Net Irrigation Use CWSA (Acre Feet)	Net Irrigation Use BSA (Acre Feet)
1	2011	10,808	31,319
2	2012	10,190	22,706
3	2011	10,808	31,319
4	2012	10,190	22,706
5	2011	10,808	31,319
6	2012	10,190	22,706
7	2011	10,808	31,319
8	2012	10,190	22,706
9	2010	7,743	22,022
10	2010	7,743	22,022

2.4.4 Groundwater Pumping – City of Wichita

The total simulated City of Wichita groundwater pumping from the EBWF for drought years 1 through 8 is based on the MODSIM-DSS 1% drought modeling work completed by the City. The City examined projected demands through 2060, the magnitude and duration of 1% drought, and the effects of the City's DRP on available water resources. From this information MODSIM-DSS was utilized to optimize the City's integrated water resources strategy and to formally quantify the amount of water that should be utilized from each major water resource during a 1% drought. BMcD utilized the simulated demands directly from the City's MODSIM results as the City pumping inputs for the EBGWM during stress periods one through eight (see Table 2-7 below). City well pumping was distributed based on the actual water rights allocation for each well as a percentage of total authorized EBWF water rights. For the two requested recovery years, the actual City water use for the year 2010 was utilized (20,067 AF applied in model stress periods nine and ten).

Cheney Reservoir is not included within the bounds of the EBWGM and therefore has no direct simulated effect on groundwater elevations or the EBGWM results. The condition of Cheney Reservoir during 1% drought is only considered within the City's MODSIM-DSS model, which generated the distribution of projected raw water resource demands throughout the simulated drought.

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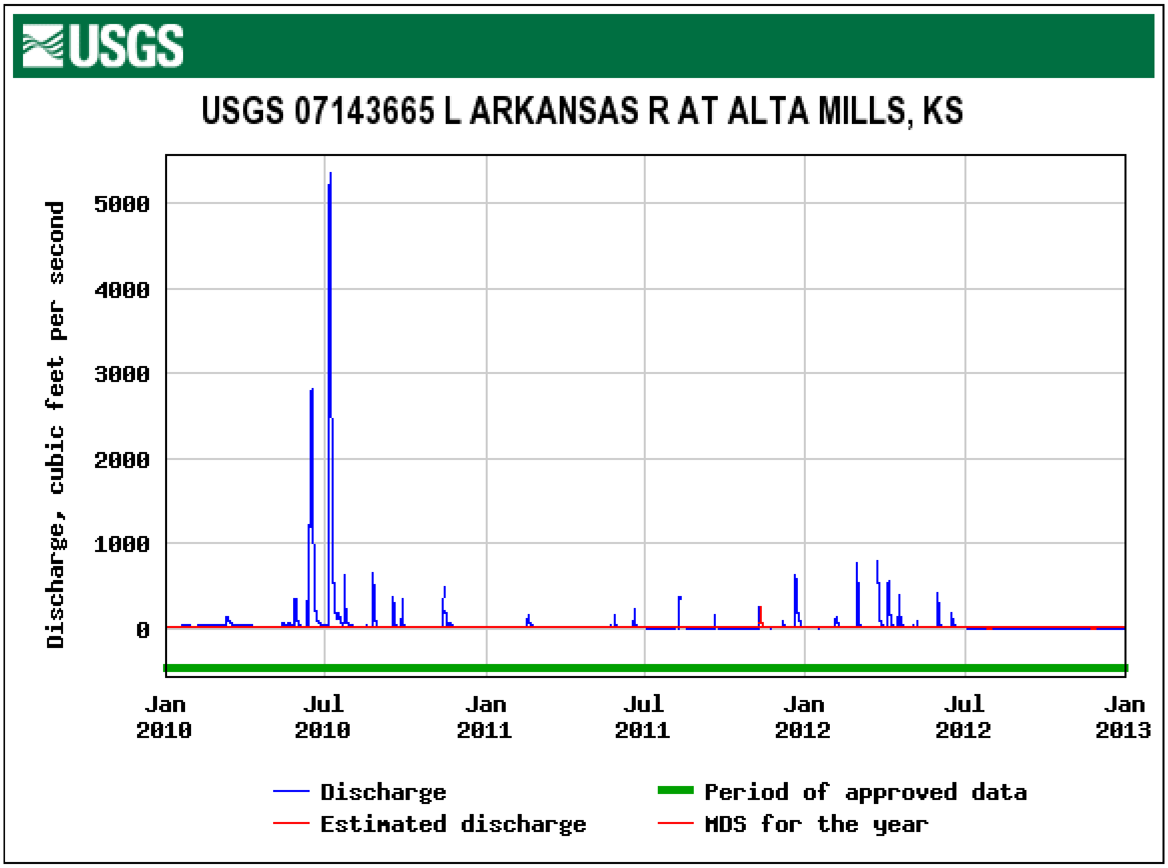
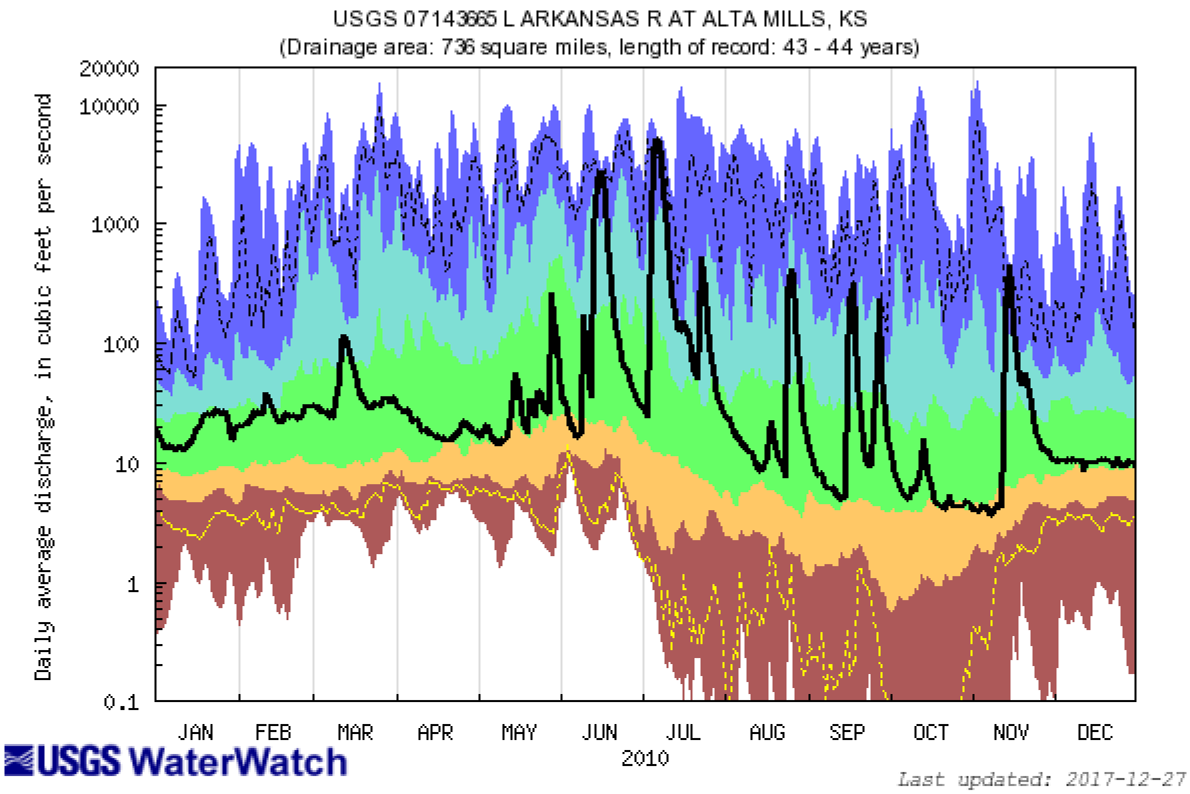
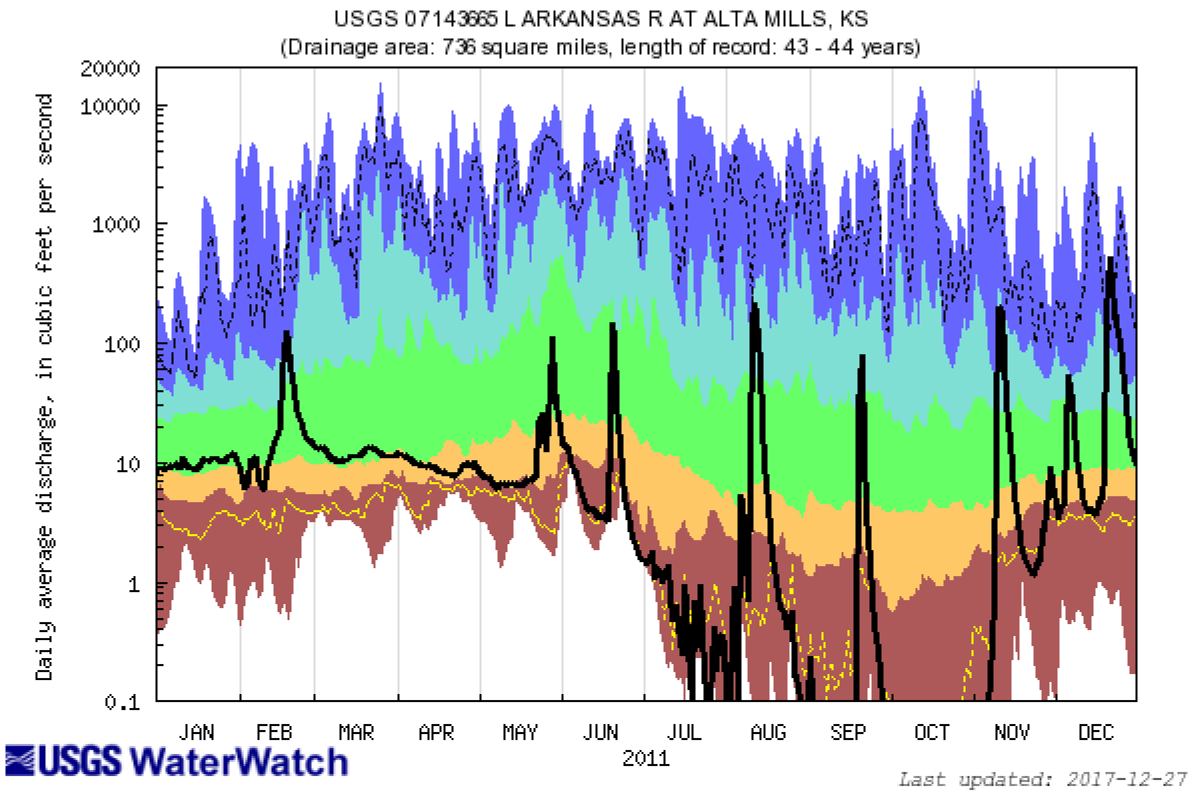
ATTACHMENT G
Streamflows For Arkansas & Little Arkansas Rivers 2011-2012


USGS
USGS 07143665 L ARKANSAS R AT ALTA MILLS, KS
Discharge, cubic feet per second
5000
4000
3000
2000
1000
0
Jan 2010
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012
Jan 2013
Discharge
Estimated discharge
Period of approved data
MDS for the year

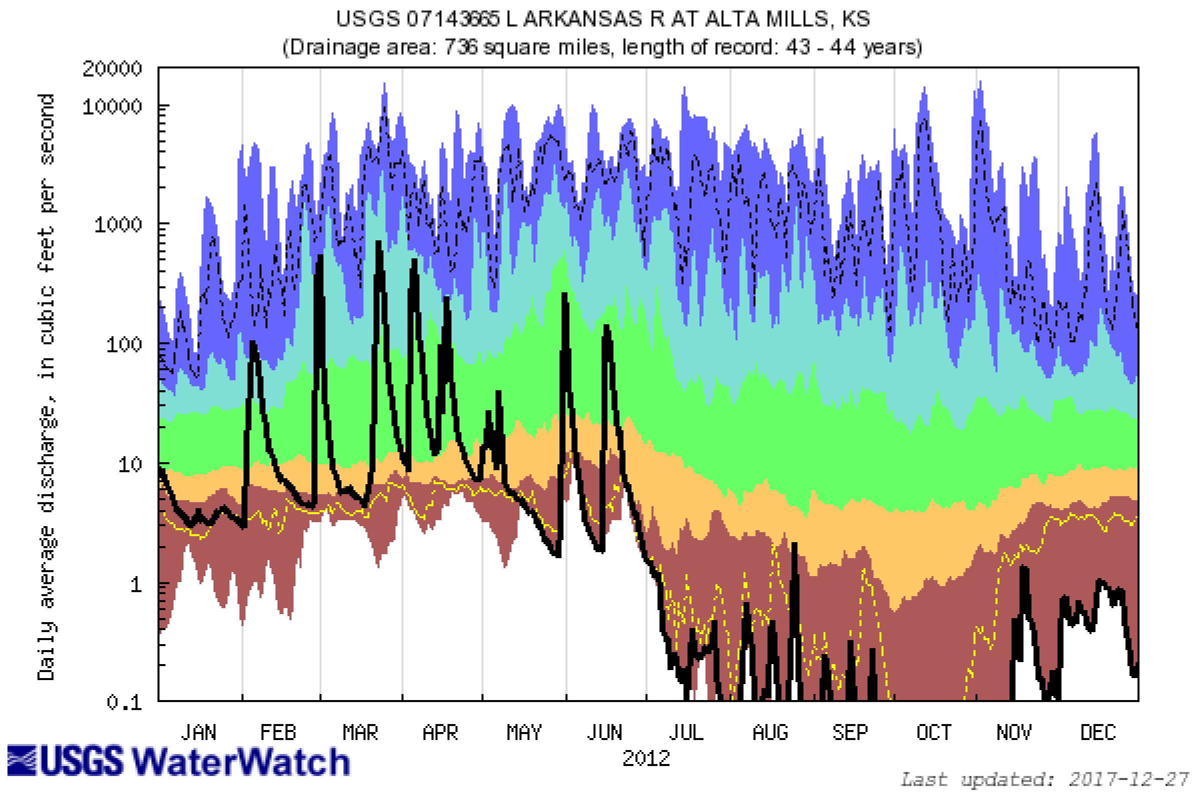


Explanation - Percentile classes

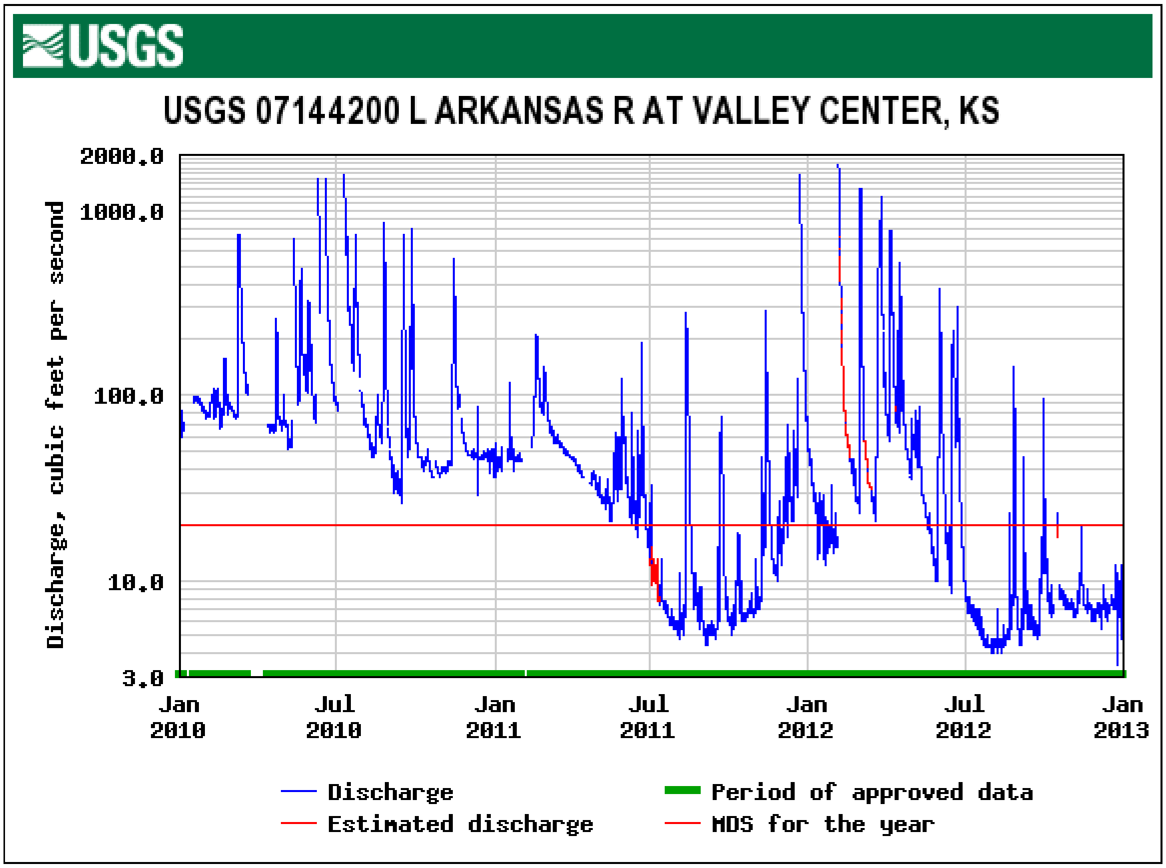
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		



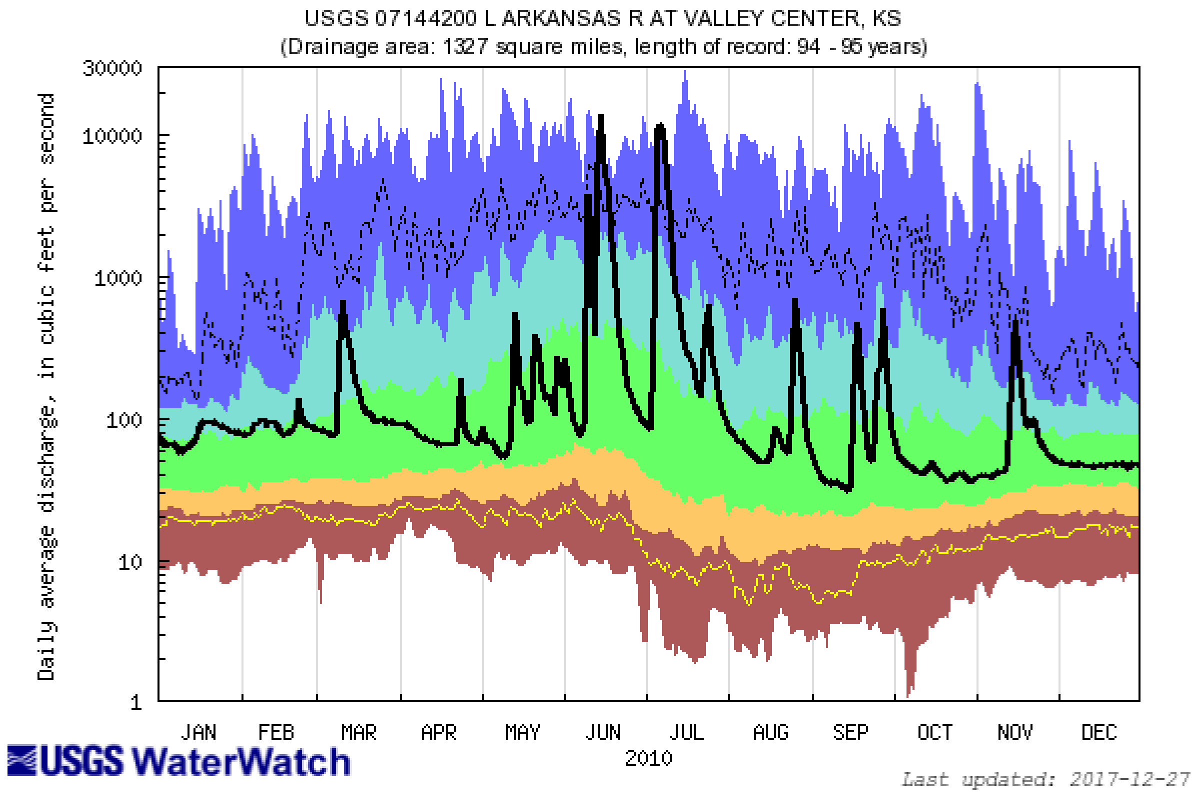
Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		



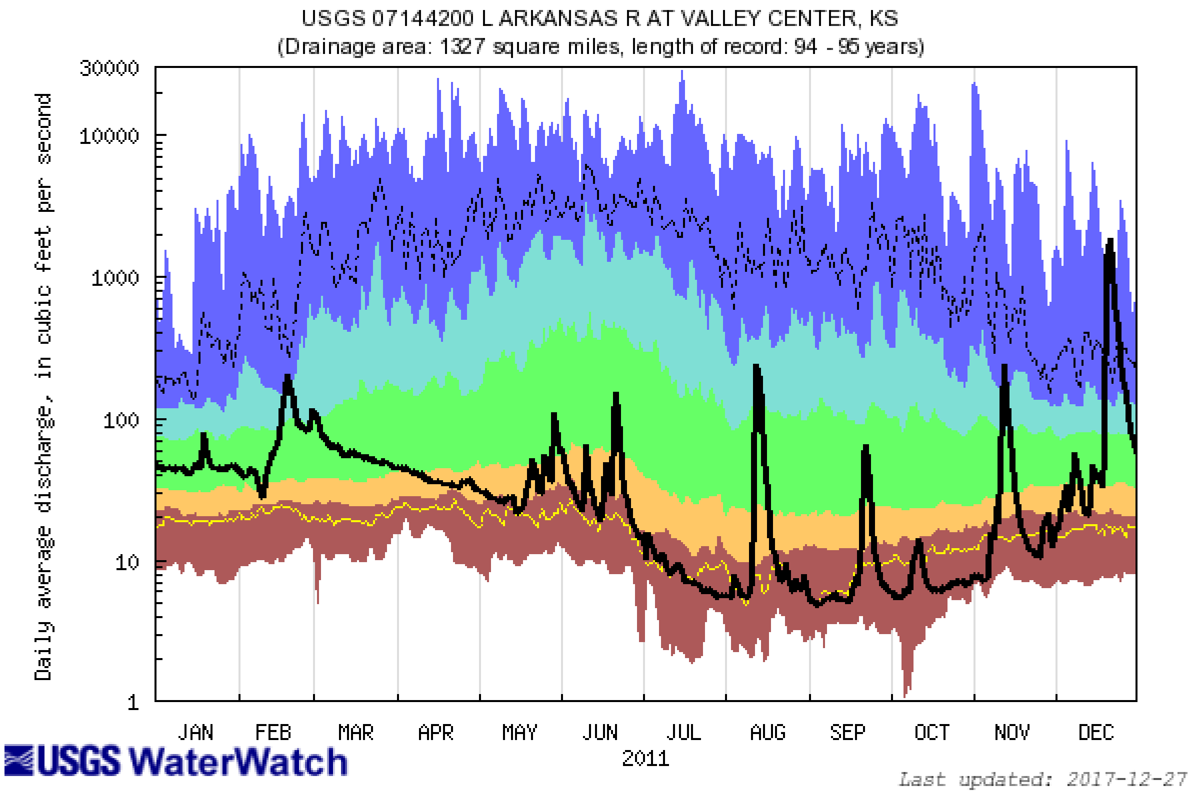
Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		



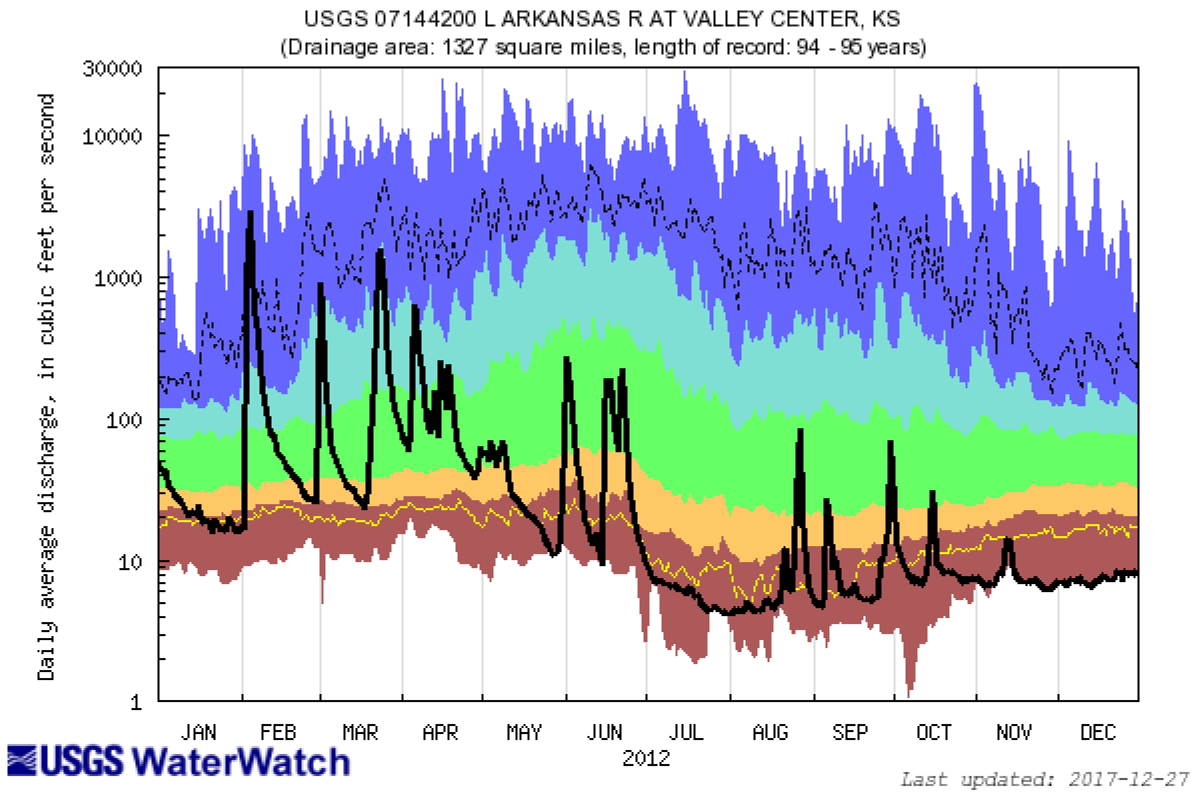
USGS
USGS 07144200 L ARKANSAS R AT VALLEY CENTER, KS
Discharge, cubic feet per second
2000.0
1000.0
100.0
10.0
3.0
Jan 2010
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012
Jan 2013
Discharge
Estimated discharge
Period of approved data
MDS for the year



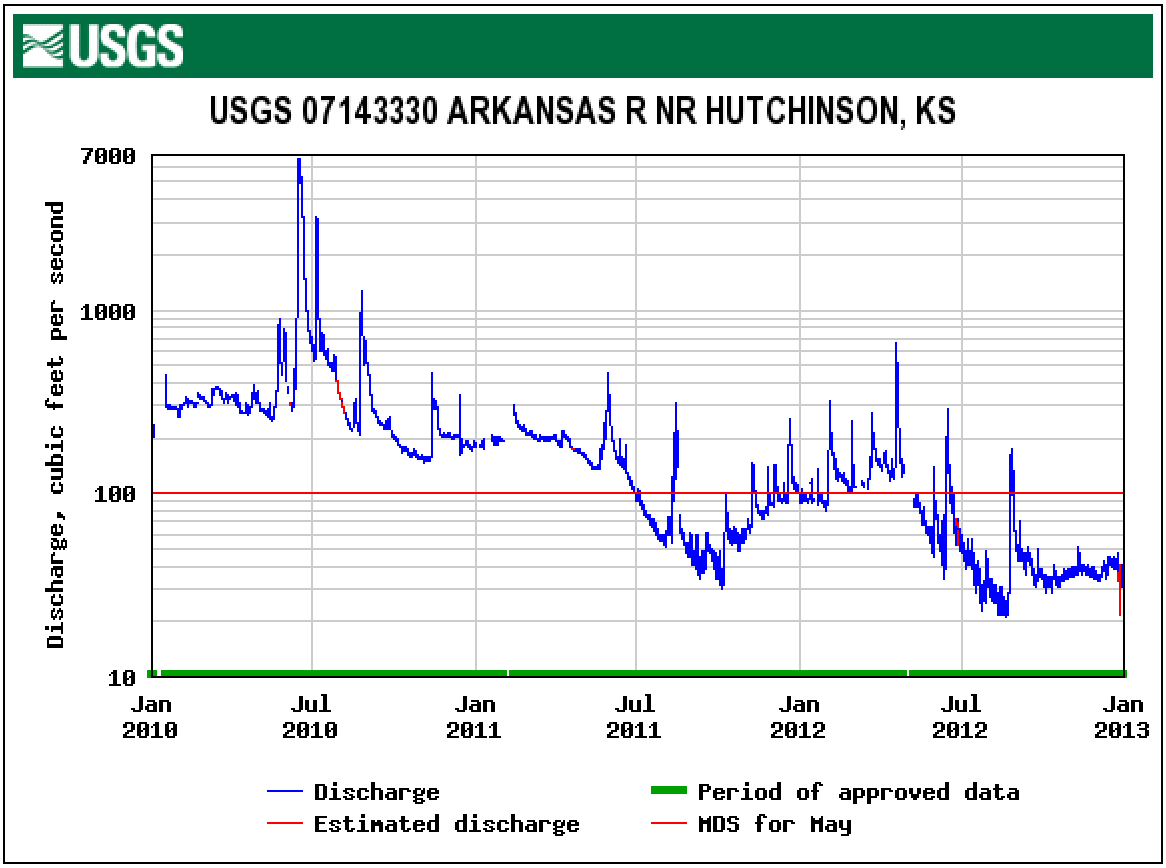
Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		

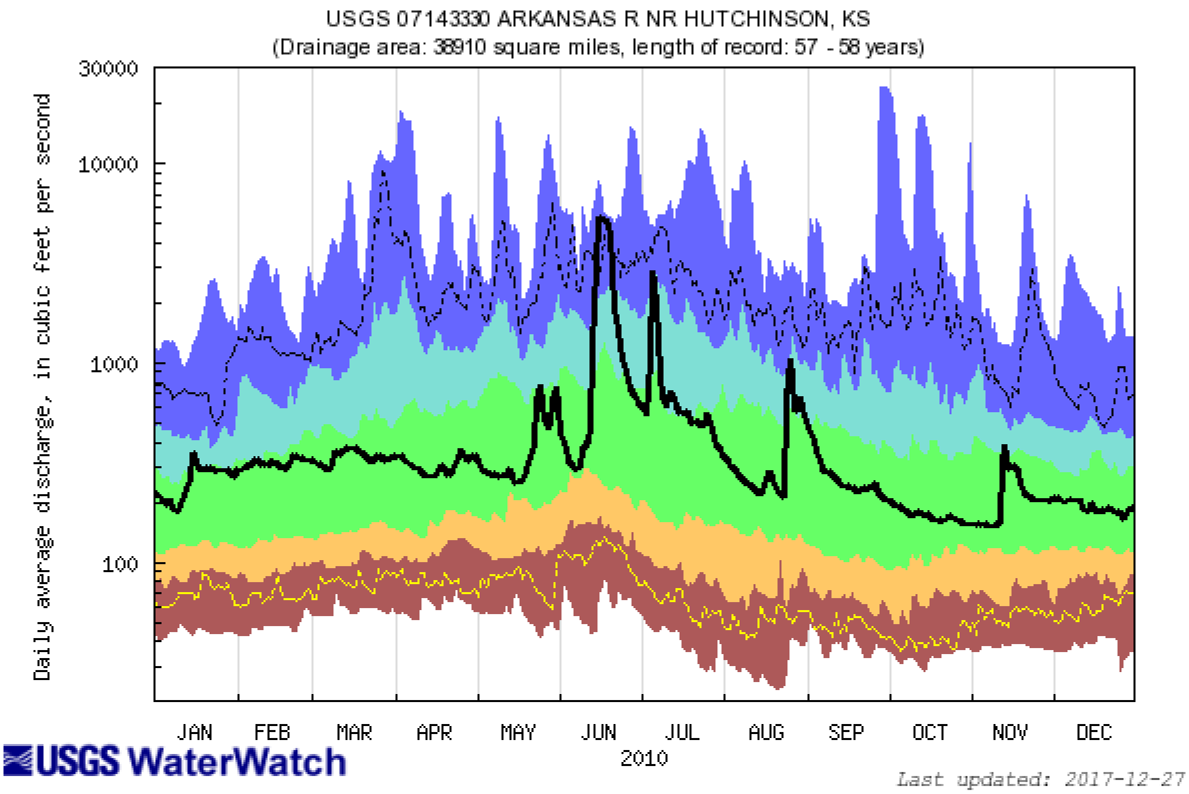


Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		

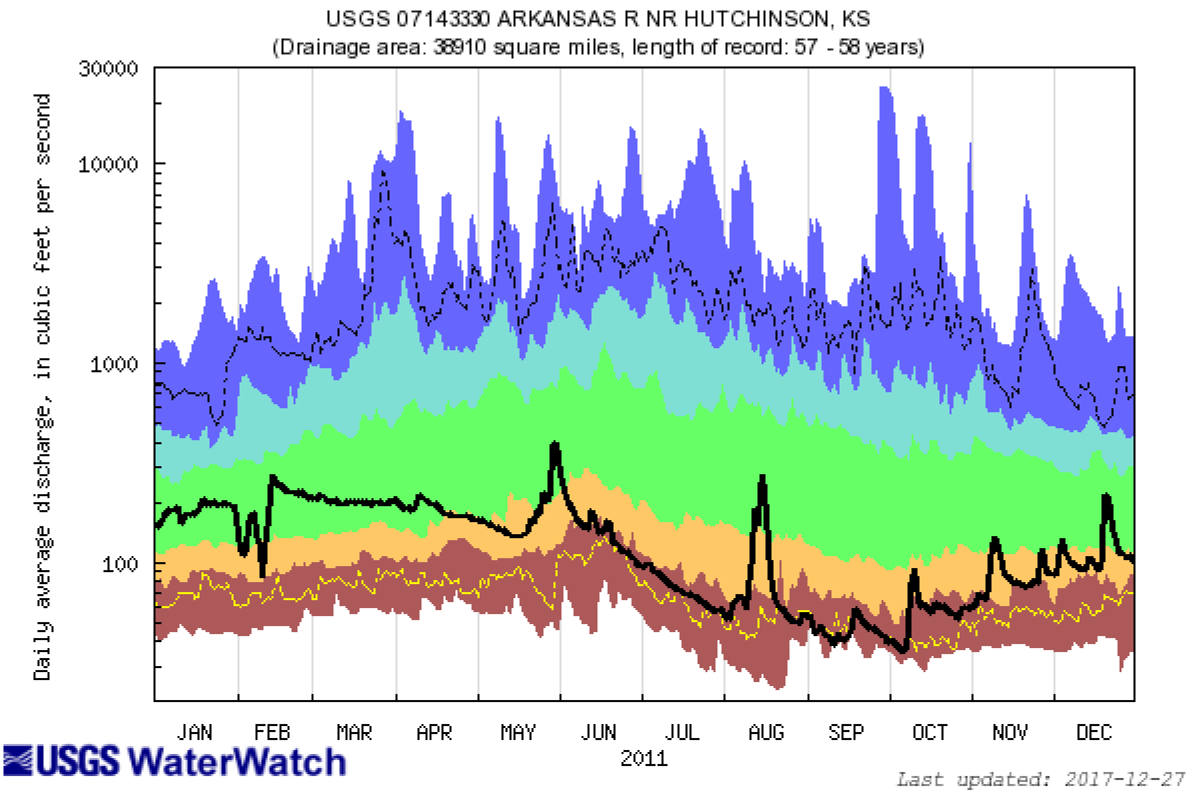


Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		


USGS
USGS 07143330 ARKANSAS R NR HUTCHINSON, KS
Discharge, cubic feet per second
7000
1000
100
10
Jan 2010
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012
Jan 2013
Discharge
Estimated discharge
Period of approved data
MDS for May



Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile-highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		



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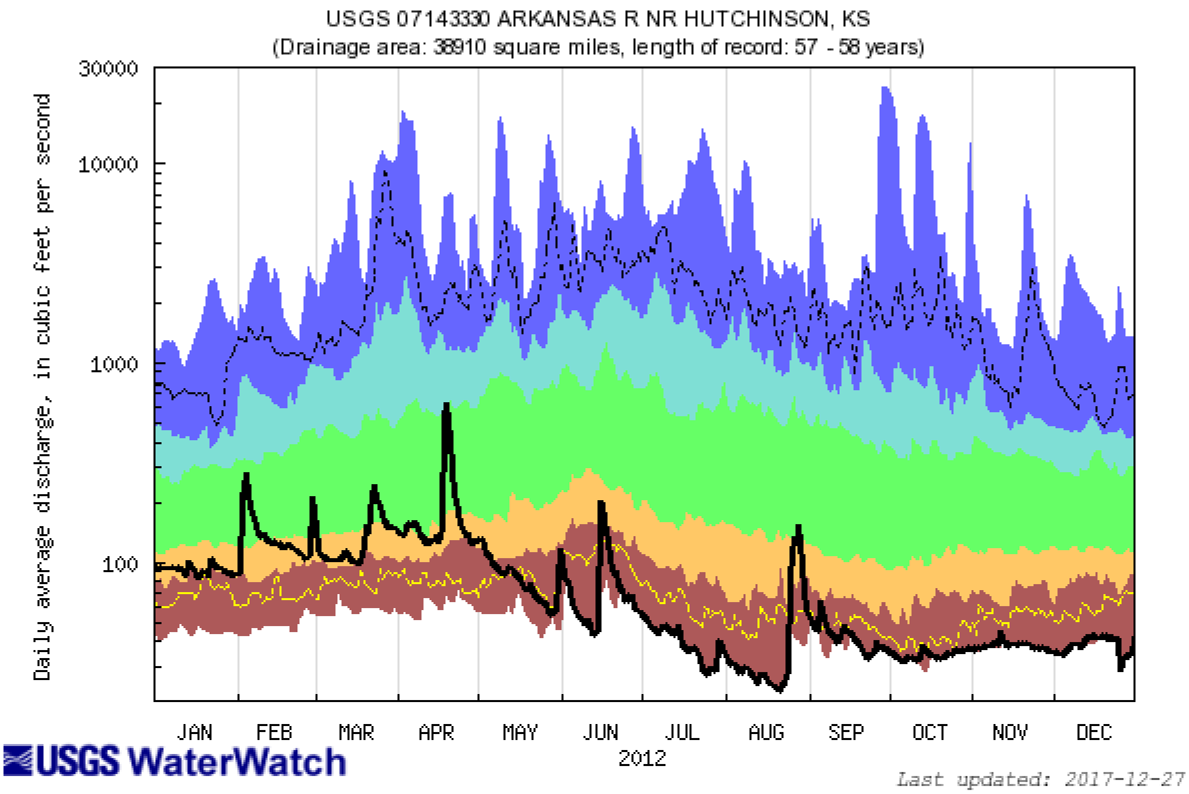
Much below Normal		Below normal	Normal	Above normal	Much above normal		



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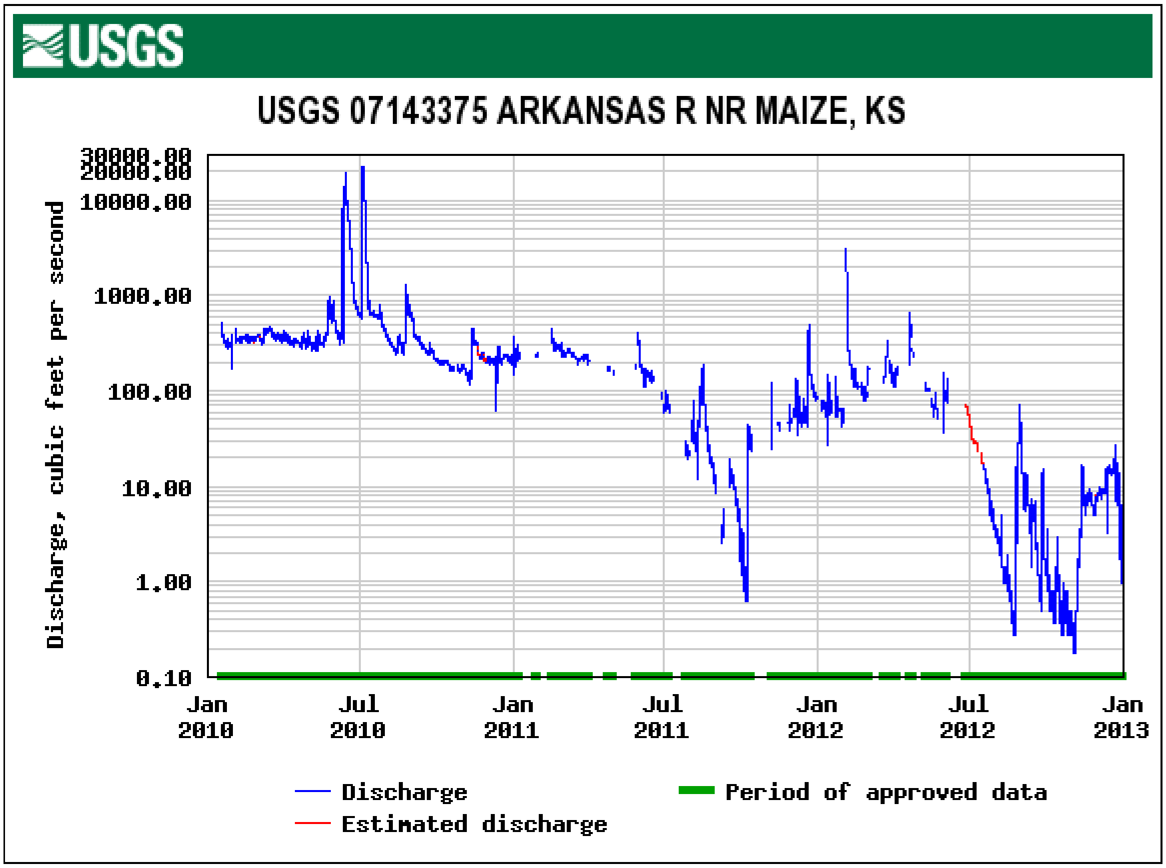
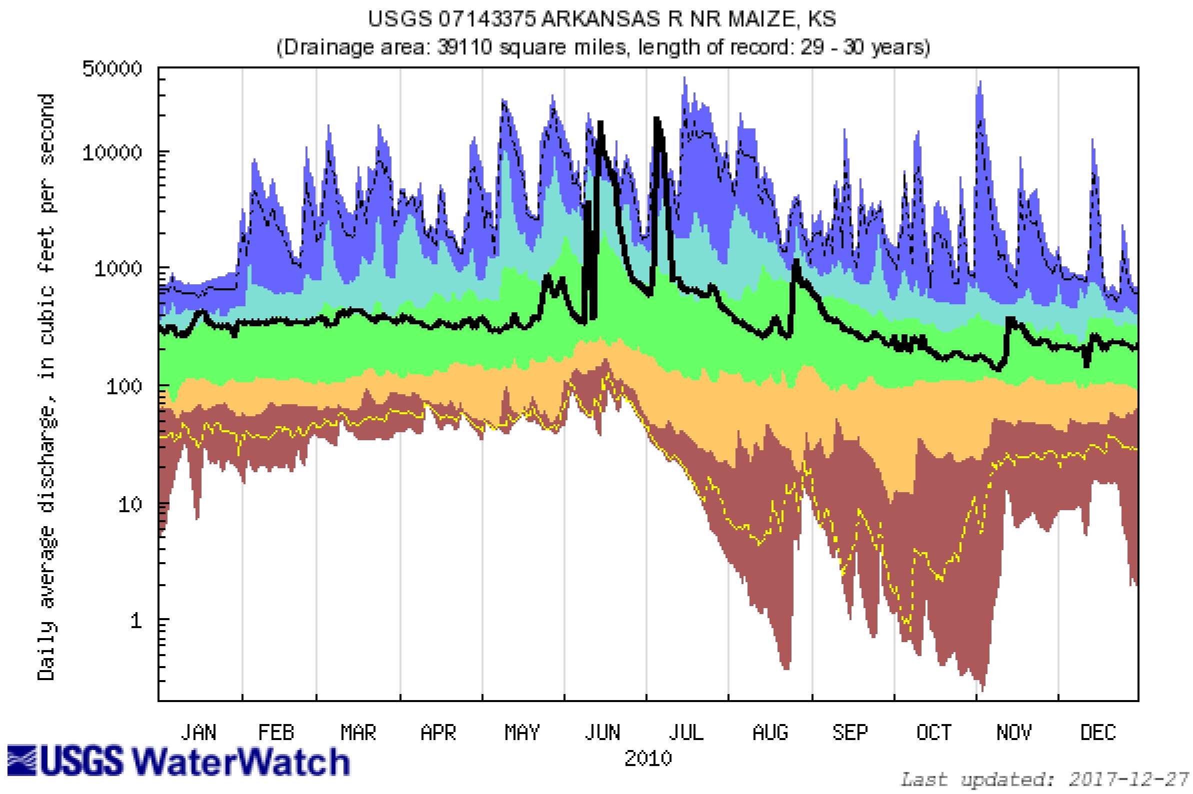
Much below Normal		Below normal	Normal	Above normal	Much above normal		


USGS
USGS 07143375 ARKANSAS R NR MAIZE, KS
Discharge, cubic feet per second
30000.00
20000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
Jan 2010
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012
Jan 2013
Discharge
Estimated discharge
Period of approved data



Explanation - Percentile classes

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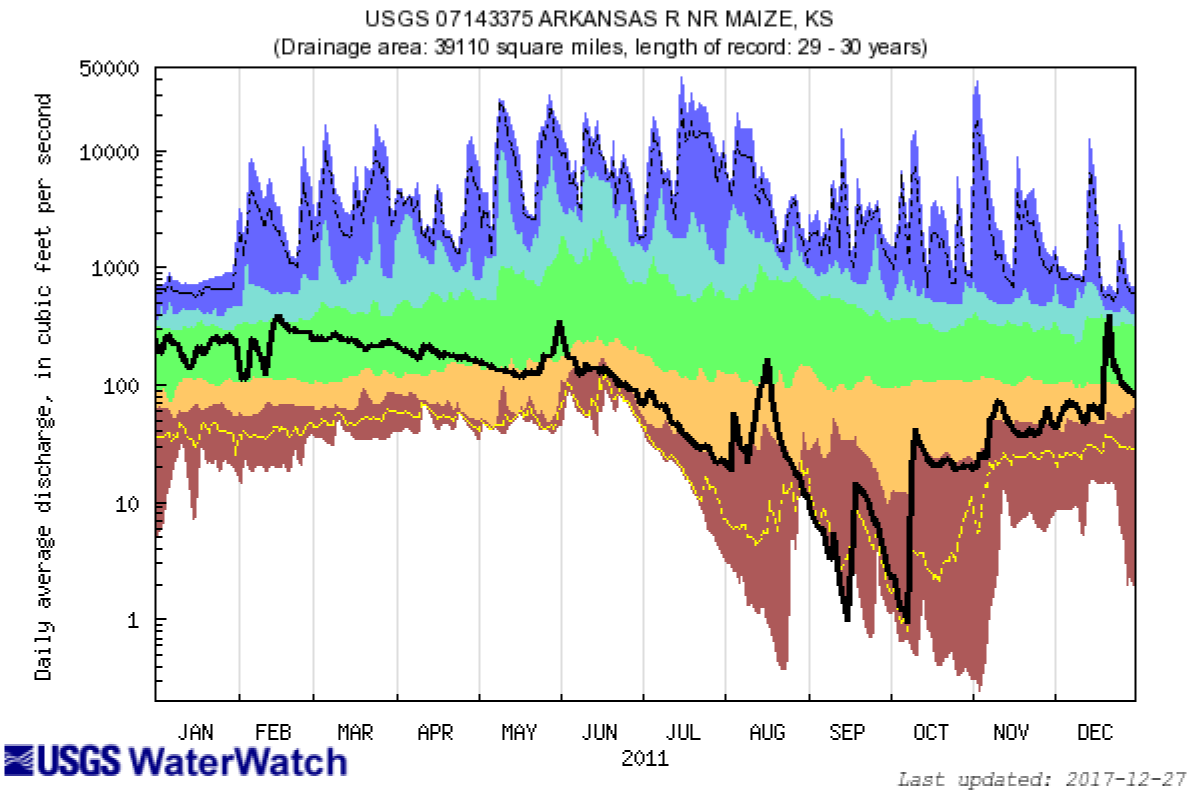

Explanation - Percentile classes

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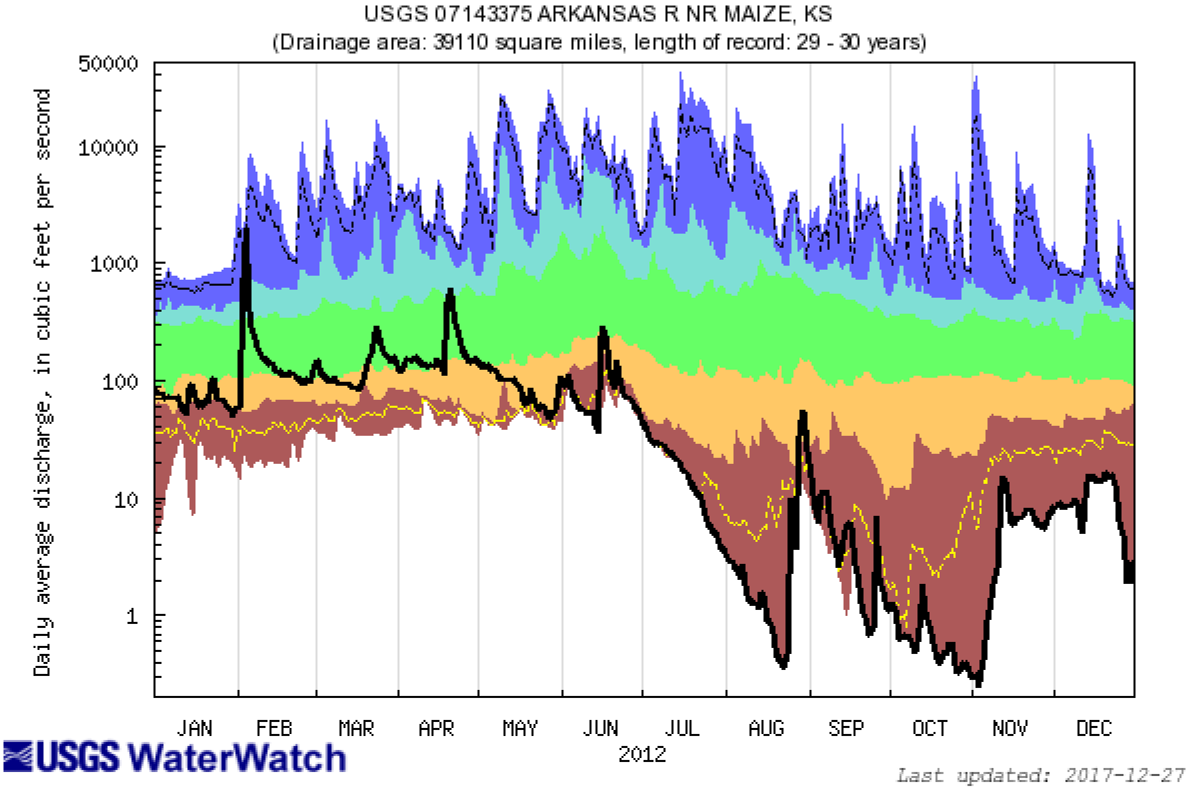


Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		

Table 2-7: *Distributed City of Wichita Pumping by Stress Period*

	Drought Year								Recovery Year	
Raw Water Resource Name	1 (SP1)	2 (SP2)	3 (SP3)	4 (SP4)	5 (SP5)	6 (SP6)	7 (SP7)	8 (SP8)	1 (SP9)	2 (SP10)
Simulated Cheney Demand (AF)	47,060	26,841	11,209	25,158	14,233	28,831	31,808	31,173	Not Simulated	Not Simulated
Simulated EBWF + ASR Demand (AF)	34,202	45,651	59,907	46,732	56,579	41,980	39,308	39,491	20,067	20,067
Total Simulated City of Wichita Demand (AF)	81,262	72,492	71,116	71,890	70,812	70,811	71,116	70,664	Not Simulated	Not Simulated

2.4.5 Streamflow – Arkansas River, Little Arkansas River, Cow Creek

Streams, creeks, and rivers can contribute to aquifer recharge or discharge depending on river stage, river bed conductivity, and elevation of the underlying groundwater table. Variations in river stage and flow are considered in the groundwater model using the MODFLOW-2000 stream package, and smaller streams and tributaries were simulated using the drain package. The USGS maintains several gaging stations for each of the streams included in the groundwater flow model. Data from the USGS streamflow gages on the Arkansas River, Little Arkansas River, and Cow Creek were utilized to calculate an average annual stage for each river for the years 2010, 2011, and 2012. Stage elevation for the cells between gages were assigned by interpolation of the flow gradient consistent with the original groundwater model documentation (USGS Scientific Investigations Report 2013-5042). Figure 4 illustrates the location of USGS stream gages throughout the active groundwater model and BSA. Attachment G provides streamflow hydrographs and flow percentile classification for calendar years 2010 through 2012 at gaging stations located above and below the BSA.

2.4.6 Precipitation & Natural Aquifer Recharge

A percentage of annual precipitation contributes to natural recharge within the EBGWM. The amount of natural recharge entering an aquifer system can be based on many factors including the amount of precipitation, surface soil texture, slope, and type and amount of groundcover. The EBGWM uses average precipitation from area weather stations and then distributes the recharge across the model to recharge zones grouped and developed based on soil type, ground cover and model calibration (USGS Scientific Investigations Report 2013-5042). For the 1% drought model, BMcD gathered data on precipitation for calendar years 2010, 2011, and 2012 and distributed natural recharge consistent with the original model documentation. The average precipitation and the distribution of natural recharge by recharge zone for each simulated model year is summarized below in Table 2-8.

The ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity within model layer 1 ranges from 10 to 500 and is shown in figure 24. Larger values indicate smaller vertical hydraulic conductivity. Small vertical hydraulic conductivity values were assigned to account for vertical anisotropy caused by thin layers of clay, silt, and fine-grained sand in parts of the study area (Myers and others, 1996). The ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity between adjacent cells within model layers 2 and 3 was set at 10 to account for vertical anisotropy caused by thin layers of clay, silt, and fine-grained sand.

A specific yield of 0.15 was used for model layers 1, 2, and 3 to represent conditions where water is released from storage as water drains from the aquifer. A storage coefficient of 0.0005 was used for model layers 1, 2, and 3 to represent conditions where water is released from storage because of expansion of the water or compaction of the aquifer material and not actual drainage of water from the aquifer. All model layers were defined in MODFLOW-2000 as convertible and each required a specific yield and a confined storage coefficient value as model input.

Boundary Conditions

Model boundary conditions are used to specify flow into and out of the model domain. Sources of flow into and out of the aquifer include recharge, evapotranspiration, gaining and losing streams, pumping wells, and artificial recharge wells and basins. The groundwater-flow model simulates the water table as a free surface, where its position is not fixed but varies with time (Franke and others, 1984). Specified flux boundaries, where the volume of water that flows across the boundary is a function of time, position, and head, and varies as a function of flow, include the lateral boundary of the *Equus* Beds aquifer, bedrock (no flow boundaries), and recharge from precipitation. Head-dependent flux boundaries where water flow varies as a function of head and conductance include flow across lateral boundaries of the model, evapotranspiration, gaining and losing streams, pumping wells, and artificial recharge wells and basins.

Recharge

The water table is the surface across which areally distributed recharge enters the aquifer. Recharge to the model was applied to the top-most active cell in each vertical column and varied temporally as a function of average precipitation for each stress period and spatially as a percentage of precipitation.

Annual precipitation data for 1938 through 2008 for six Cooperative and Weather Bureau Army Navy (WBAN) weather stations in and near the study area were used to estimate the precipitation for the study area. Average precipitation for each stress period and periods of data from weather stations used in the model are listed in table 3 at the back of this report. Average annual precipitation for weather stations near the Wichita well field is shown in figure 25. Average precipitation calculated from weather stations was evenly distributed across the model for each stress period.

The areal distribution of soil permeability (Juracek, 2000) was used for the initial distribution of recharge rate as a percent of rainfall. Soil permeability was divided into six groups shown in figure 26. Soils with low permeability were assigned small values of recharge as a percent of precipitation and soils with large permeability were assigned large values. The initial distribution of recharge as a percent of precipitation was altered during the course of model calibration to more closely match simulated and observed groundwater levels. The final distribution of recharge as a percentage of precipitation for each recharge zone is shown in figure 27.

Evapotranspiration

Evapotranspiration is simulated in the model as removal of water from the saturated aquifer through plant transpiration and evaporation. Evapotranspiration is set to a maximum rate when the water table is at land surface and is set to zero (extinction depth) when the water table is more than a specified depth below the land surface (set at 10 ft). Evapotranspiration varies linearly with changes in the water table between the two surfaces. Maximum average evapotranspiration was calculated for each stress period using the Hamon equation (Hamon, 1961; Alkaeed and others, 2006). The Hamon equation uses only saturated vapor pressure, mean daily air temperature, and average number of daylight hours per day as input. Evapotranspiration was estimated for 1935 through 2008 using mean monthly air temperature and saturation vapor pressure from the Cooperative Weather Station at Newton, Kans. (station 145744). Daily values of maximum evapotranspiration were used to calculate evapotranspiration for each stress period in feet/day. The Hamon equation is:

$$ET_o = \frac{2.1 H_t^2 e_s}{\left(T_{mean} + 273.2\right)} \tag{2}$$

where

ET_o is the evapotranspiration for the stress period,

H_t is the average number of daylight hours per day for the stress period,

e_s is the saturation vapor pressure in millimeters per day at the mean daily air temperature for the stress period, and

T_{mean} is the mean daily air temperature (ºC) for the stress period.

and

$$e_s = 6.112 \cdot \exp[17.67 \cdot (T)/(T+243.5)] \tag{3}$$

where

T is the mean daily air temperature for the stress period (Rogers and Yau, 1989).

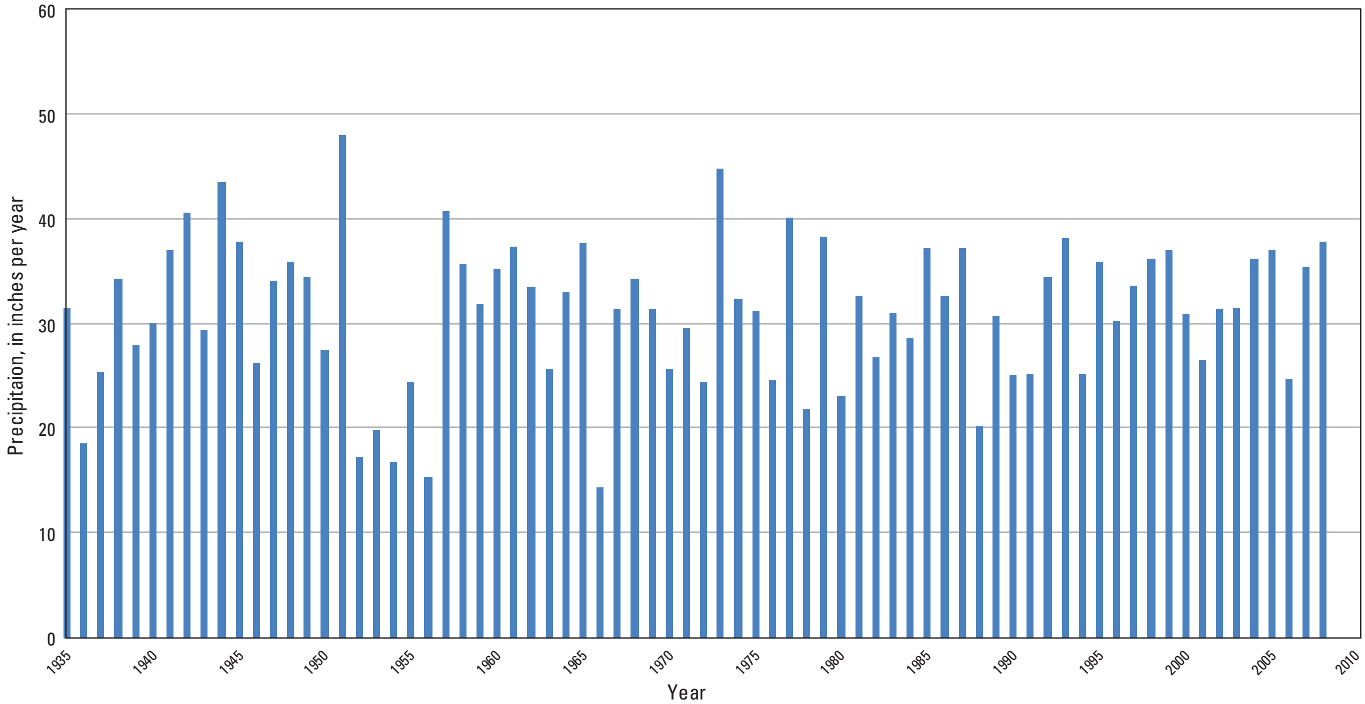


Figure 25. Average annual precipitation in inches per year for weather stations at Hutchinson (143930), Mt. Hope (145539), Newton (145744), Sedgwick and Halstead(143366) and Wichita (148830) near the Wichita well field (National Oceanic and Atmospheric Administration, 2008).

The average number of daylight hours per day was calculated for a point near the center of the model area, at Halstead, Kans. (longitude 97°31′00″ W, latitude 38°00′00″ N). Sunrise and sunset times were obtained from the Astronomical Applications Department, U.S. Naval Observatory (*http://aa.usno.navy.mil/data/docs/RS_OneYear.php*). Temperature data from Newton, Kans. were used for the computation because a complete record was available from National Climate Data Center Archives (*http://lwf.ncdc.noaa.gov/oa/climate/stationlocator.html)*. Initial estimated evapotranspiration was altered during calibration to more closely match observed and simulated groundwater levels.

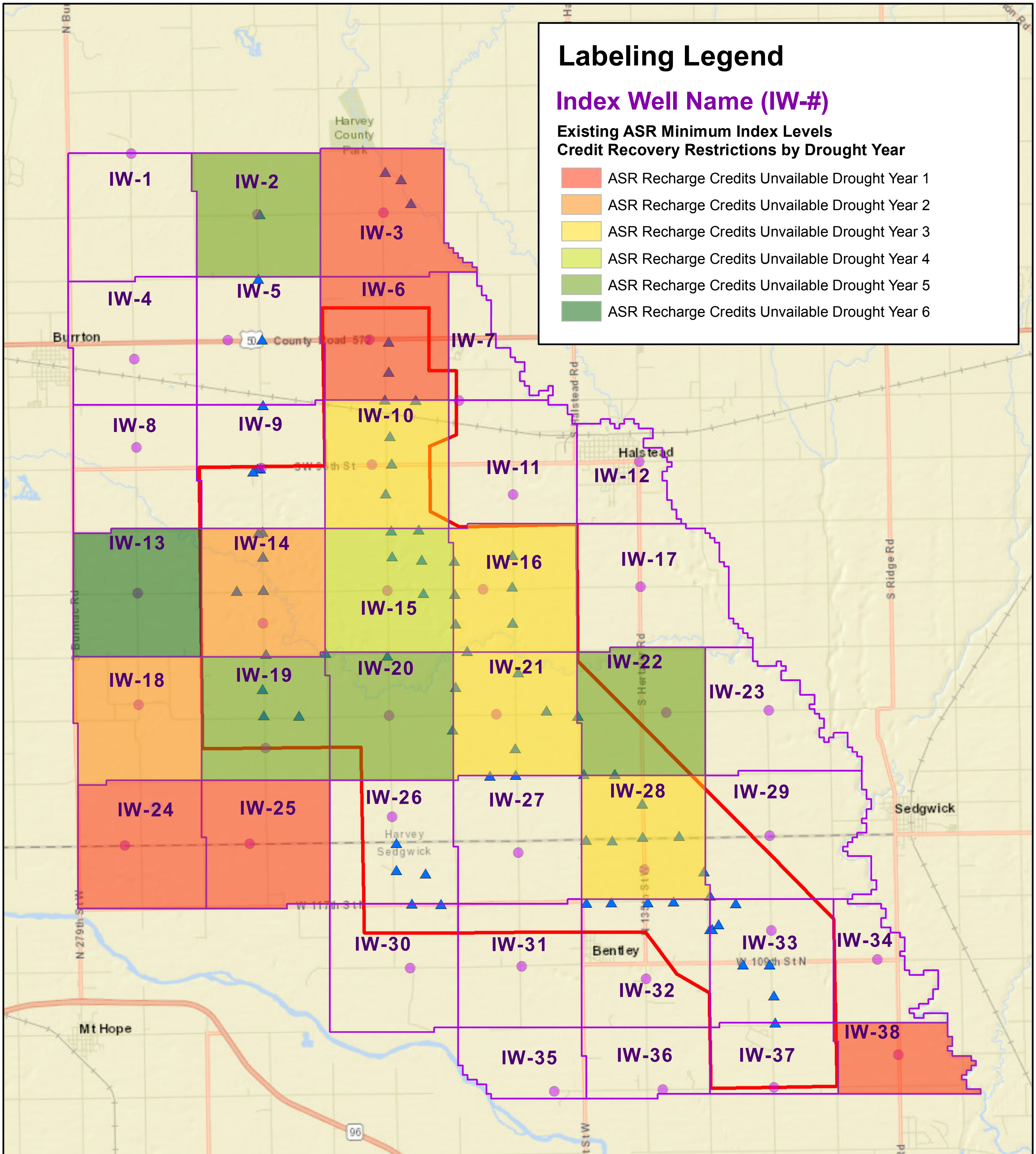
Streams

The Arkansas River, Little Arkansas River, and their tributaries are represented in the model as head-dependent flux boundaries. The Arkansas River, Little Arkansas River, and Cow Creek (near Hutchinson, Kans.) were simulated in MODFLOW-2000 using the River Package and the smaller streams and tributaries were simulated using the Drain Package (McDonald and Harbaugh, 1988). All rivers and drains are within model layer 1.

Flow into or out of the aquifer at each of the cells where a river is simulated is a function of the river stage with respect to the altitude of the potentiometric surface, the hydraulic conductivity of the streambed material, the cross-sectional area of flow between the stream and the aquifer, and the altitude of the water table with respect to the altitude of the streambed (McDonald and Harbaugh, 1988). Stream stages in the Arkansas and Little Arkansas Rivers were recorded at streamflow gages (fig. 6) hourly (U.S. Geological Survey, 2009a) and average annual stage was calculated for each gage. The average annual altitude of the river surface used in each stress period of each simulation was assigned to each model cell with a stream by interpolating the specified river surface altitude between gaging stations. Each stream was assigned a single value for streambed hydraulic conductivity. The area of the stream within each model cell was calculated and the streambed hydraulic conductivity value was multiplied by the area of the stream and then divided by the thickness of the streambed to determine the streambed conductance. Streambed thicknesses are unknown and were assigned an arbitrary value of 1 ft. Initial streambed conductances were altered during calibration to more closely match observed and simulated flow between the streams and the aquifer.

Flow into or out of the aquifer at each of the cells where a drain is simulated is a function of the altitude of the potentiometric surface, the hydraulic conductivity of the drain bed material, the cross-sectional area of flow between the drain and the aquifer, and the altitude of the water table with respect to the altitude of the drain bed (McDonald and Harbaugh, 1988). Each stream simulated as a drain was assigned a single value for streambed hydraulic conductivity. The area of the stream within each model cell was calculated and the initial streambed hydraulic conductivity value was multiplied by the area of the stream and then divided by the thickness of the streambed to determine the streambed conductance.

ATTACHMENT I
Drought Model Simulation Results & Hydrographs



Legend

- ASR Index Cells (Numbered)
- USGS Central Wellfield Study Area
- ASR Index Well Locations

N

1:130,000

0 0.5 1 2
Miles

CITY OF WICHITA

BURNS McDONNELL

Simulated Drought Results
Recovery of ASR Credits
Limited by Existing
Minimum Index
Level Elevations

Modeled Groundwater Elevations at ASR Index Wells During Simulated Drought
Extracted from Lower Model Layer (3) - Equivalent to IW(C) Aquifer Interval

Index Well Name	Initial Heads	Stress Period 1	Stress Period 2	Stress Period 3	Stress Period 4	Stress Period 5	Stress Period 6	Stress Period 7	Stress Period 8	Stress Period 9	Stress Period 10	Existing ASR Minimum Index Level*
IW01C	1436.80	1435.51	1434.33	1432.97	1432.03	1431.01	1430.36	1429.58	1429.14	1430.11	1431.18	1413.42
IW02C	1416.44	1414.55	1413.15	1411.81	1410.86	1409.86	1409.19	1408.43	1407.96	1409.16	1410.31	1410.52
IW03C	1393.89	1392.11	1391.44	1391.10	1390.64	1390.44	1390.10	1390.01	1389.76	1391.32	1391.79	1396.93
IW04C	1429.43	1427.77	1426.70	1425.38	1424.36	1423.10	1422.19	1421.06	1420.35	1420.82	1421.53	1417.60
IW05C	1419.79	1417.04	1415.67	1413.94	1412.73	1411.15	1410.16	1408.85	1408.21	1409.68	1410.78	1407.23
IW06C	1389.71	1388.71	1386.24	1383.58	1382.70	1380.95	1380.94	1380.72	1380.42	1382.78	1384.69	1388.74
IW07C	1381.46	1379.56	1377.80	1375.74	1374.69	1373.49	1373.07	1373.02	1372.79	1375.38	1377.15	1369.95
IW08C	1426.82	1425.15	1424.22	1423.01	1421.91	1420.72	1419.74	1418.75	1418.06	1418.37	1419.22	1417.56
IW09C	1406.62	1406.12	1404.70	1398.16	1400.00	1395.52	1396.49	1395.39	1394.74	1395.42	1397.17	1394.10
IW10C	1383.29	1380.79	1377.93	1373.81	1372.08	1369.35	1368.80	1368.40	1368.08	1372.32	1375.45	1375.09
IW11C	1375.71	1374.25	1372.15	1369.56	1367.89	1366.28	1365.61	1365.35	1365.27	1367.45	1369.79	1363.75
IW12C	1372.80	1371.10	1370.80	1370.97	1370.68	1370.88	1370.61	1370.84	1370.60	1371.91	1371.97	1365.78
IW13C	1424.92	1423.14	1422.20	1420.76	1419.92	1418.76	1418.21	1417.43	1417.21	1419.08	1420.98	1418.27
IW14C	1402.76	1398.40	1396.07	1392.10	1391.00	1388.48	1387.84	1387.08	1386.60	1392.49	1395.75	1396.56
IW15C	1382.13	1379.64	1376.35	1371.05	1369.08	1365.69	1365.00	1364.41	1364.07	1368.98	1372.89	1369.75
IW16C	1373.72	1370.01	1365.87	1360.00	1358.34	1354.50	1354.58	1354.35	1354.11	1359.07	1362.81	1360.21
IW17C	1368.19	1366.63	1365.86	1365.11	1364.33	1363.86	1363.40	1363.28	1363.16	1364.63	1365.37	1360.59
IW18C	1423.66	1421.81	1421.06	1419.81	1419.28	1418.30	1418.00	1417.32	1417.28	1419.01	1420.61	1421.40
IW19C	1405.80	1403.97	1402.34	1400.17	1399.08	1397.66	1396.98	1396.45	1396.07	1398.51	1400.64	1398.95
IW20C	1387.37	1386.22	1384.12	1380.32	1378.30	1375.84	1374.60	1373.79	1373.34	1375.03	1377.85	1376.05
IW21C	1370.45	1367.37	1364.82	1359.25	1357.66	1353.96	1353.24	1352.31	1352.12	1355.65	1358.77	1363.04
IW22C	1362.11	1360.18	1358.79	1356.97	1355.75	1354.63	1354.04	1353.79	1353.82	1355.64	1357.16	1354.92
IW23C	1360.00	1357.82	1357.46	1357.30	1357.08	1357.04	1356.94	1357.05	1356.98	1358.60	1358.81	1355.55
IW24C	1419.62	1418.12	1417.50	1417.45	1416.93	1416.97	1416.53	1416.65	1416.31	1417.80	1418.33	1418.96
IW25C	1408.27	1406.90	1405.97	1405.18	1404.42	1403.93	1403.44	1403.26	1403.00	1404.85	1405.95	1407.27
IW26C	1389.71	1388.05	1386.28	1384.06	1383.07	1381.56	1381.20	1380.84	1380.64	1382.55	1384.16	1374.89
IW27C	1373.52	1372.90	1371.10	1368.37	1366.20	1364.35	1363.35	1363.16	1363.22	1364.60	1366.65	1360.92
IW28C	1356.73	1356.09	1351.91	1347.19	1346.18	1343.80	1345.29	1346.61	1347.37	1350.80	1353.30	1349.14
IW29C	1354.92	1352.61	1351.59	1350.81	1350.76	1350.36	1350.74	1350.98	1351.05	1353.05	1353.51	1349.51
IW30C	1389.81	1387.93	1387.03	1386.85	1386.39	1386.42	1386.13	1386.50	1386.13	1387.80	1388.17	1379.77
IW31C	1379.78	1378.31	1377.29	1377.06	1376.46	1376.53	1376.18	1376.65	1376.33	1378.06	1378.53	1366.06
IW32C	1366.87	1365.23	1363.78	1363.30	1362.89	1362.86	1362.90	1363.54	1363.30	1365.30	1365.86	1356.51
IW33C	1353.74	1351.50	1350.02	1349.23	1349.33	1348.93	1349.59	1350.03	1350.00	1352.14	1352.55	1344.68
IW34C	1347.28	1345.11	1344.76	1344.67	1344.63	1344.62	1344.67	1344.82	1344.75	1346.24	1346.34	1344.24
IW35C	1375.72	1374.78	1373.95	1374.47	1373.77	1374.37	1373.74	1374.44	1373.79	1375.25	1375.37	1366.76
IW36C	1365.95	1364.28	1363.30	1363.61	1363.02	1363.49	1363.04	1363.72	1363.17	1364.87	1365.06	1360.13
IW37C	1355.80	1354.12	1353.14	1353.20	1352.85	1353.08	1352.93	1353.47	1353.11	1354.91	1355.14	1350.51
IW38C	1345.99	1343.83	1343.35	1343.33	1343.19	1343.27	1343.23	1343.47	1343.32	1344.96	1345.10	1344.65

Note: Red highlight indicates elevation below current ASR Minimum Index Level

Existing ASR Minimum Index Levels sourced from joint review process including the City, the Division of Water Resources, Groundwater Management District No. 2, and the United States Geological Survey as revised in 2015

Modeled Groundwater Elevations at ASR Index Wells During Simulated Drought
Extracted from Lower Model Layer (3) - Equivalent to IW(C) Aquifer Interval
Showing Index Cells within USGS Central Wellfield Study Area

Index Well Name	Initial Heads	Stress Period 1	Stress Period 2	Stress Period 3	Stress Period 4	Stress Period 5	Stress Period 6	Stress Period 7	Stress Period 8	Stress Period 9	Stress Period 10	Existing ASR Minimum Index Level
IW06C	1389.71	1388.71	1386.24	1383.58	1382.70	1380.95	1380.94	1380.72	1380.42	1382.78	1384.69	1388.74
IW10C	1383.29	1380.79	1377.93	1373.81	1372.08	1369.35	1368.80	1368.40	1368.08	1372.32	1375.45	1375.09
IW14C	1402.76	1398.40	1396.07	1392.10	1391.00	1388.48	1387.84	1387.08	1386.60	1392.49	1395.75	1396.56
IW15C	1382.13	1379.64	1376.35	1371.05	1369.08	1365.69	1365.00	1364.41	1364.07	1368.98	1372.89	1369.75
IW16C	1373.72	1370.01	1365.87	1360.00	1358.34	1354.50	1354.58	1354.35	1354.11	1359.07	1362.81	1360.21
IW19C	1405.80	1403.97	1402.34	1400.17	1399.08	1397.66	1396.98	1396.45	1396.07	1398.51	1400.64	1398.95
IW20C	1387.37	1386.22	1384.12	1380.32	1378.30	1375.84	1374.60	1373.79	1373.34	1375.03	1377.85	1376.05
IW21C	1370.45	1367.37	1364.82	1359.25	1357.66	1353.96	1353.24	1352.31	1352.12	1355.65	1358.77	1363.04
IW22C	1362.11	1360.18	1358.79	1356.97	1355.75	1354.63	1354.04	1353.79	1353.82	1355.64	1357.16	1354.92
IW26C	1389.71	1388.05	1386.28	1384.06	1383.07	1381.56	1381.20	1380.84	1380.64	1382.55	1384.16	1374.89
IW27C	1373.52	1372.90	1371.10	1368.37	1366.20	1364.35	1363.35	1363.16	1363.22	1364.60	1366.65	1360.92
IW28C	1356.73	1356.09	1351.91	1347.19	1346.18	1343.80	1345.29	1346.61	1347.37	1350.80	1353.30	1349.14
IW32C	1366.87	1365.23	1363.78	1363.30	1362.89	1362.86	1362.90	1363.54	1363.30	1365.30	1365.86	1356.51
IW33C	1353.74	1351.50	1350.02	1349.23	1349.33	1348.93	1349.59	1350.03	1350.00	1352.14	1352.55	1344.68
IW37C	1355.80	1354.12	1353.14	1353.20	1352.85	1353.08	1352.93	1353.47	1353.11	1354.91	1355.14	1350.51

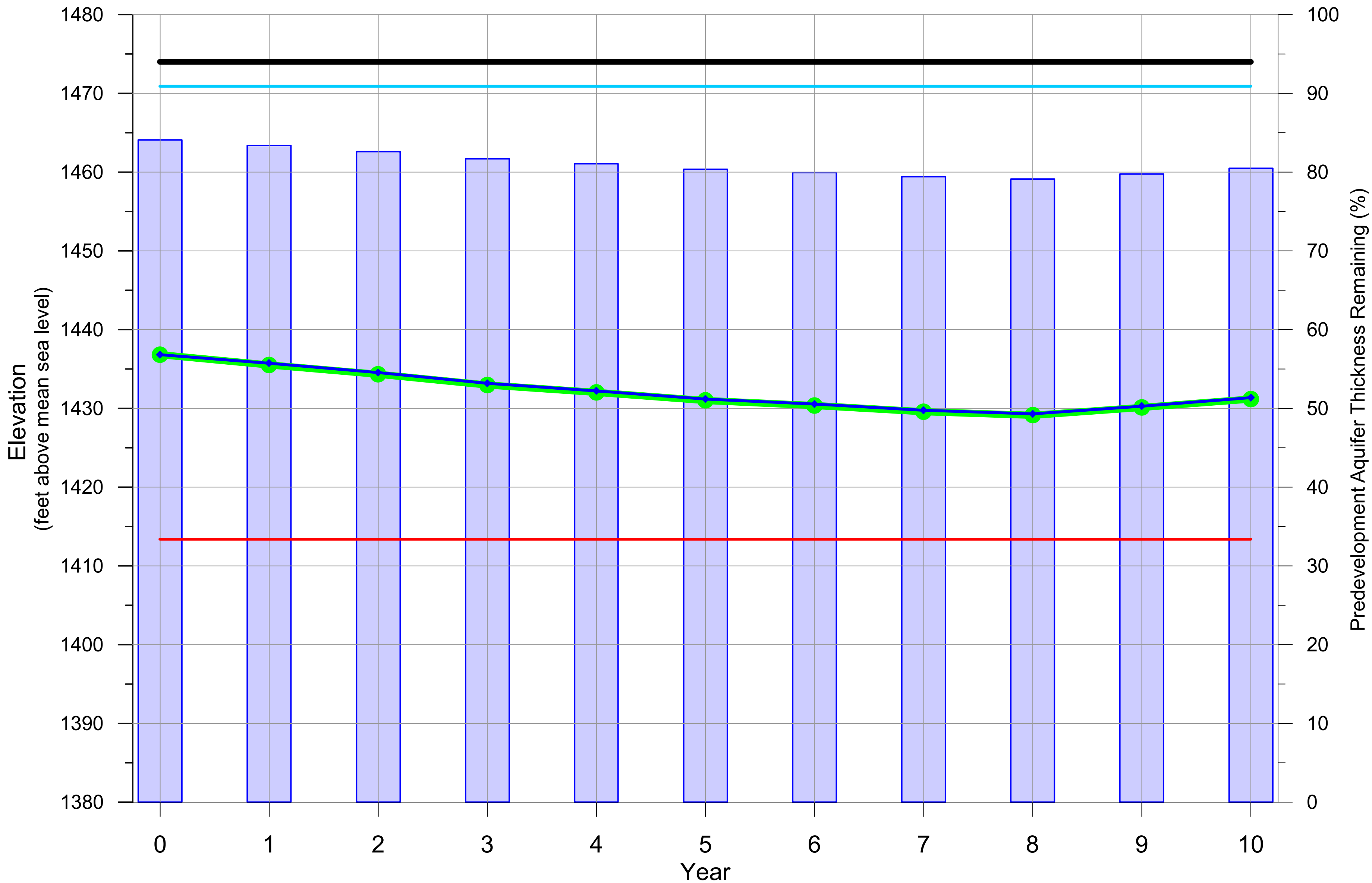
Note: Red text indicates elevation below current ASR Minimum Index Level (1993 Index Level Elevations)

Existing ASR Minimum Index Levels sourced from joint review process including the City, the Division of Water Resources, Groundwater Management District No. 2, and the United States Geological Survey as revised in 2015

Modeled Aquifer Conditions as a Percentage of Predevelopment Aquifer Thickness by ASR Index Well
Extracted from Upper Model Layer (1) - Equivalent to IW(A) Aquifer Interval

		Drought Years								Recovery Years	
Index Well Site Name	**Initial Aquifer Condition (% Full)**	**SP1 Aquifer Condition (% Full)**	**SP2 Aquifer Condition (% Full)**	**SP3 Aquifer Condition (% Full)**	**SP4 Aquifer Condition (% Full)**	**SP5 Aquifer Condition (% Full)**	**SP6 Aquifer Condition (% Full)**	**SP7 Aquifer Condition (% Full)**	**SP8 Aquifer Condition (% Full)**	**SP9 Aquifer Condition (% Full)**	**SP10 Aquifer Condition (% Full)**
IW01A	84%	83%	83%	82%	81%	80%	80%	79%	79%	80%	80%
IW02A	88%	88%	87%	87%	86%	86%	86%	85%	85%	86%	86%
IW03A	96%	95%	94%	94%	94%	94%	93%	93%	93%	94%	94%
IW04A	99%	98%	98%	97%	97%	96%	96%	95%	95%	95%	95%
IW05A	96%	94%	93%	92%	91%	90%	90%	89%	89%	89%	90%
IW06A	86%	85%	84%	83%	82%	81%	81%	81%	81%	82%	83%
IW07A	90%	89%	88%	87%	86%	85%	85%	85%	85%	87%	88%
IW08A	99%	98%	98%	97%	97%	96%	96%	96%	95%	95%	96%
IW09A	95%	94%	94%	91%	92%	90%	91%	90%	90%	90%	91%
IW10A	82%	80%	79%	76%	75%	73%	73%	73%	72%	75%	77%
IW11A	86%	86%	84%	83%	82%	81%	80%	80%	80%	82%	83%
IW12A	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
IW13A	97%	96%	96%	95%	94%	93%	93%	92%	92%	94%	95%
IW14A	93%	91%	90%	89%	88%	87%	87%	86%	86%	89%	90%
IW15A	89%	88%	86%	84%	83%	82%	81%	81%	81%	83%	85%
IW16A	85%	83%	80%	77%	76%	74%	74%	73%	73%	76%	78%
IW17A	91%	90%	89%	88%	88%	87%	87%	87%	86%	88%	89%
IW18A	97%	96%	95%	94%	94%	93%	93%	92%	92%	93%	95%
IW19A	93%	92%	91%	90%	89%	88%	87%	87%	87%	88%	90%
IW20A	93%	92%	91%	90%	89%	88%	87%	87%	87%	87%	89%
IW21A	87%	86%	84%	81%	80%	78%	78%	77%	77%	79%	81%
IW22A	92%	90%	90%	88%	88%	87%	87%	86%	86%	88%	88%
IW23A	97%	95%	95%	95%	95%	95%	95%	95%	95%	96%	96%
IW24A	98%	97%	97%	97%	96%	96%	96%	96%	96%	97%	97%
IW25A	97%	96%	95%	95%	94%	94%	93%	93%	93%	94%	95%
IW26A	94%	93%	93%	92%	91%	90%	90%	90%	90%	91%	92%
IW27A	93%	93%	92%	91%	90%	90%	89%	89%	89%	90%	90%
IW28A	89%	89%	86%	84%	83%	82%	83%	83%	84%	86%	87%
IW29A	91%	90%	89%	88%	88%	88%	88%	88%	88%	90%	90%
IW30A	95%	93%	92%	92%	92%	92%	92%	92%	92%	93%	93%
IW31A	97%	97%	96%	96%	96%	96%	96%	96%	96%	96%	97%
IW32A	95%	94%	94%	93%	93%	93%	93%	94%	93%	95%	95%
IW33A	93%	92%	91%	90%	91%	90%	91%	91%	91%	92%	93%
IW34A	98%	96%	96%	96%	96%	96%	96%	96%	96%	97%	97%
IW35A	96%	95%	95%	95%	94%	95%	94%	95%	94%	96%	96%
IW36A	98%	97%	96%	96%	96%	96%	96%	96%	96%	97%	97%
IW37A	97%	96%	95%	95%	95%	95%	95%	96%	95%	97%	97%
IW38A	96%	93%	93%	93%	93%	93%	93%	93%	93%	95%	95%

Predevelopment groundwater elevations used to calculate aquifer conditions sourced from: "*Revised Shallow and Deep Water-Level and Storage-Volume Changes in the Equus Beds Aquifer near Wichita, Kansas Predevelopment to 1993*" *USGS Scientific Investigations Report 2013-5170 (Hansen C.V., Lanning-Rush J.L., and Ziegler A.C., 2013)*

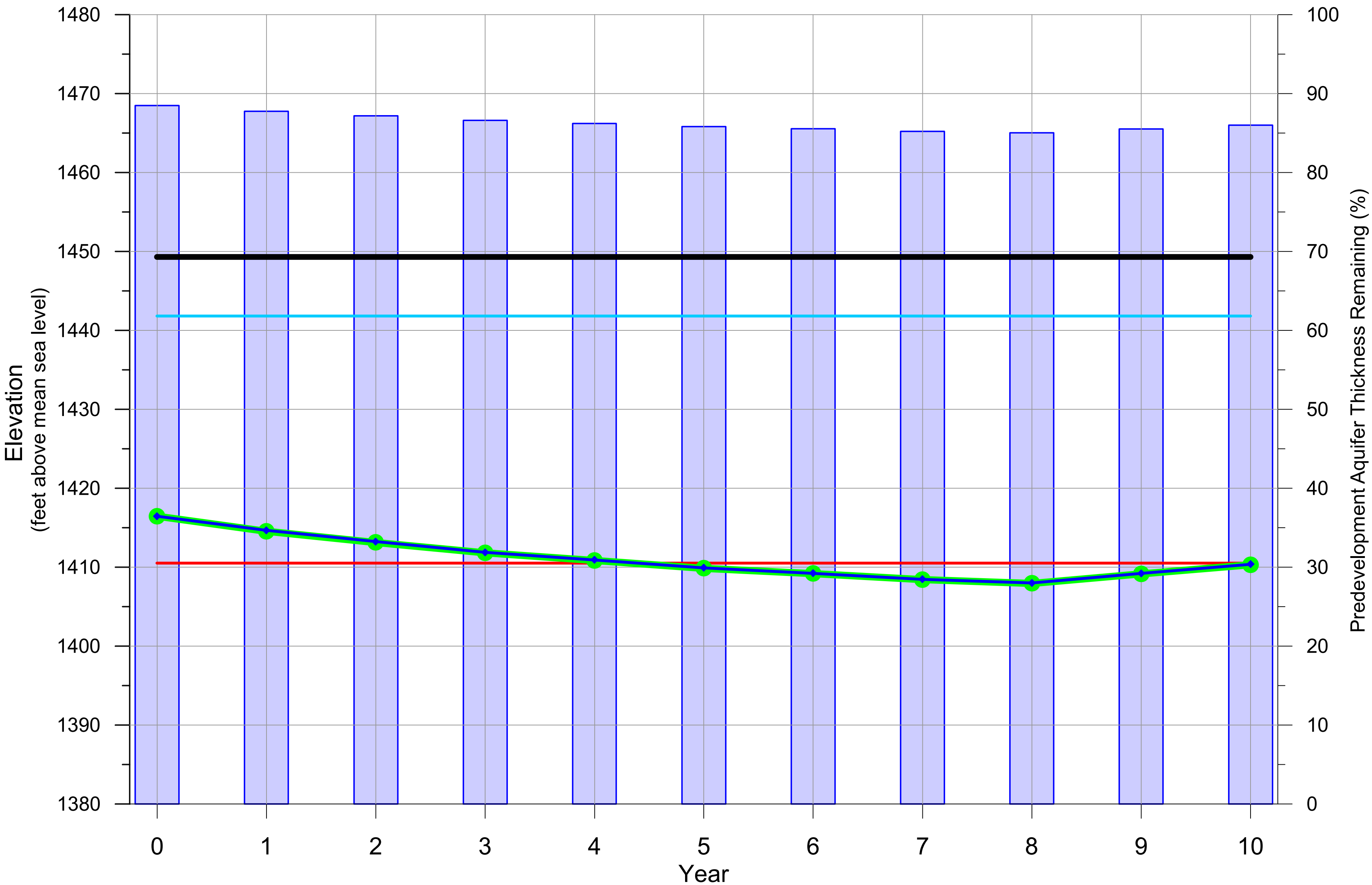


LEGEND

- IW-01A
- IW-01C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 1
Index Well Hydrographs
IW-01A & IW-01C
Stress Periods 1 through 10

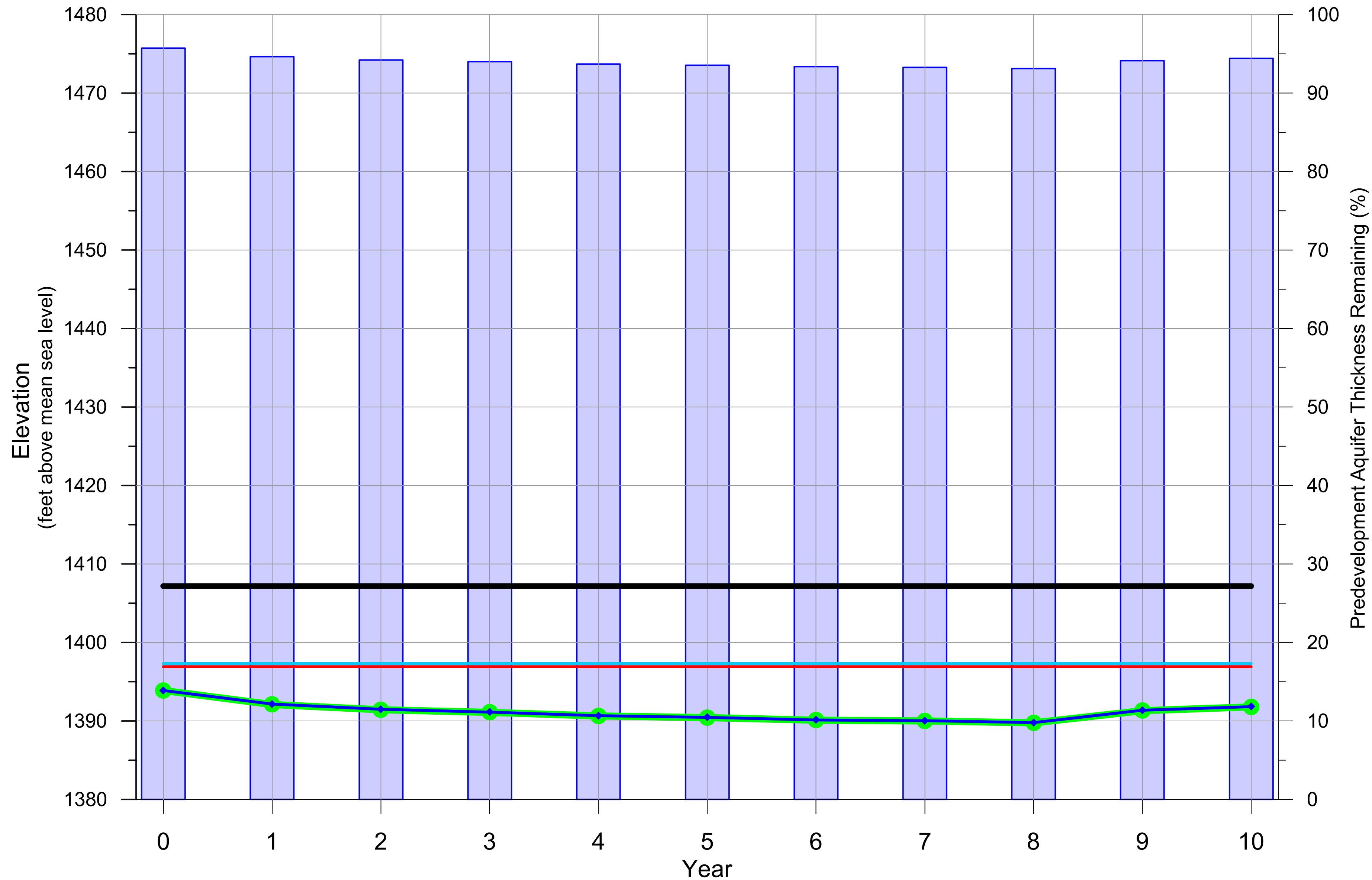


LEGEND

- IW-02A
- IW-02C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 2
Index Well Hydrographs
IW-02A & IW-02C
Stress Periods 1 through 10

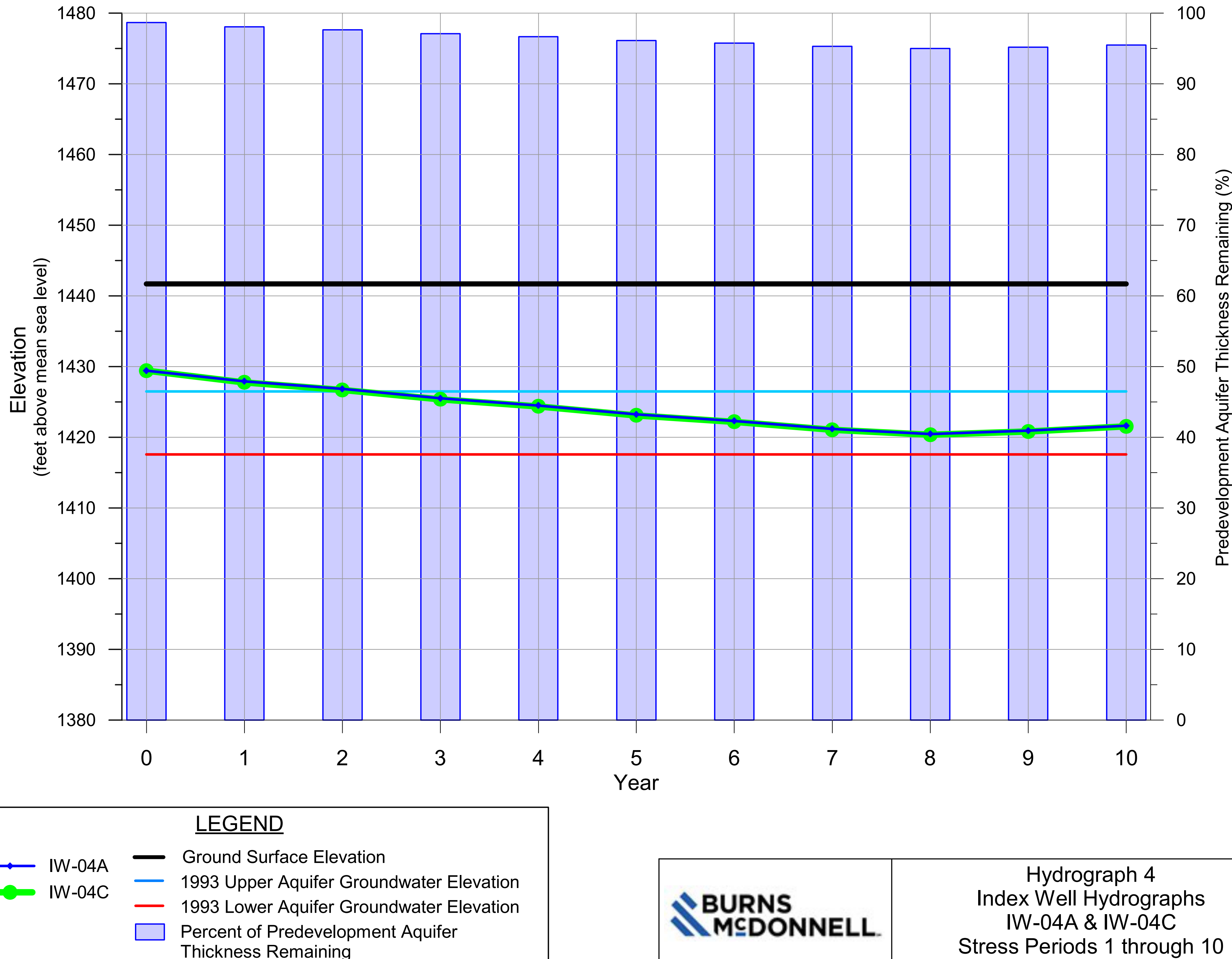


LEGEND

- IW-03A
- IW-03C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

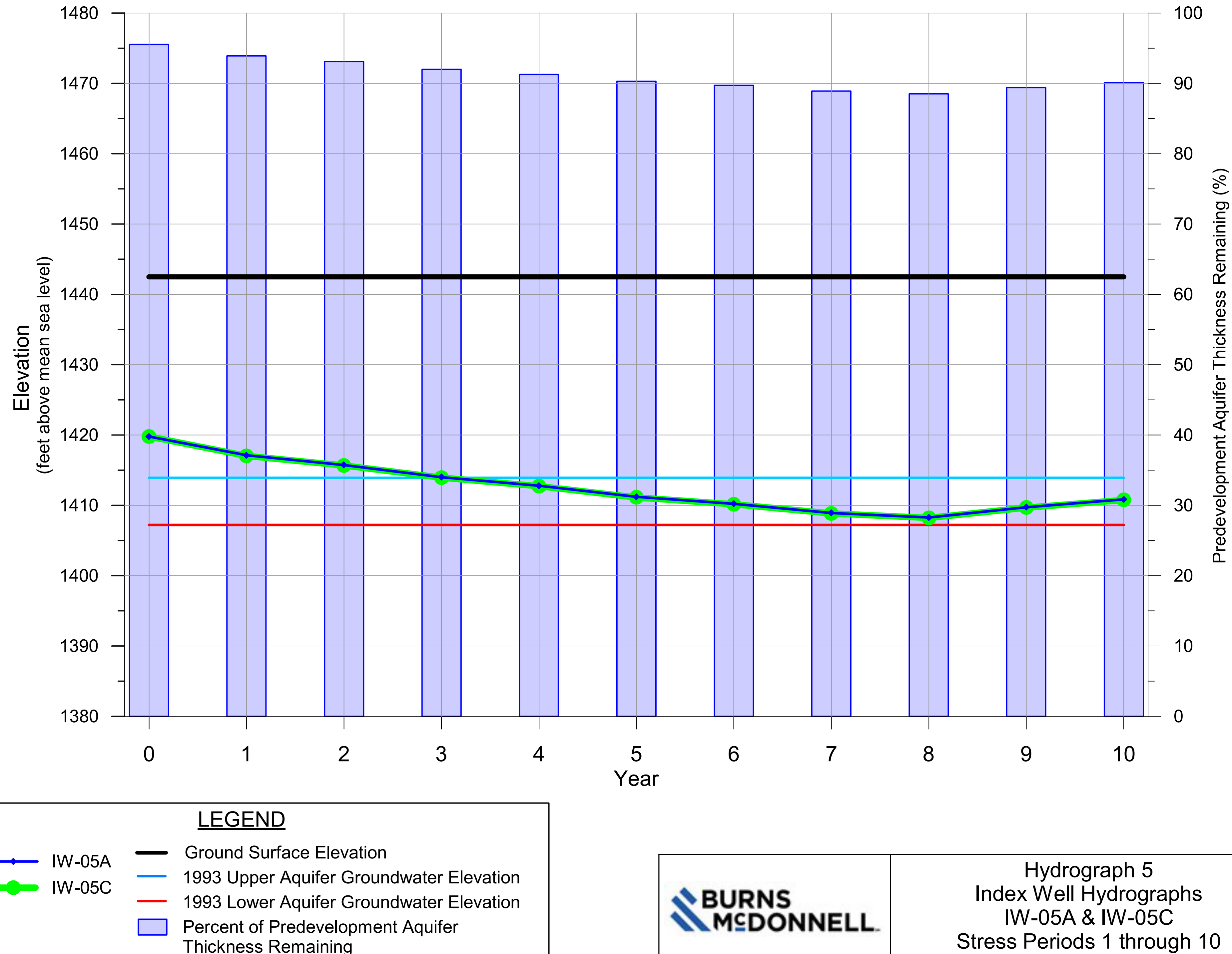
BURNS McDONNELL

Hydrograph 3
Index Well Hydrographs
IW-03A & IW-03C
Stress Periods 1 through 10



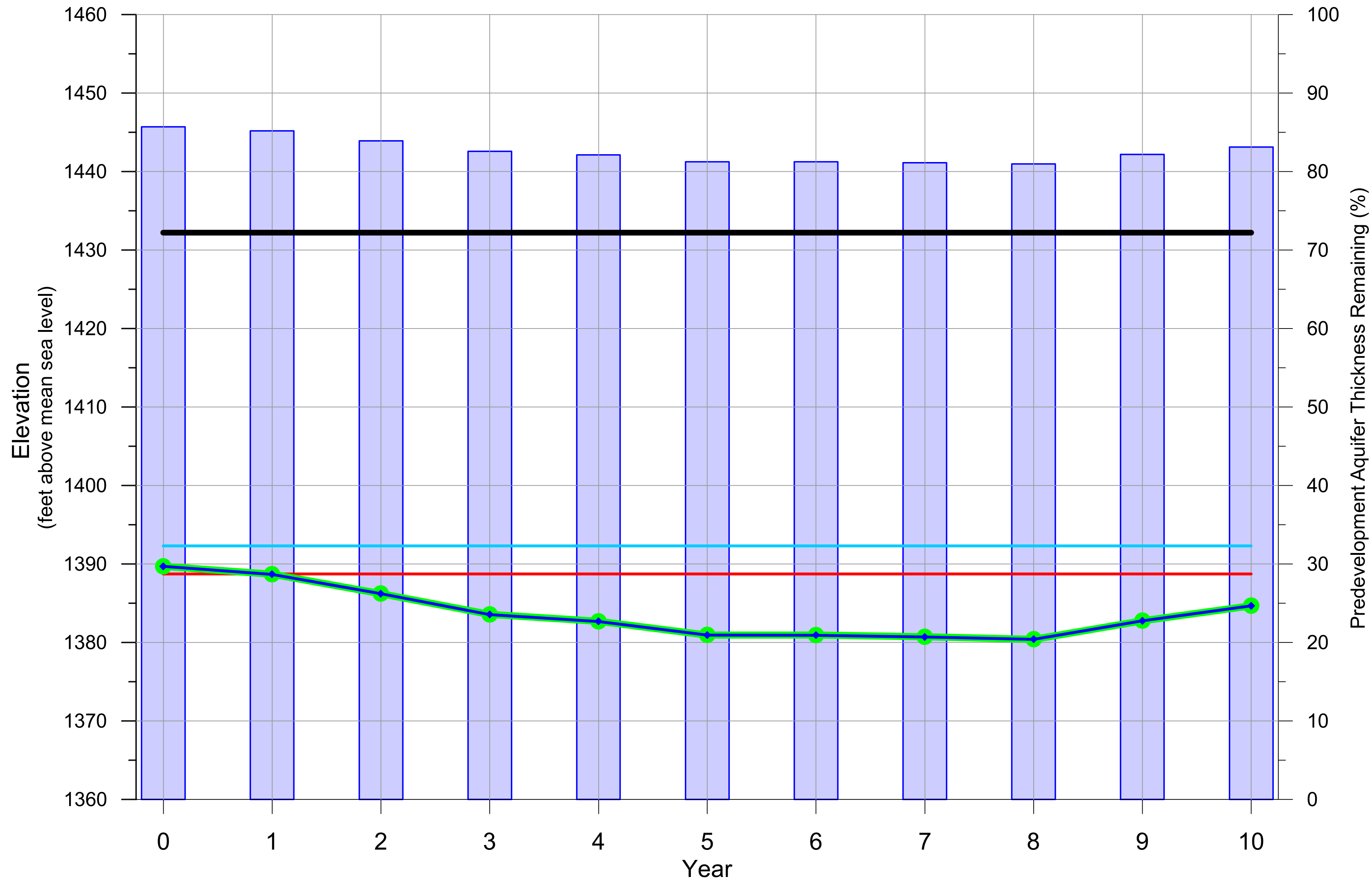
BURNS McDONNELL

Hydrograph 4
Index Well Hydrographs
IW-04A & IW-04C
Stress Periods 1 through 10



BURNS McDONNELL

Hydrograph 5
Index Well Hydrographs
IW-05A & IW-05C
Stress Periods 1 through 10

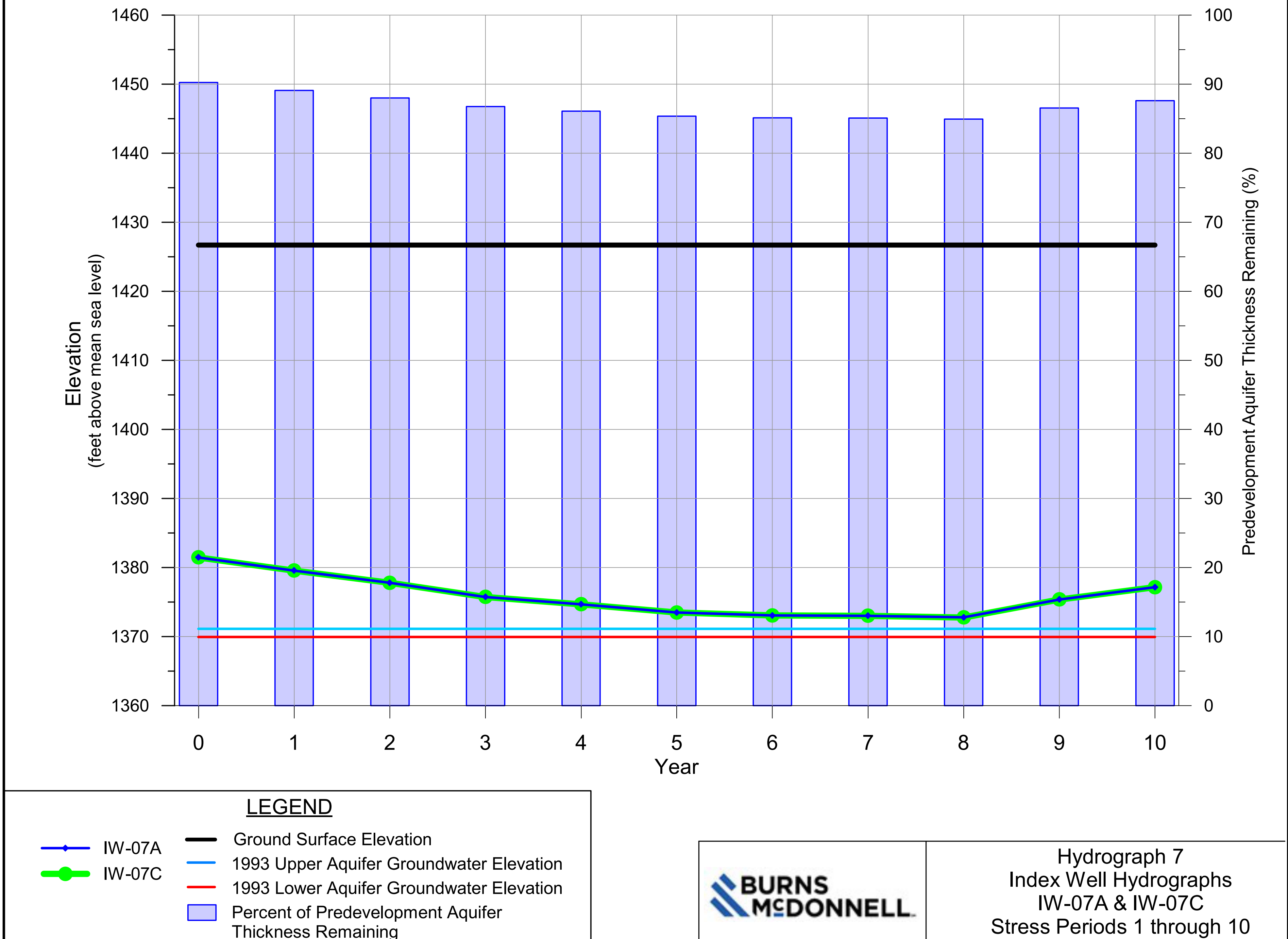


LEGEND

IW-06A
IW-06C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

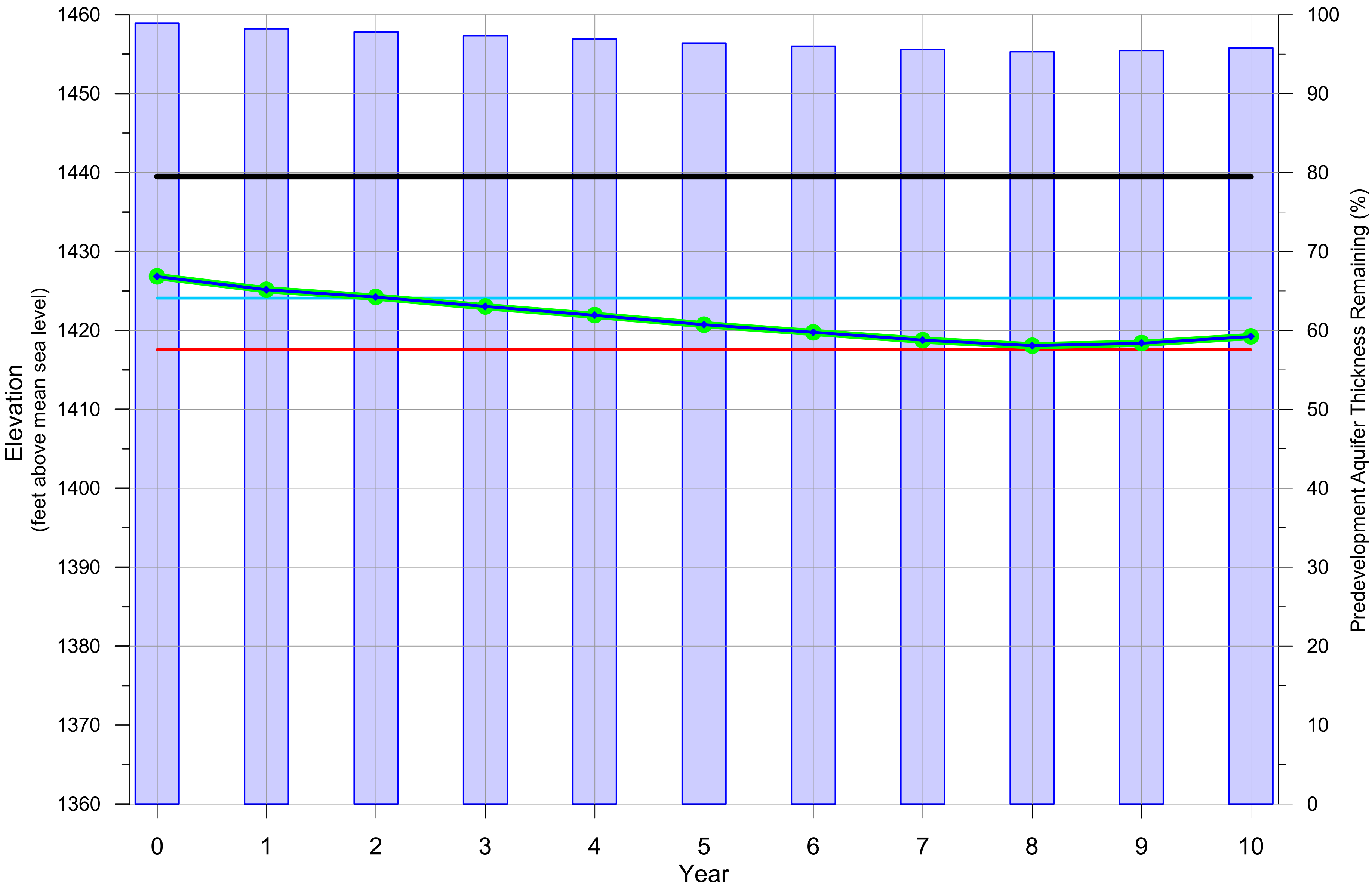
BURNS McDONNELL

Hydrograph 6
Index Well Hydrographs
IW-06A & IW-06C
Stress Periods 1 through 10



BURNS McDONNELL

Hydrograph 7
Index Well Hydrographs
IW-07A & IW-07C
Stress Periods 1 through 10

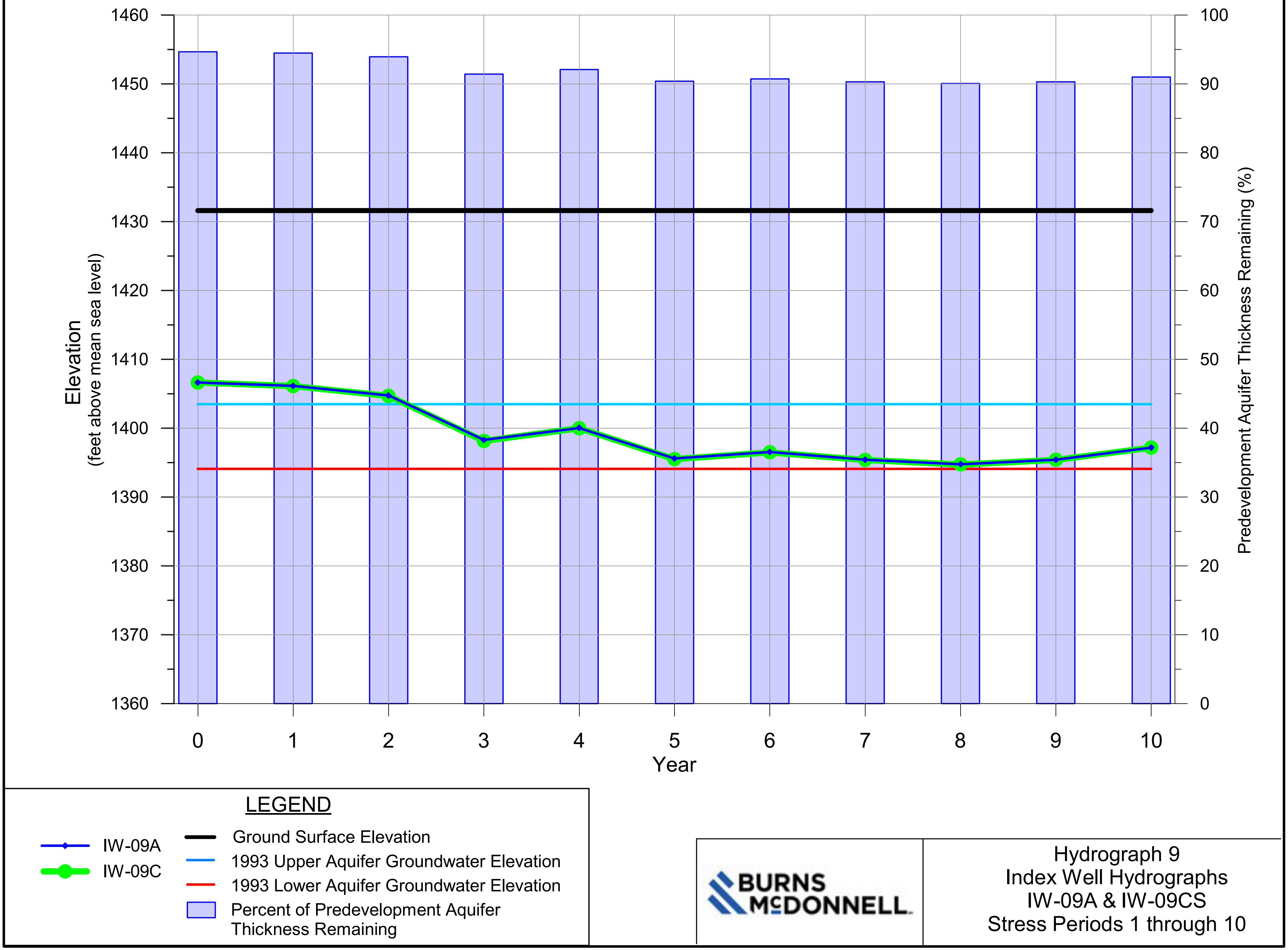


LEGEND

IW-08A
IW-08C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

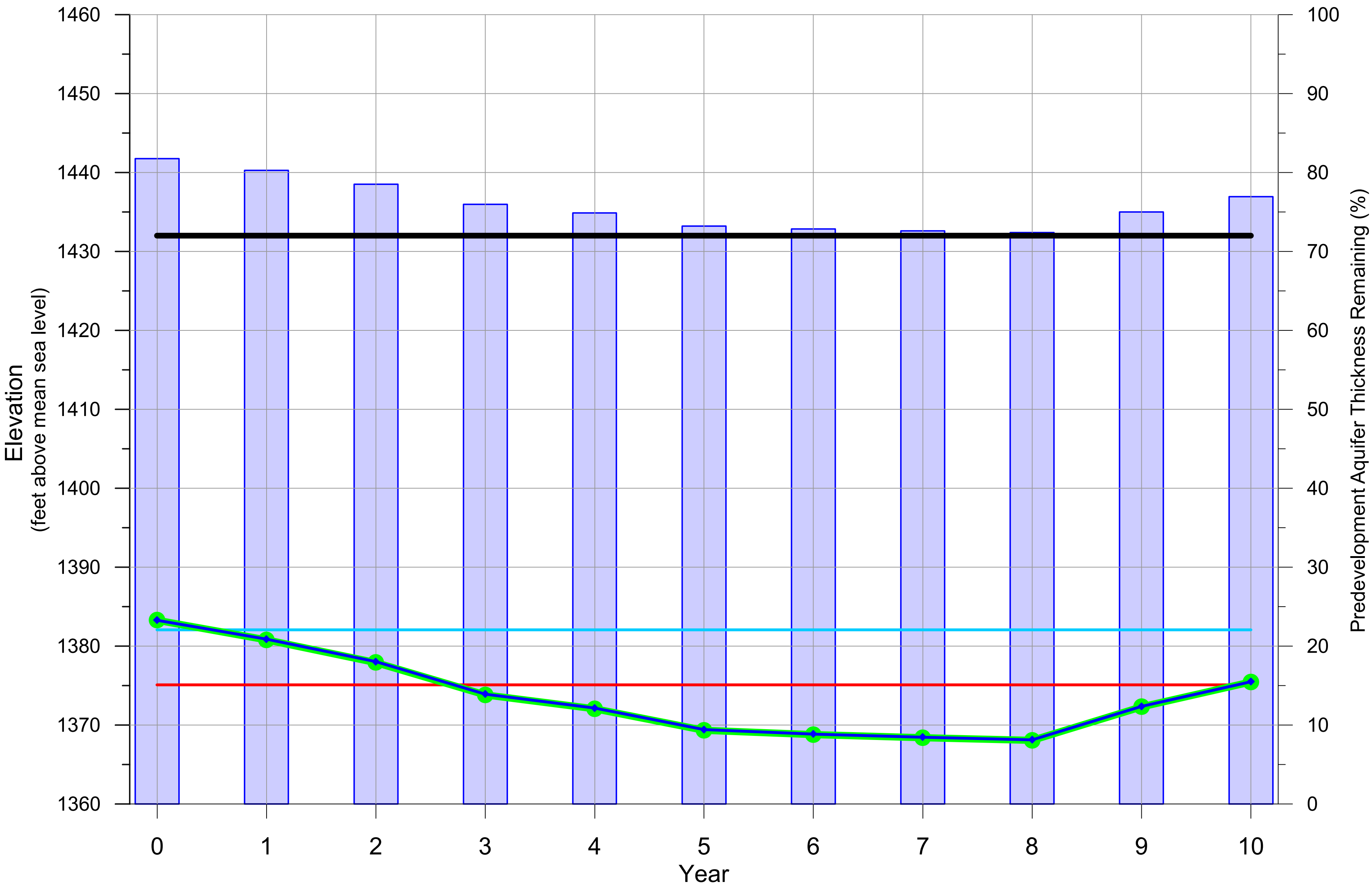
BURNS McDONNELL

Hydrograph 8
Index Well Hydrographs
IW-08A & IW-08C
Stress Periods 1 through 10



BURNS McDONNELL

Hydrograph 9
Index Well Hydrographs
IW-09A & IW-09CS
Stress Periods 1 through 10

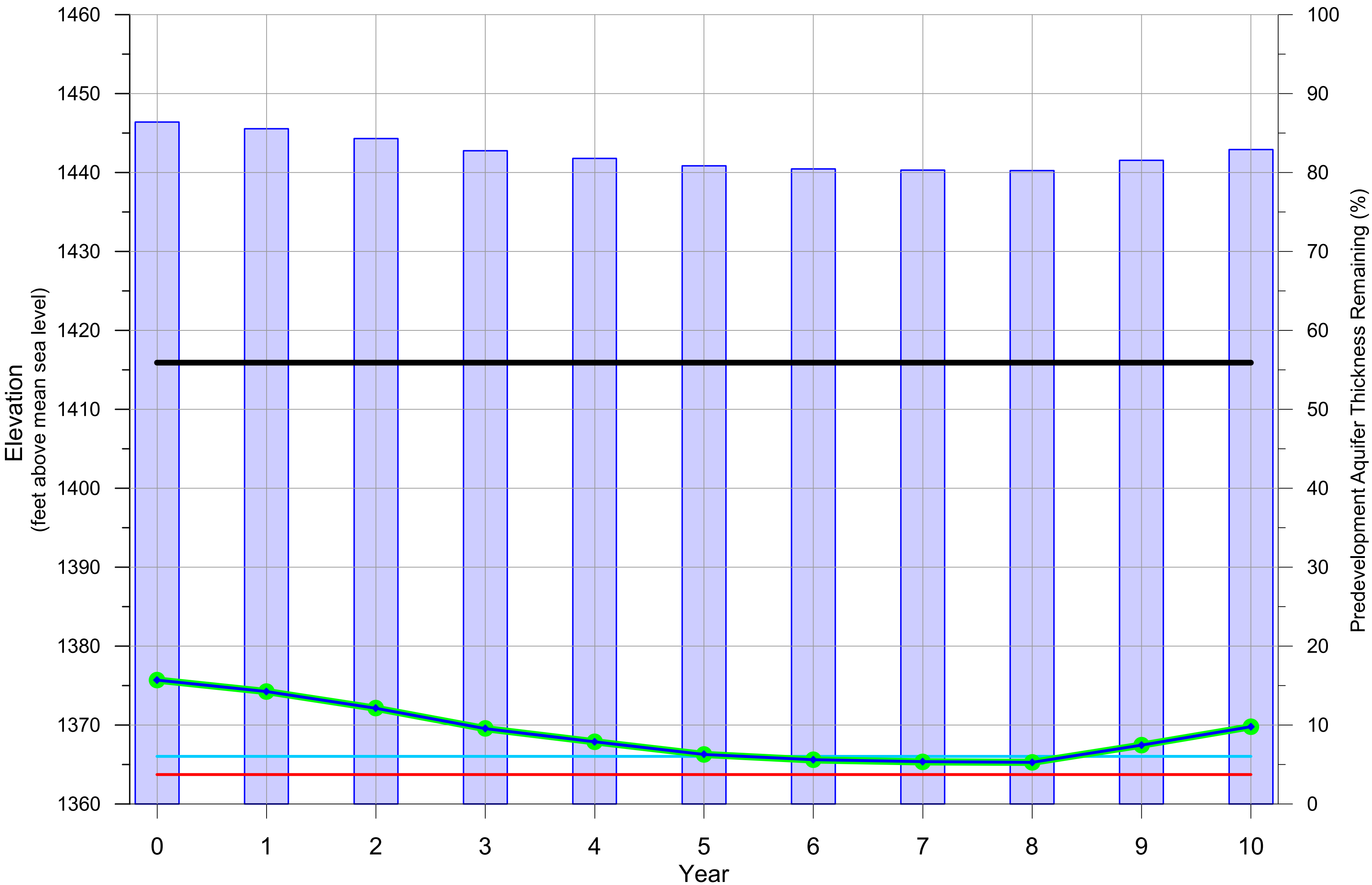


LEGEND

- IW-10A
- IW-10C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 10
Index Well Hydrographs
IW-10A & IW-10C
Stress Periods 1 through 10



LEGEND

IW-11A

IW-11C

Ground Surface Elevation

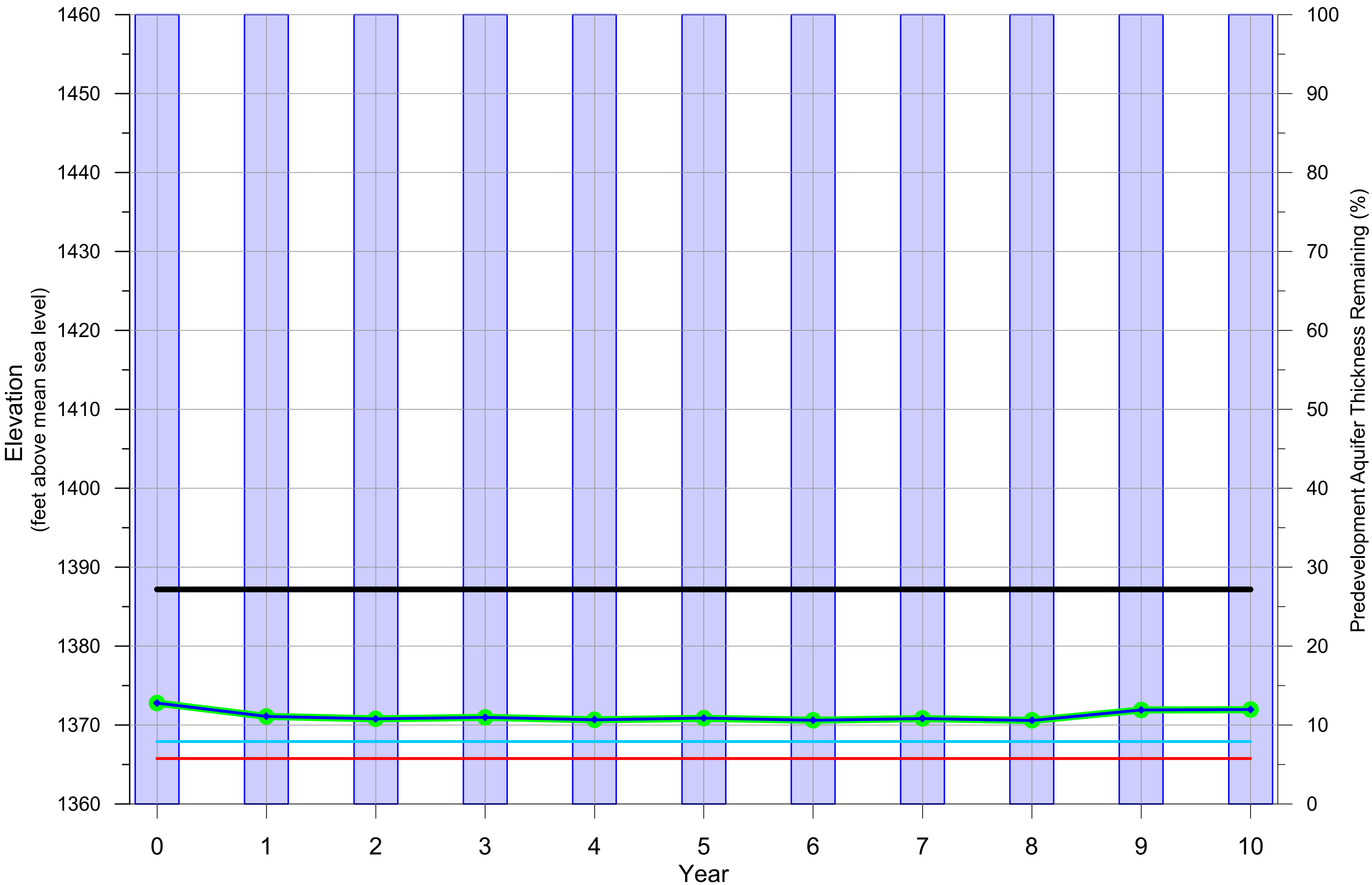
1993 Upper Aquifer Groundwater Elevation

1993 Lower Aquifer Groundwater Elevation

Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 11
Index Well Hydrographs
IW-11A & IW-11C
Stress Periods 1 through 10



LEGEND

IW-12A

IW-12C

Ground Surface Elevation

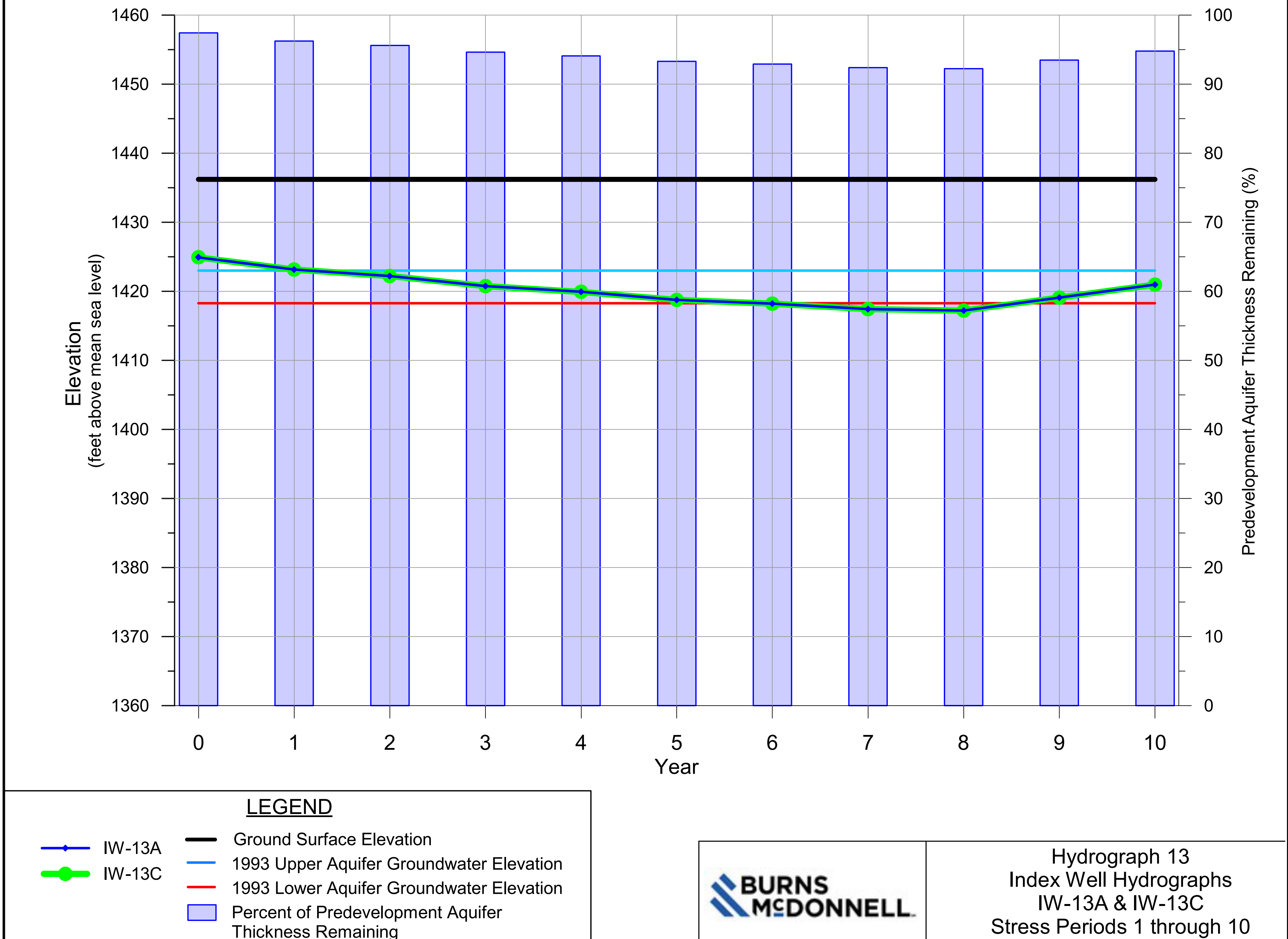
1993 Upper Aquifer Groundwater Elevation

1993 Lower Aquifer Groundwater Elevation

Percent of Predevelopment Aquifer Thickness Remaining

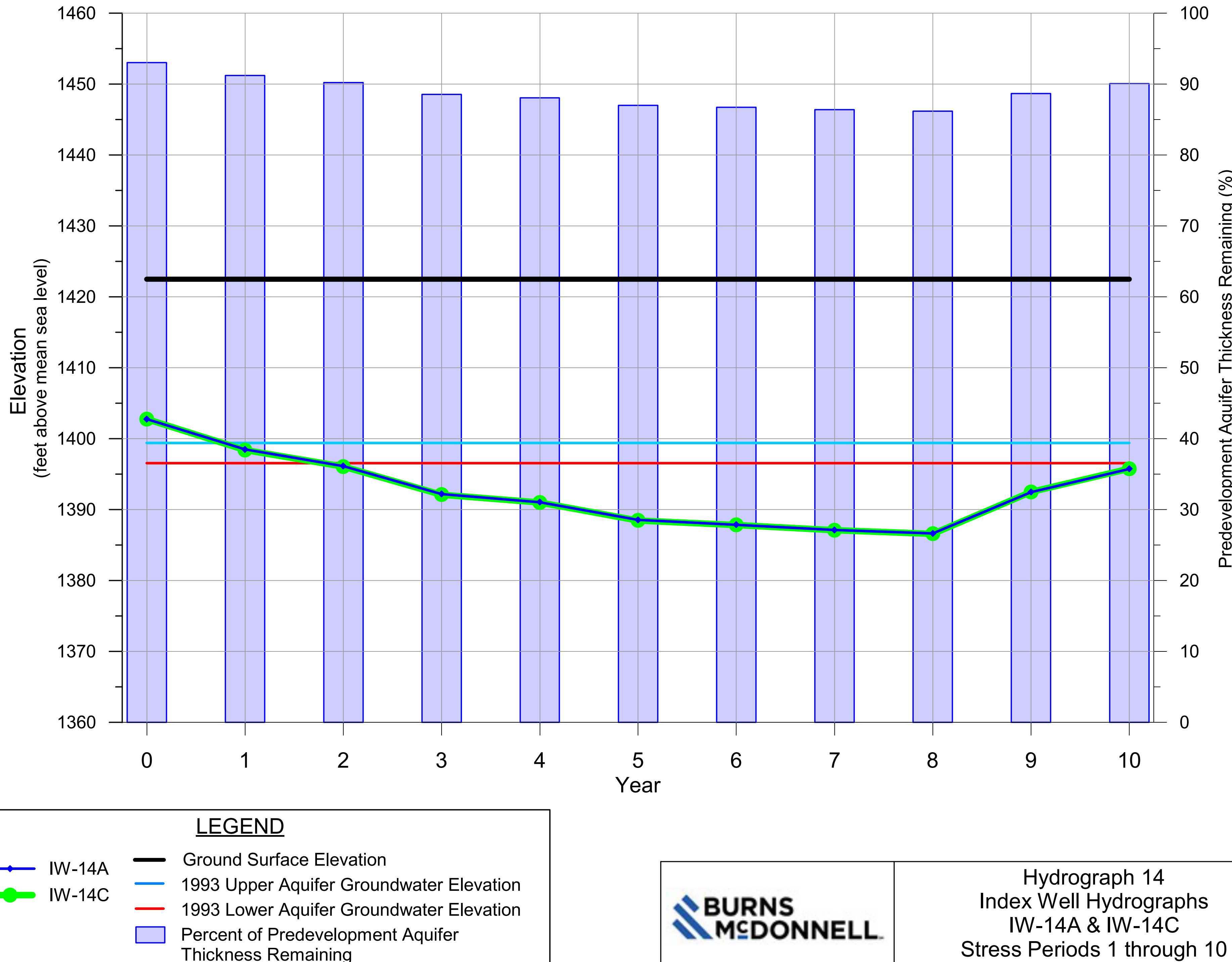
BURNS McDONNELL

Hydrograph 12
Index Well Hydrographs
IW-12A & IW-12C
Stress Periods 1 through 10



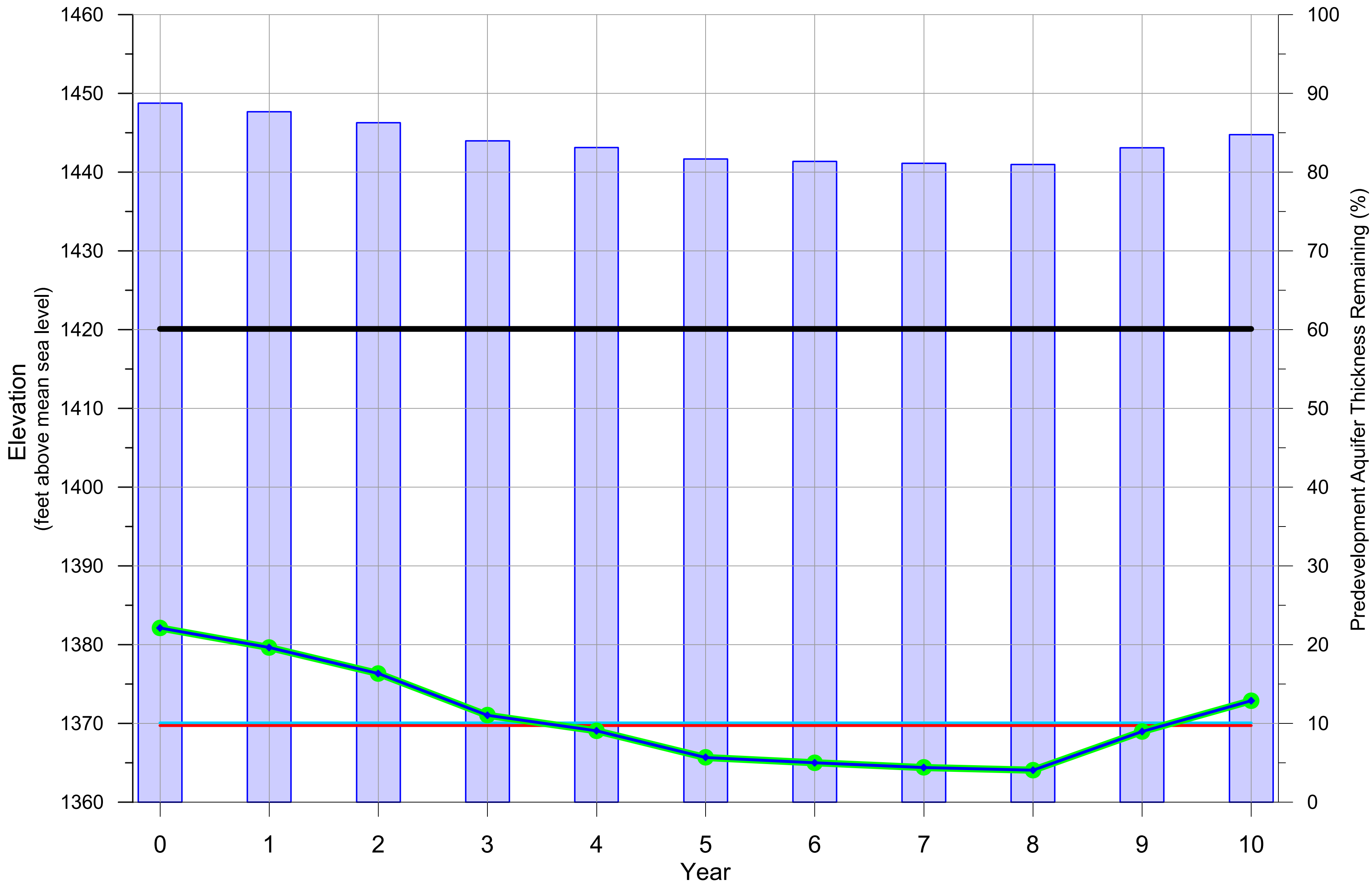
BURNS McDONNELL

Hydrograph 13
Index Well Hydrographs
IW-13A & IW-13C
Stress Periods 1 through 10



BURNS McDONNELL

Hydrograph 14
Index Well Hydrographs
IW-14A & IW-14C
Stress Periods 1 through 10

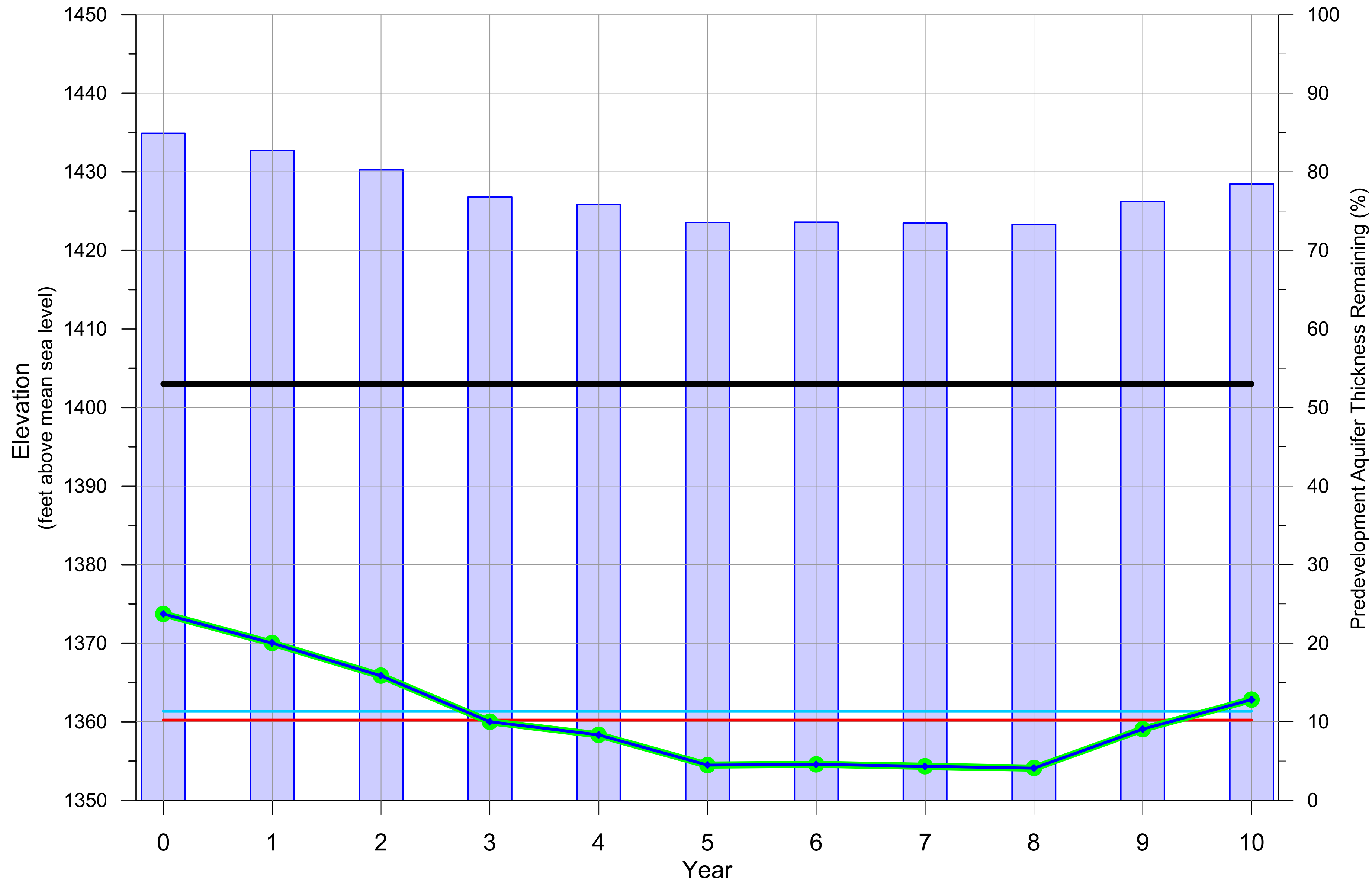


LEGEND

IW-15A
IW-15C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 15
Index Well Hydrographs
IW-15A & IW-15C
Stress Periods 1 through 10

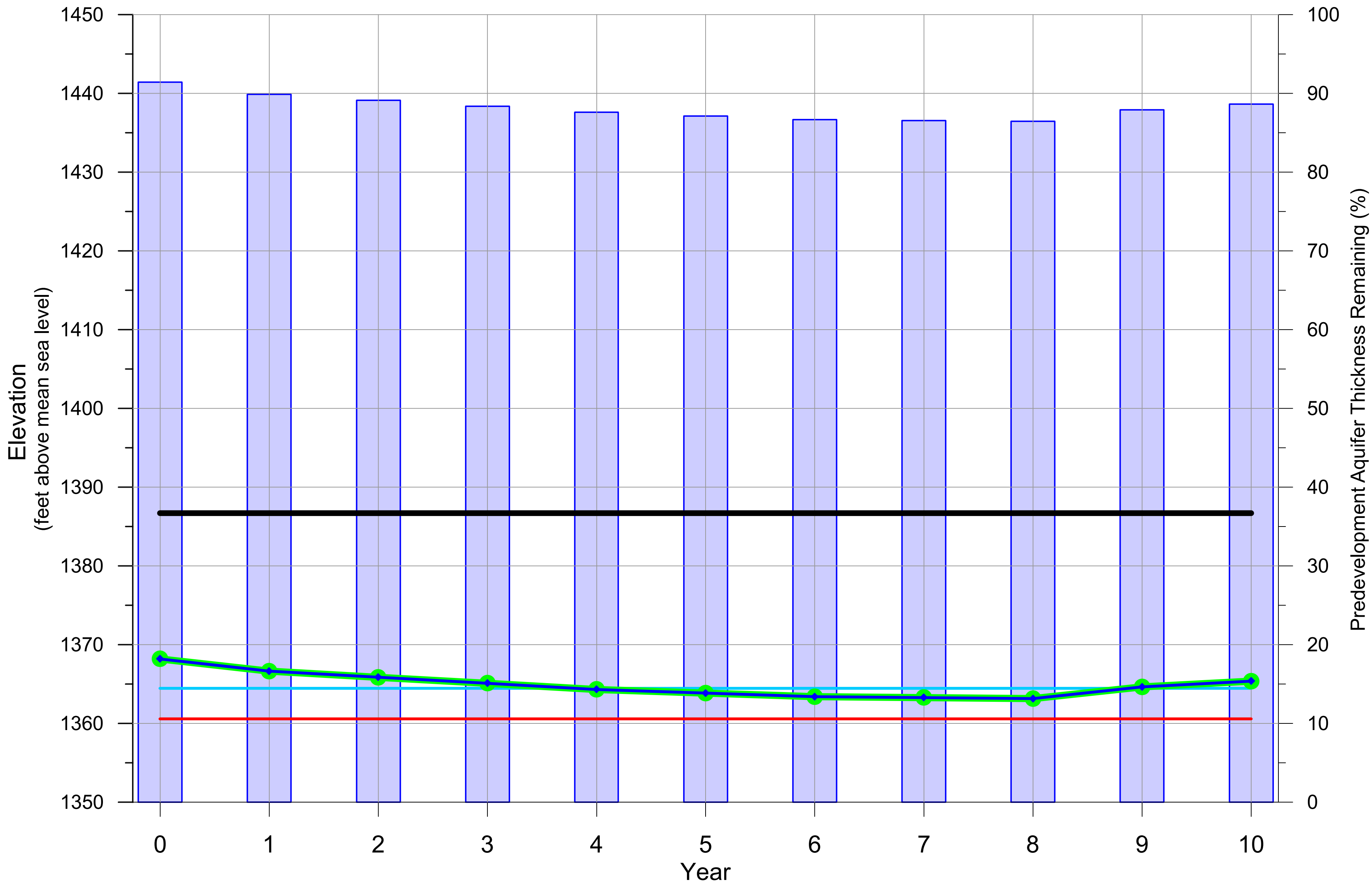


LEGEND

- IW-16A
- IW-16C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 16
Index Well Hydrographs
IW-16A & IW-16C
Stress Periods 1 through 10

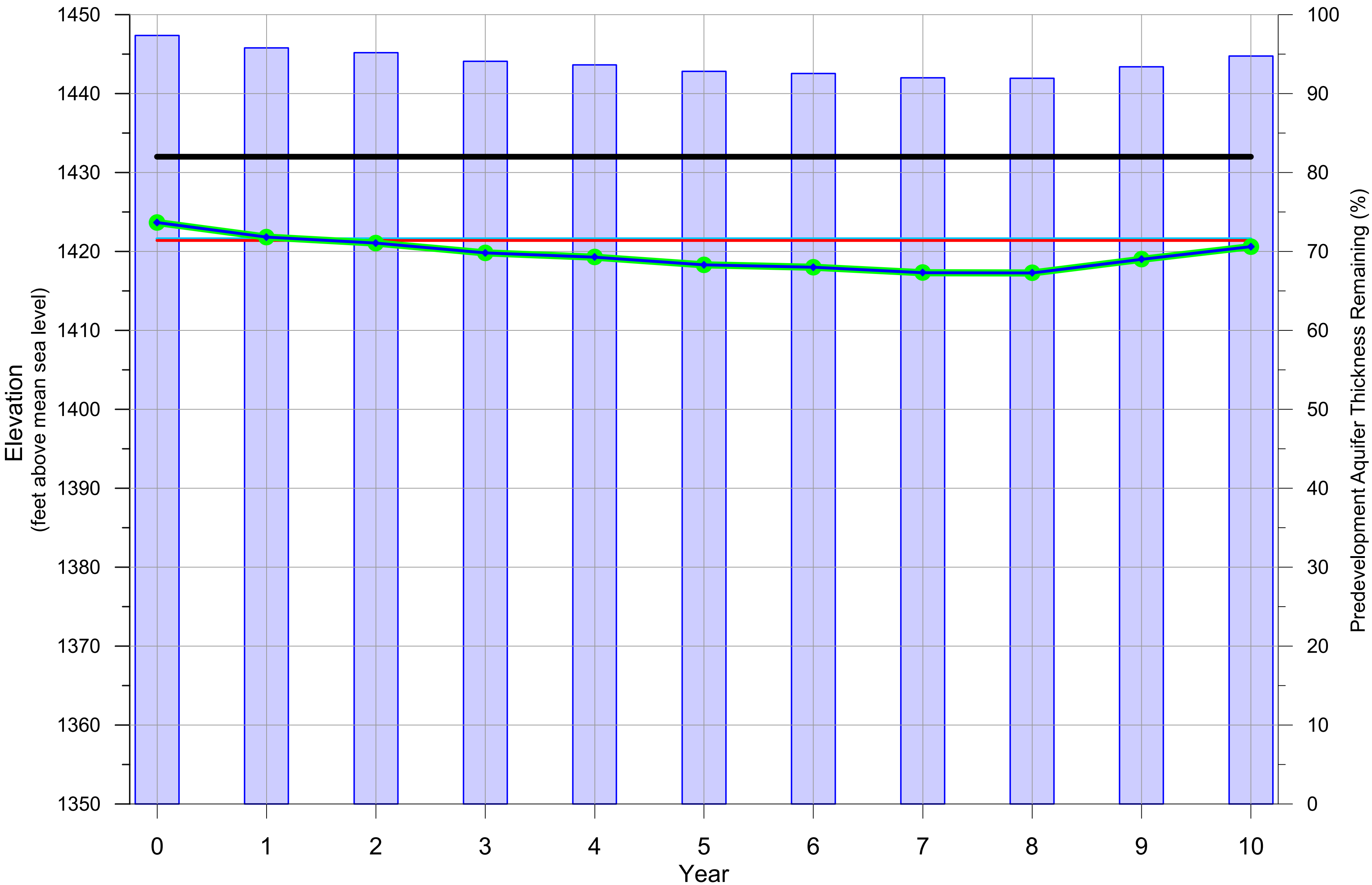


LEGEND

- IW-17A
- IW-17C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 17
Index Well Hydrographs
IW-17A & IW-17C
Stress Periods 1 through 10

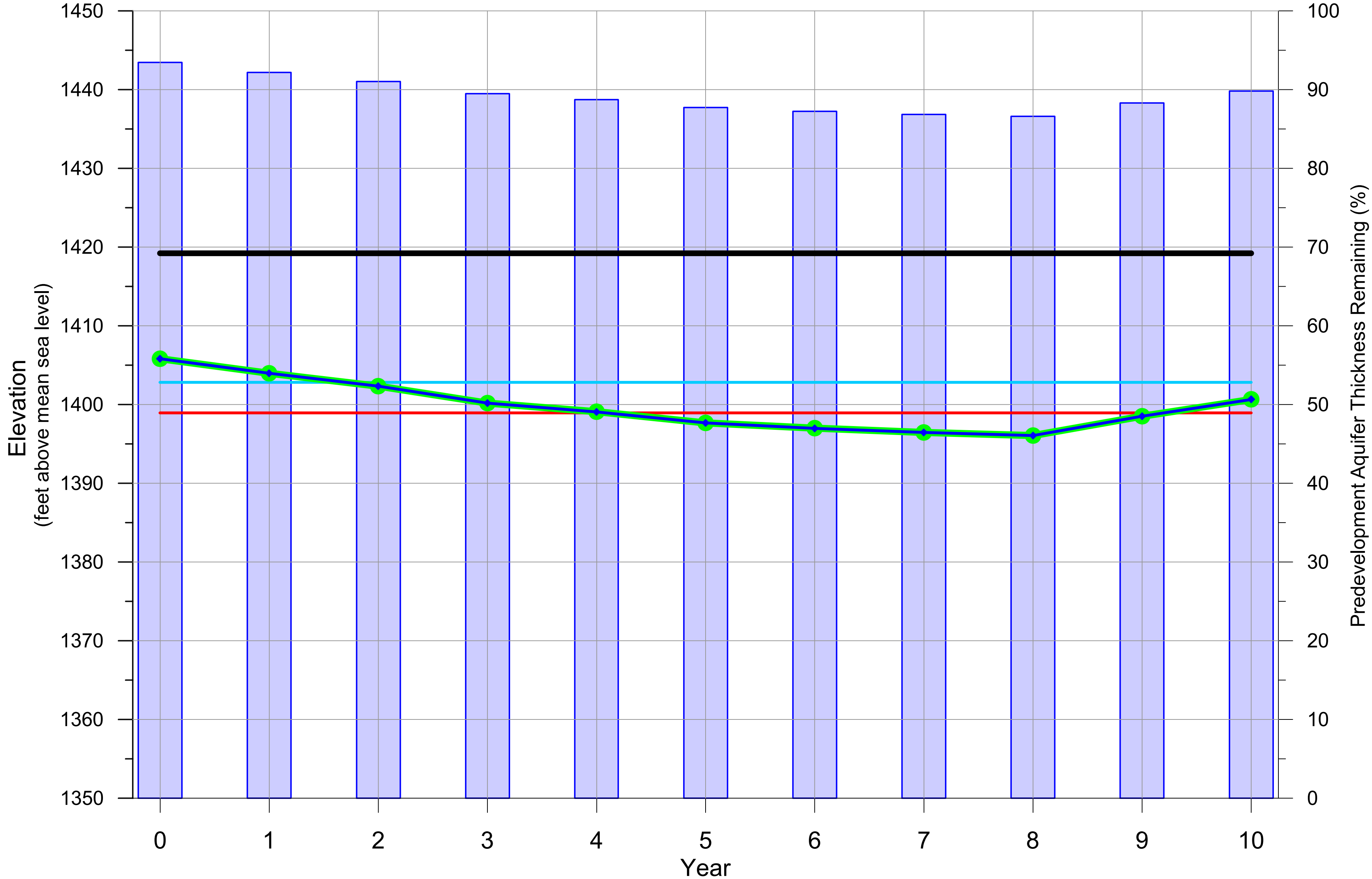


LEGEND

- IW-18A
- IW-18C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 18
Index Well Hydrographs
IW-18A & IW-18C
Stress Periods 1 through 10

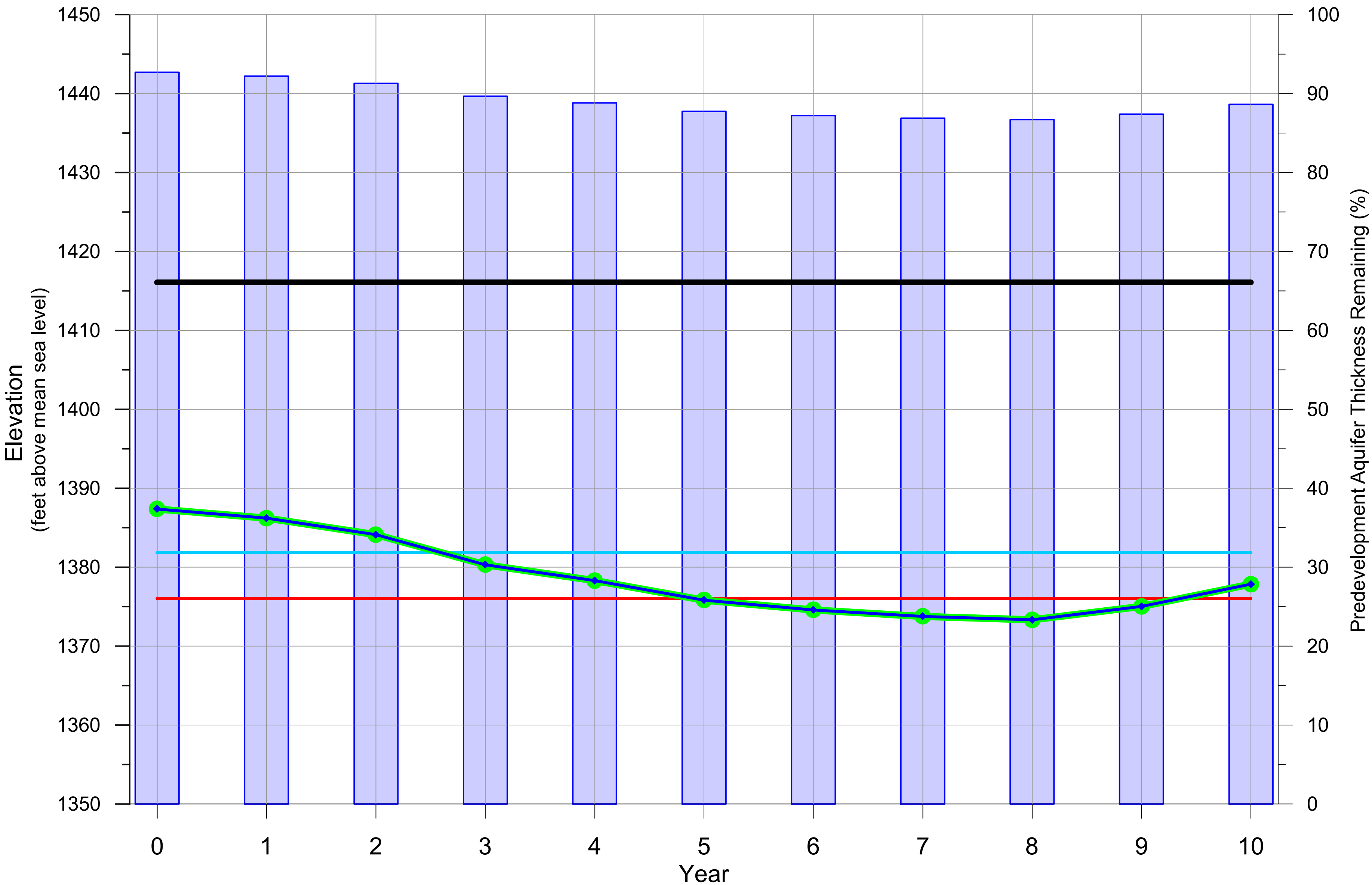


LEGEND

IW-19A	Ground Surface Elevation
IW-19C	1993 Upper Aquifer Groundwater Elevation
	1993 Lower Aquifer Groundwater Elevation
	Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 19
Index Well Hydrographs
IW-19A & IW-19C
Stress Periods 1 through 10

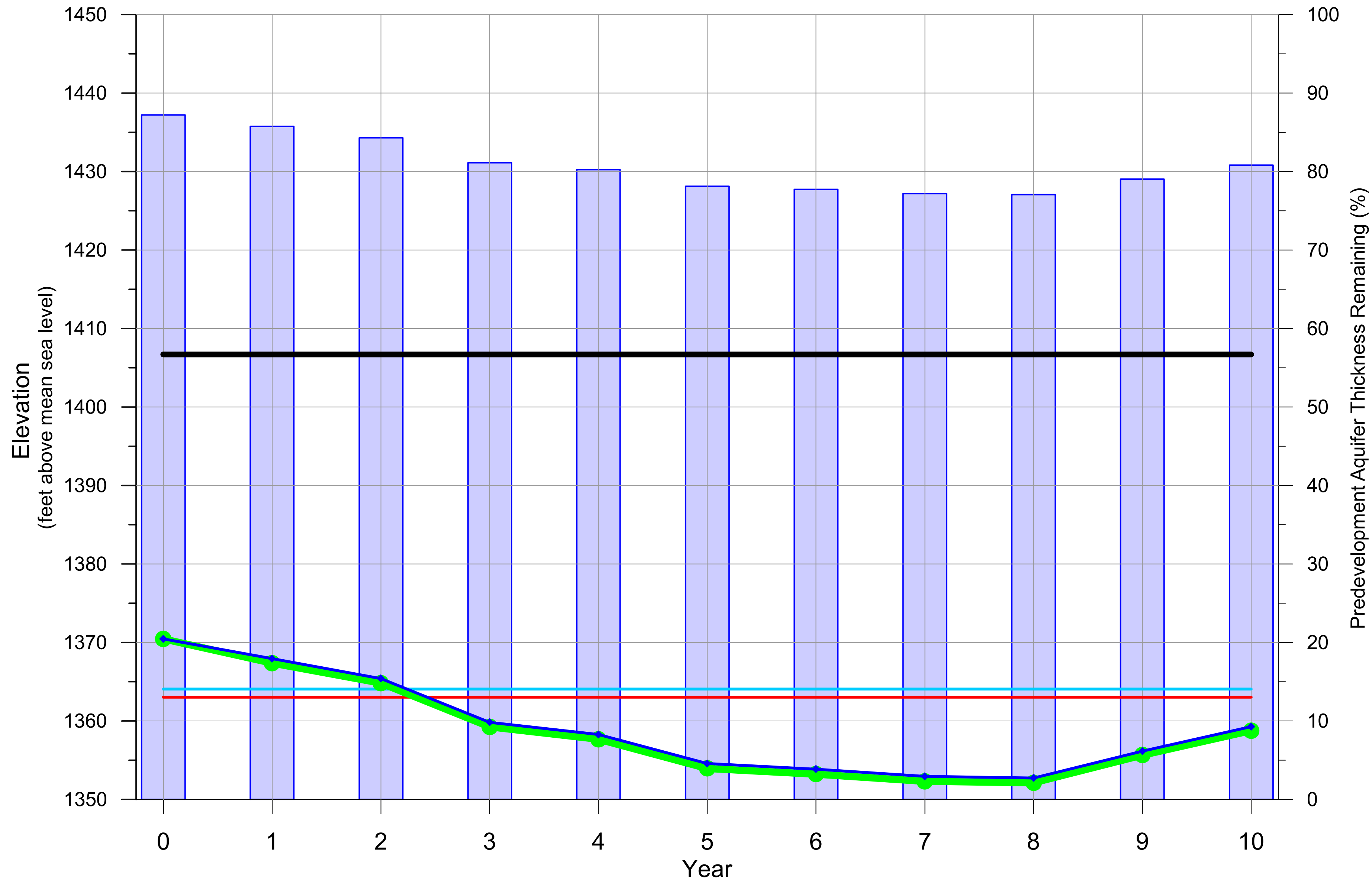


LEGEND

- IW-20A
- IW-20C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 20
Index Well Hydrographs
IW-20A & IW-20C
Stress Periods 1 through 10

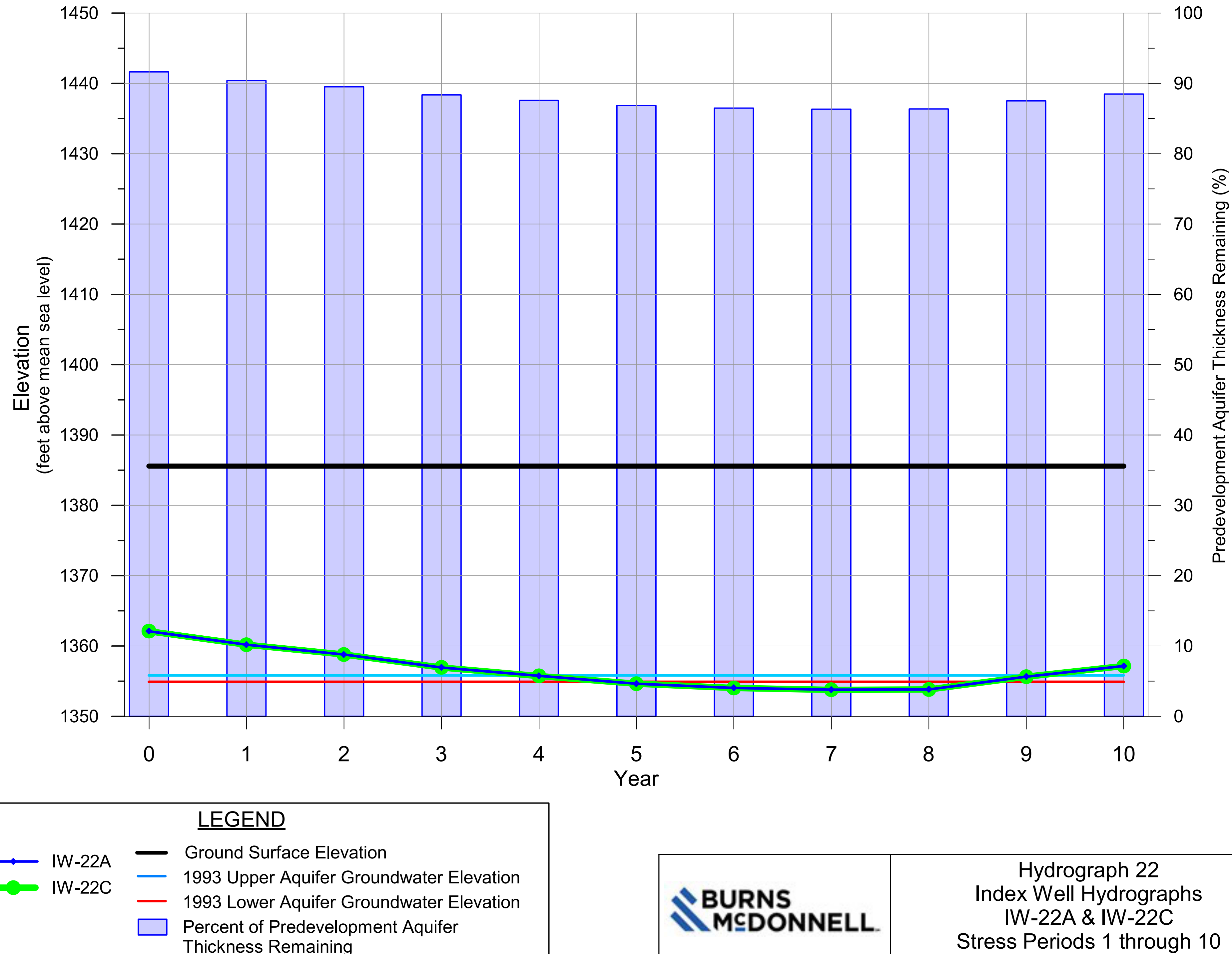


LEGEND

IW-21A	Ground Surface Elevation
IW-21C	1993 Upper Aquifer Groundwater Elevation
	1993 Lower Aquifer Groundwater Elevation
	Percent of Predevelopment Aquifer Thickness Remaining

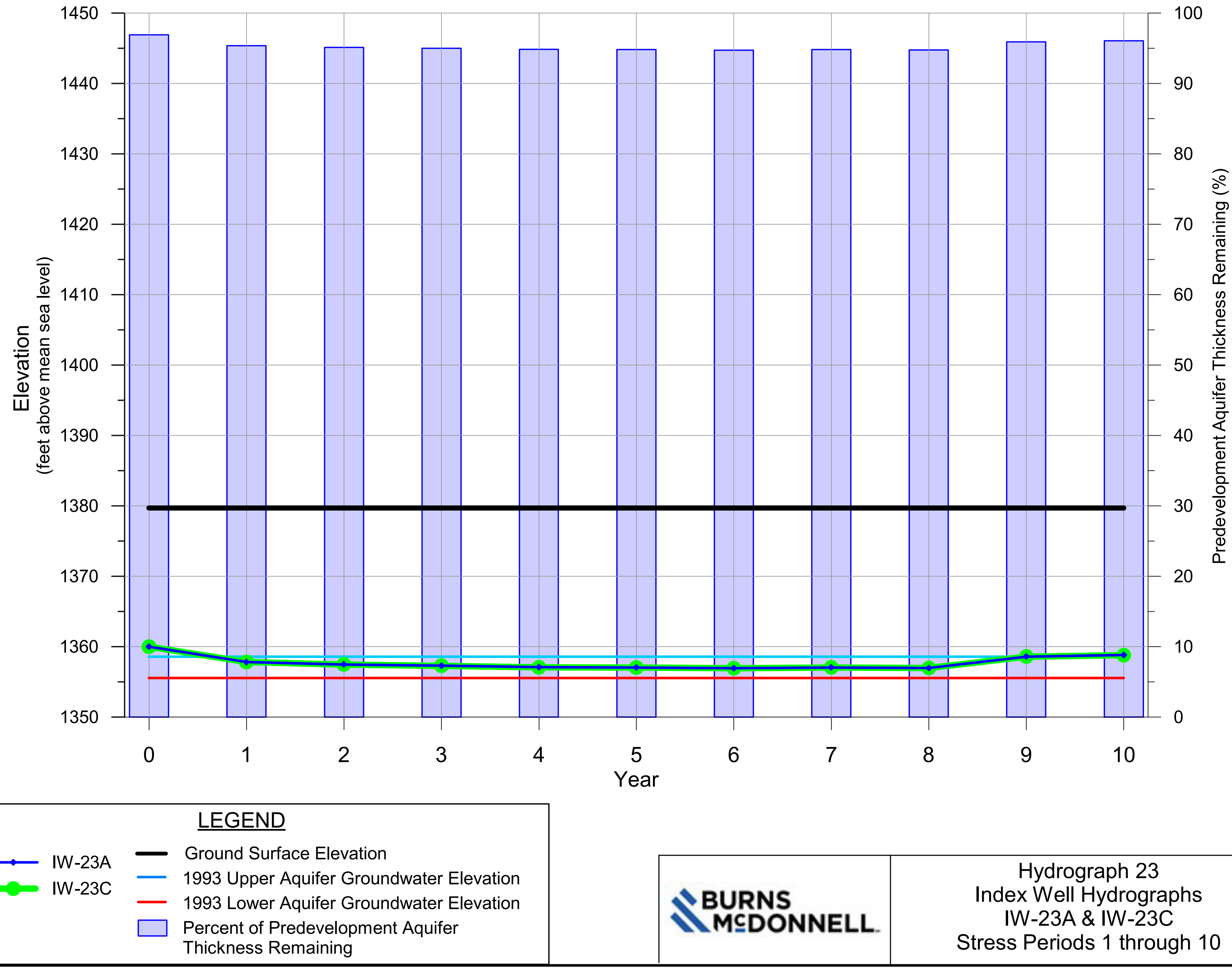
BURNS McDONNELL

Hydrograph 21
Index Well Hydrographs
IW-21A & IW-21C
Stress Periods 1 through 10



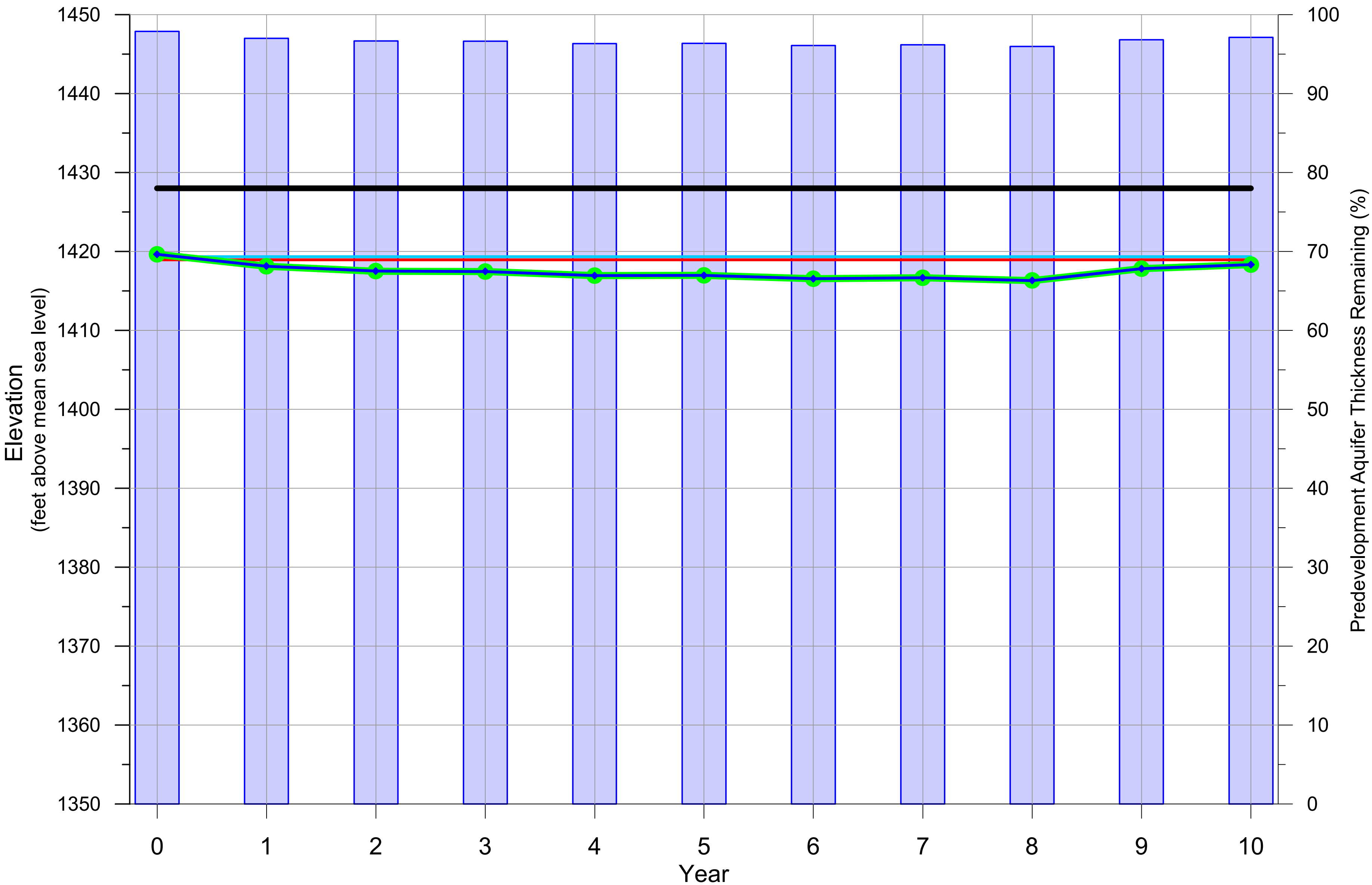
BURNS McDONNELL

Hydrograph 22
Index Well Hydrographs
IW-22A & IW-22C
Stress Periods 1 through 10



BURNS McDONNELL

Hydrograph 23
Index Well Hydrographs
IW-23A & IW-23C
Stress Periods 1 through 10

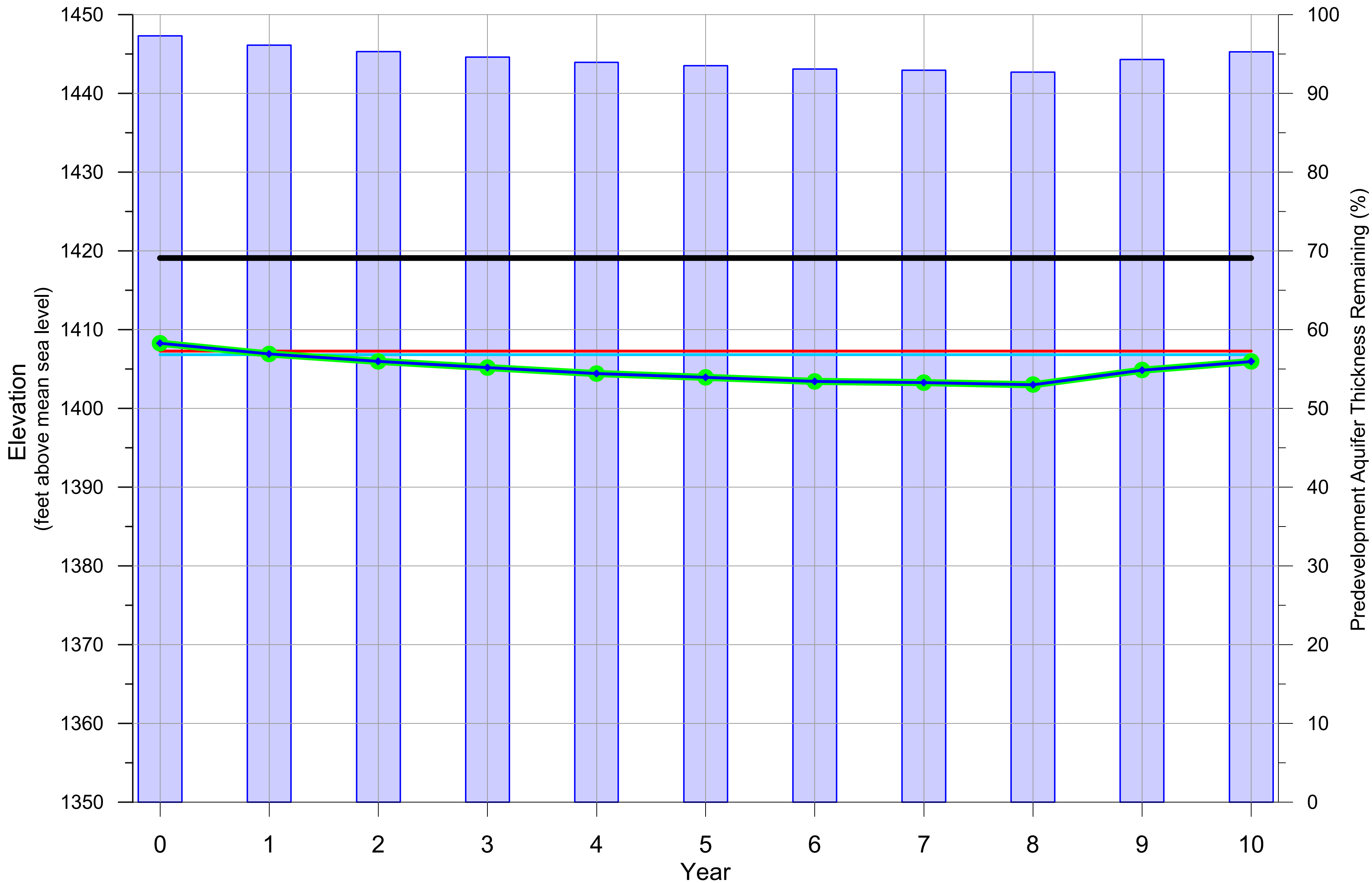


LEGEND

- IW-24A
- IW-24C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 24
Index Well Hydrographs
IW-24A & IW-24C
Stress Periods 1 through 10

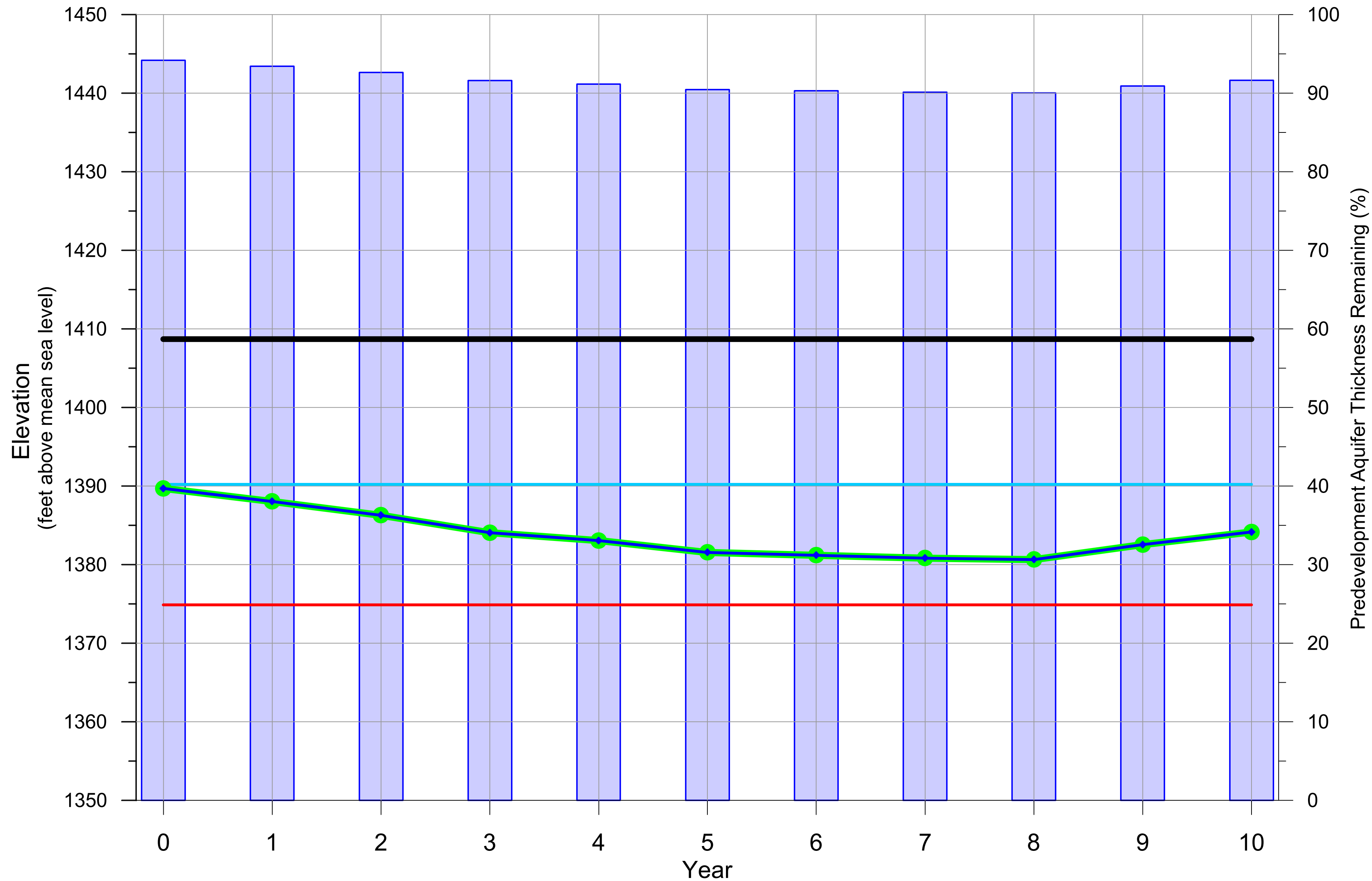


LEGEND

- IW-25A
- IW-25C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 25
Index Well Hydrographs
IW-25A & IW-25C
Stress Periods 1 through 10

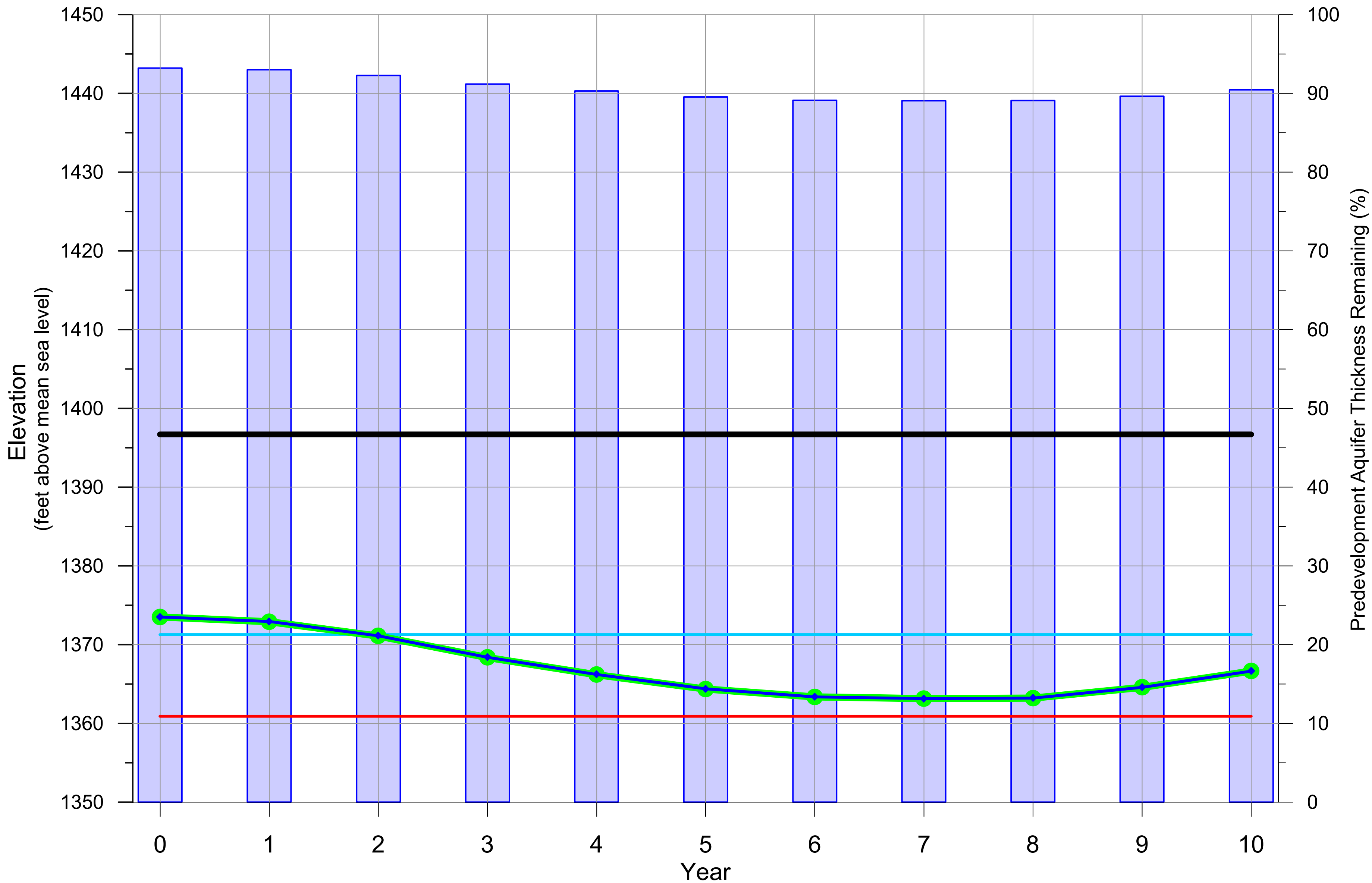


LEGEND

- IW-26A
- IW-26C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 26
Index Well Hydrographs
IW-26A & IW-26C
Stress Periods 1 through 10



LEGEND

IW-27A

IW-27C

Ground Surface Elevation

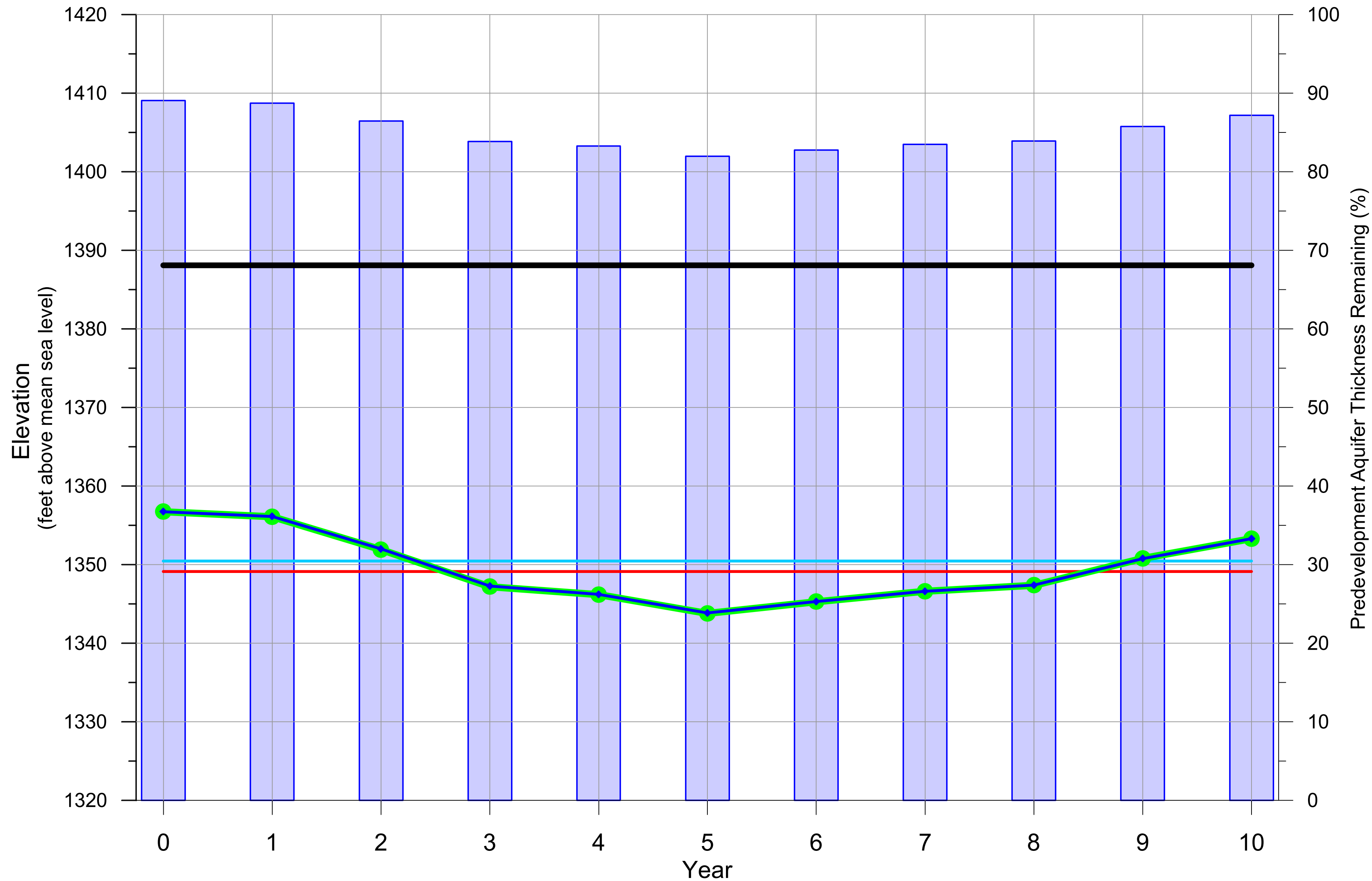
1993 Upper Aquifer Groundwater Elevation

1993 Lower Aquifer Groundwater Elevation

Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 27
Index Well Hydrographs
IW-27A & IW-27C
Stress Periods 1 through 10



LEGEND

IW-28A

IW-28C

Ground Surface Elevation

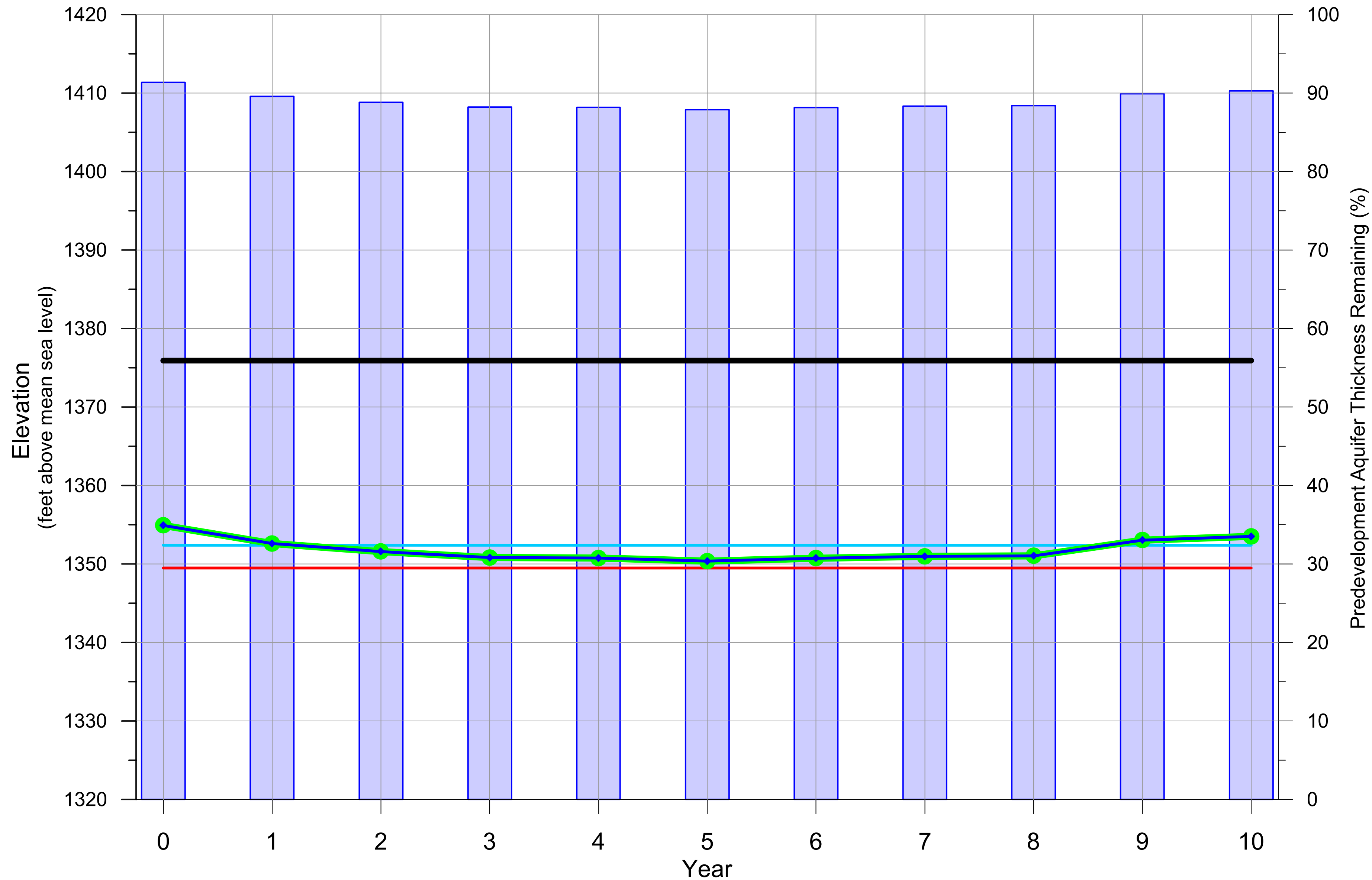
1993 Upper Aquifer Groundwater Elevation

1993 Lower Aquifer Groundwater Elevation

Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 28
Index Well Hydrographs
IW-28A & IW-28C
Stress Periods 1 through 10

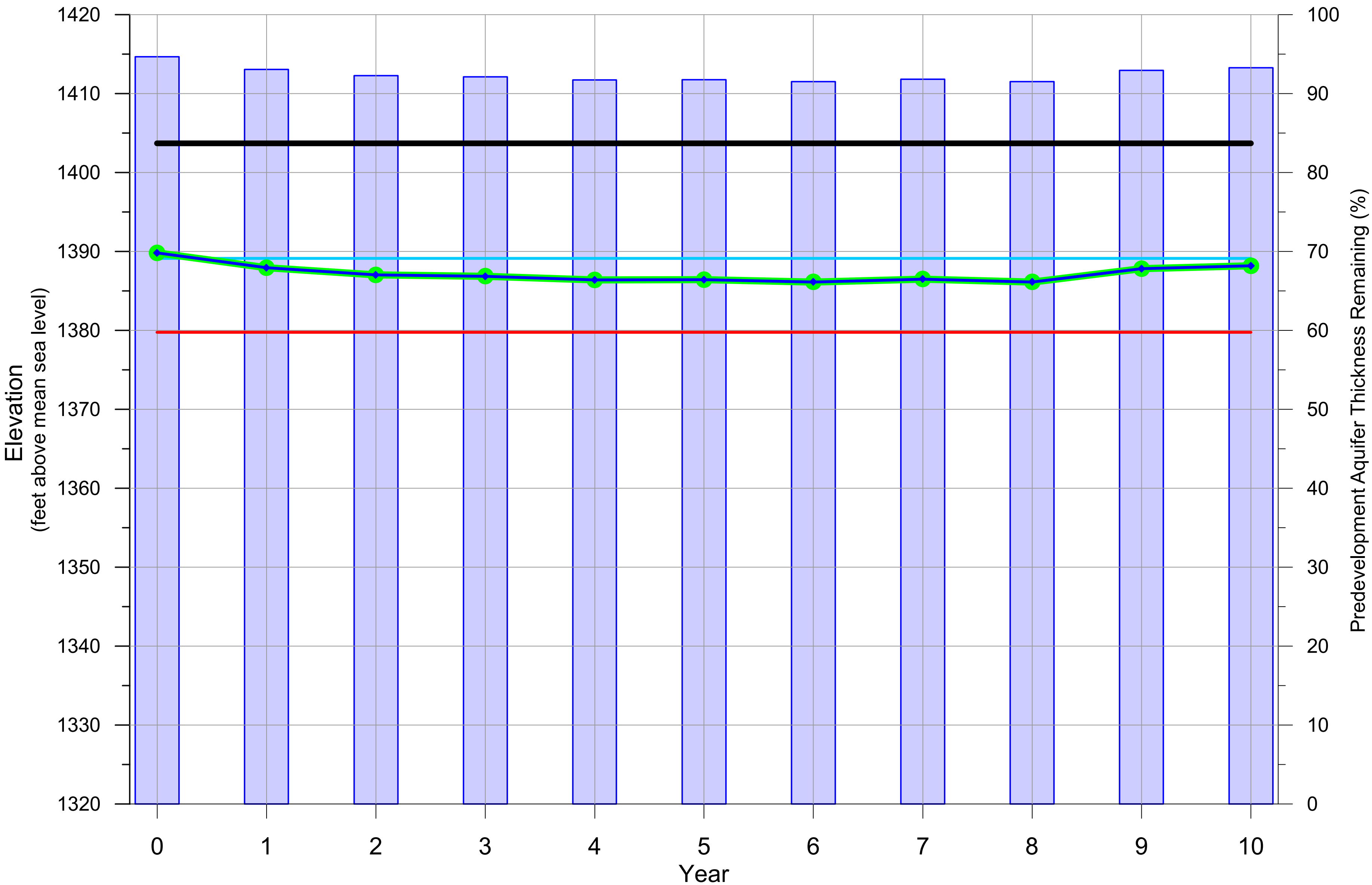


LEGEND

- IW-29A
- IW-29C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 29
Index Well Hydrographs
IW-29A & IW-29C
Stress Periods 1 through 10

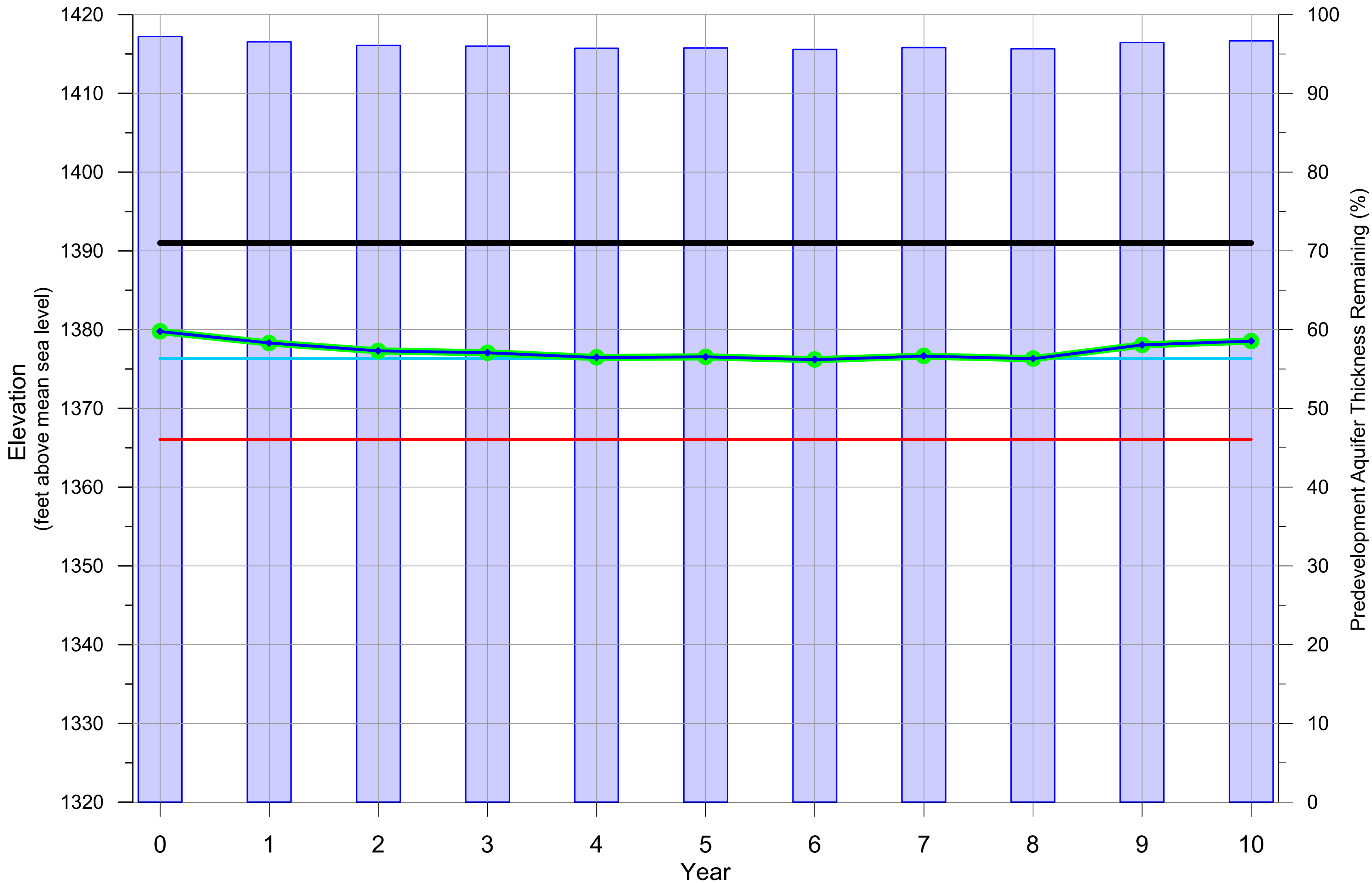


LEGEND

IW-30A
IW-30C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 30
Index Well Hydrographs
IW-30A & IW-30C
Stress Periods 1 through 10

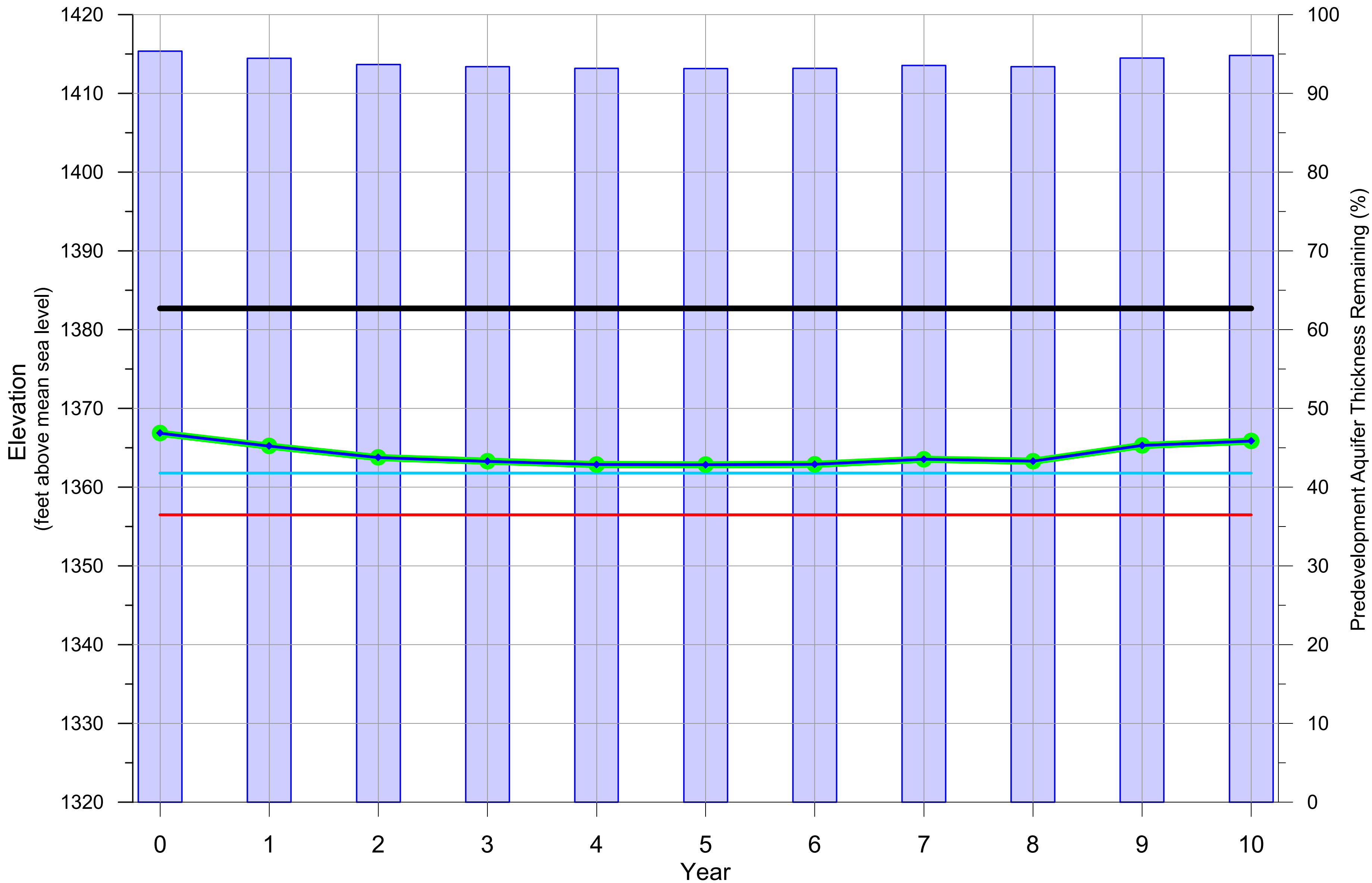


LEGEND

IW-31A
IW-31C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 31
Index Well Hydrographs
IW-31A & IW-31C
Stress Periods 1 through 10

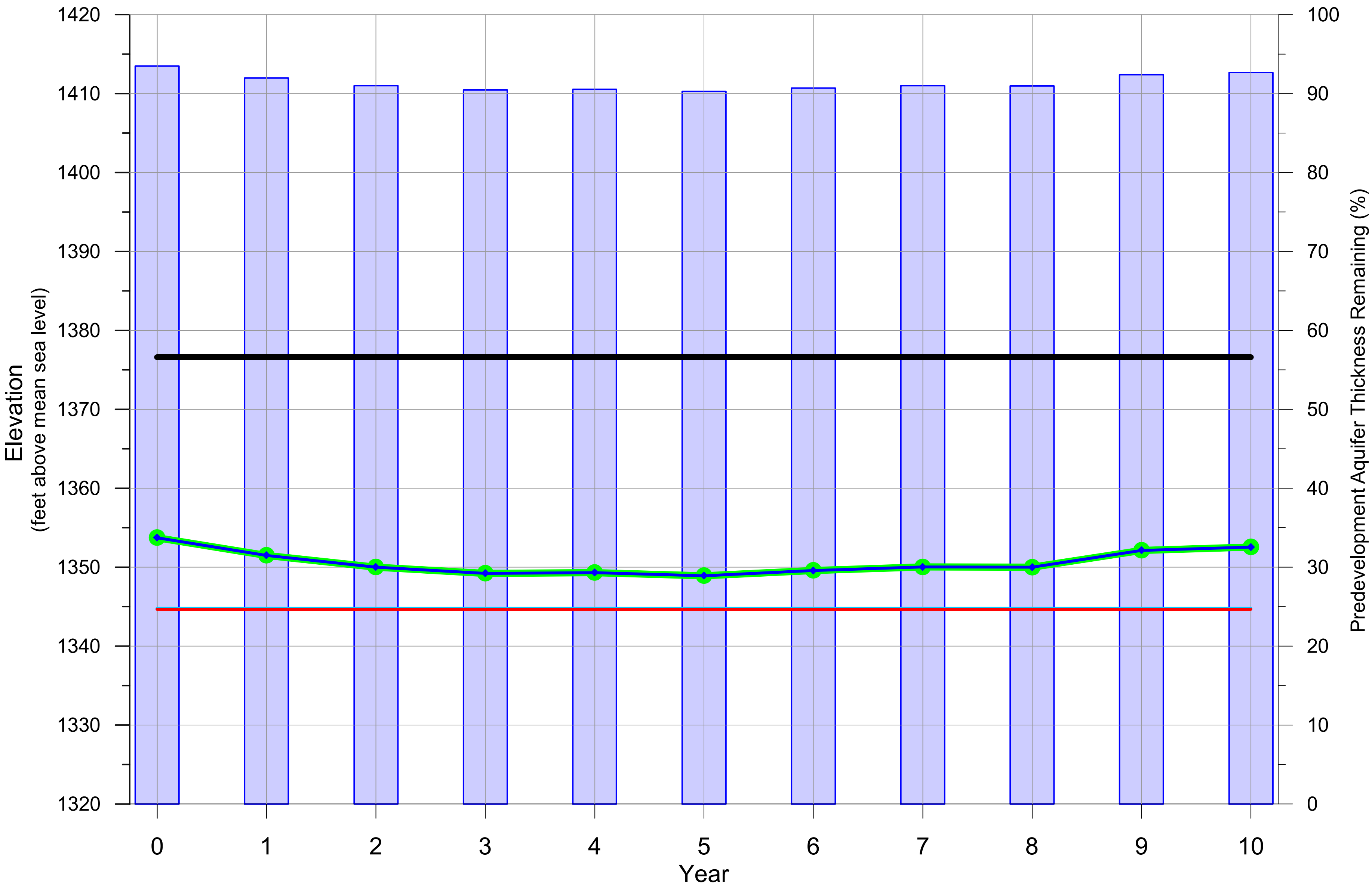


LEGEND

- IW-32A
- IW-32C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 32
Index Well Hydrographs
IW-32A & IW-32C
Stress Periods 1 through 10

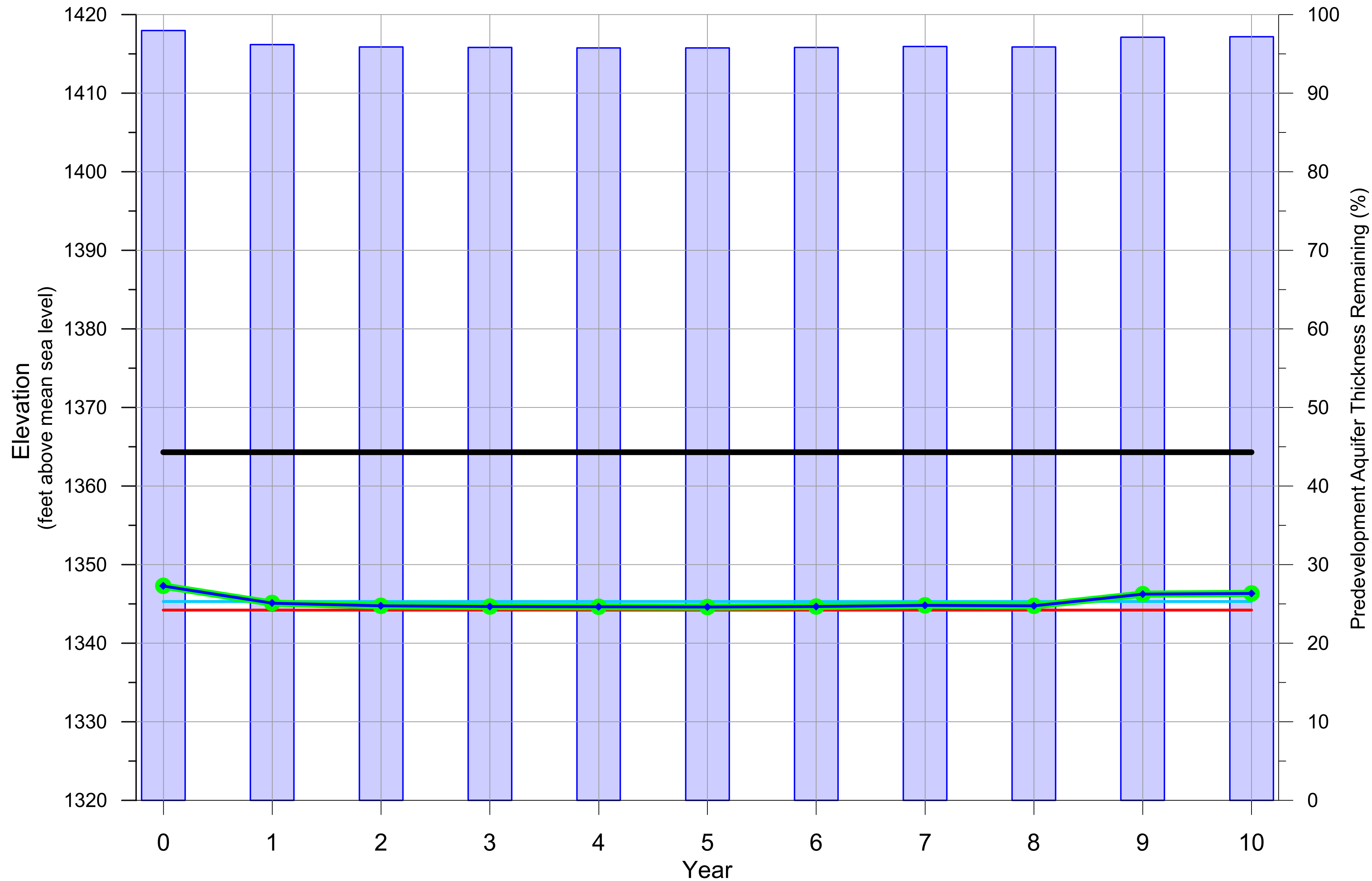


LEGEND

IW-33A
IW-33C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 33
Index Well Hydrographs
IW-33A & IW-33C
Stress Periods 1 through 10



LEGEND

IW-34A

IW-34C

Ground Surface Elevation

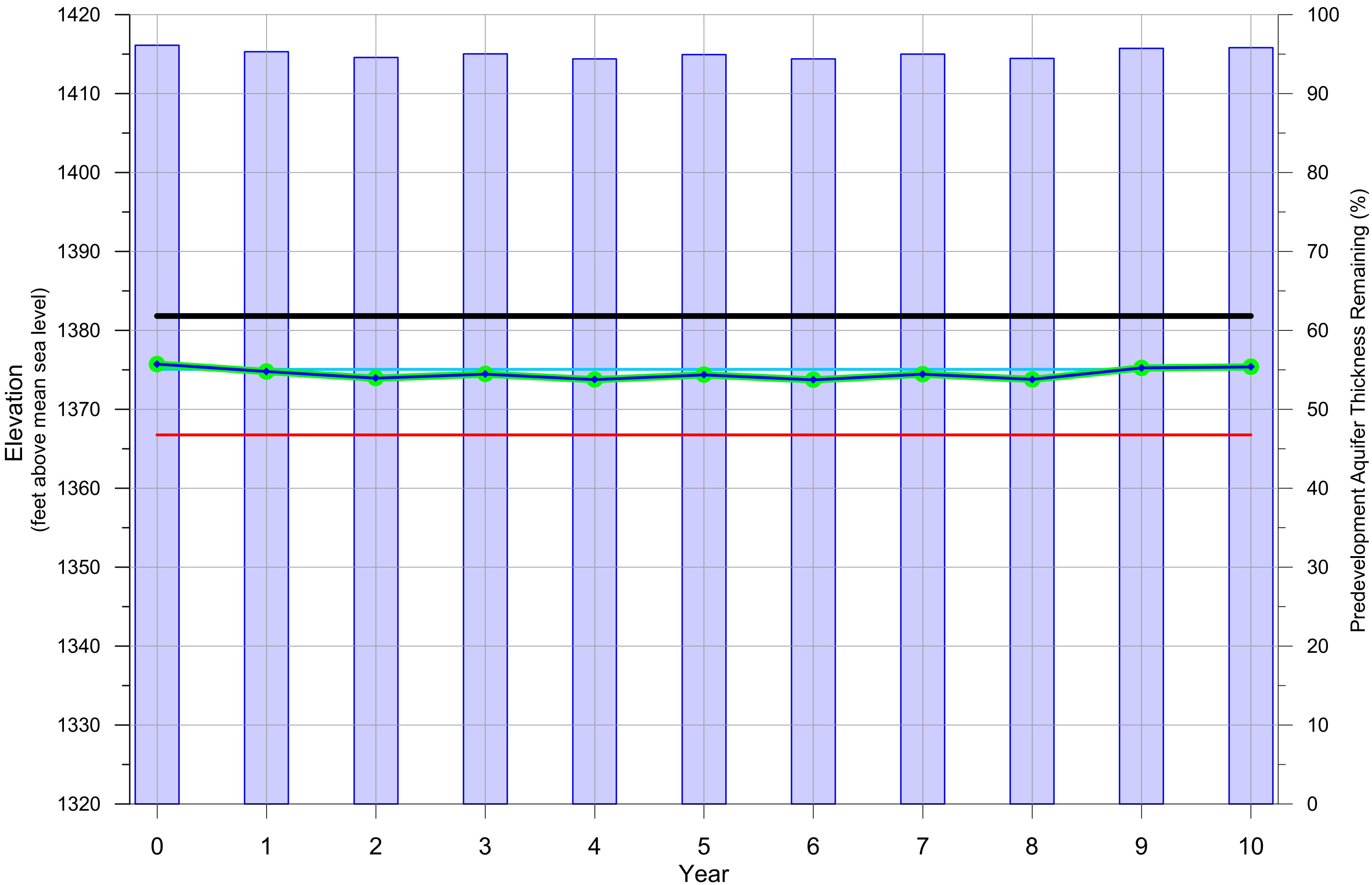
1993 Upper Aquifer Groundwater Elevation

1993 Lower Aquifer Groundwater Elevation

Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 34
Index Well Hydrographs
IW-34A & IW-34C
Stress Periods 1 through 10

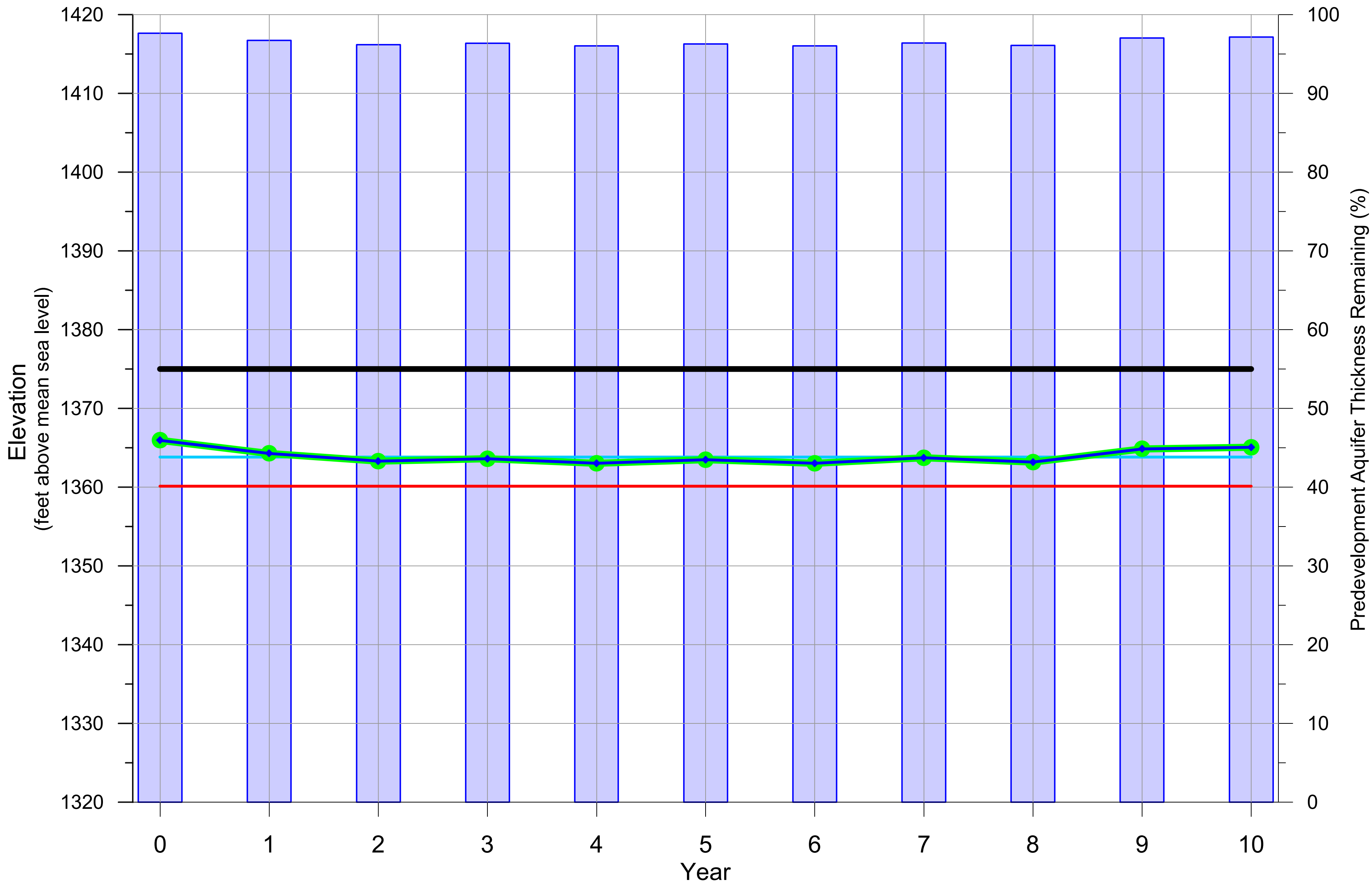


LEGEND

IW-35A	Ground Surface Elevation
IW-35C	1993 Upper Aquifer Groundwater Elevation
	1993 Lower Aquifer Groundwater Elevation
	Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 35
Index Well Hydrographs
IW-35A & IW-35C
Stress Periods 1 through 10

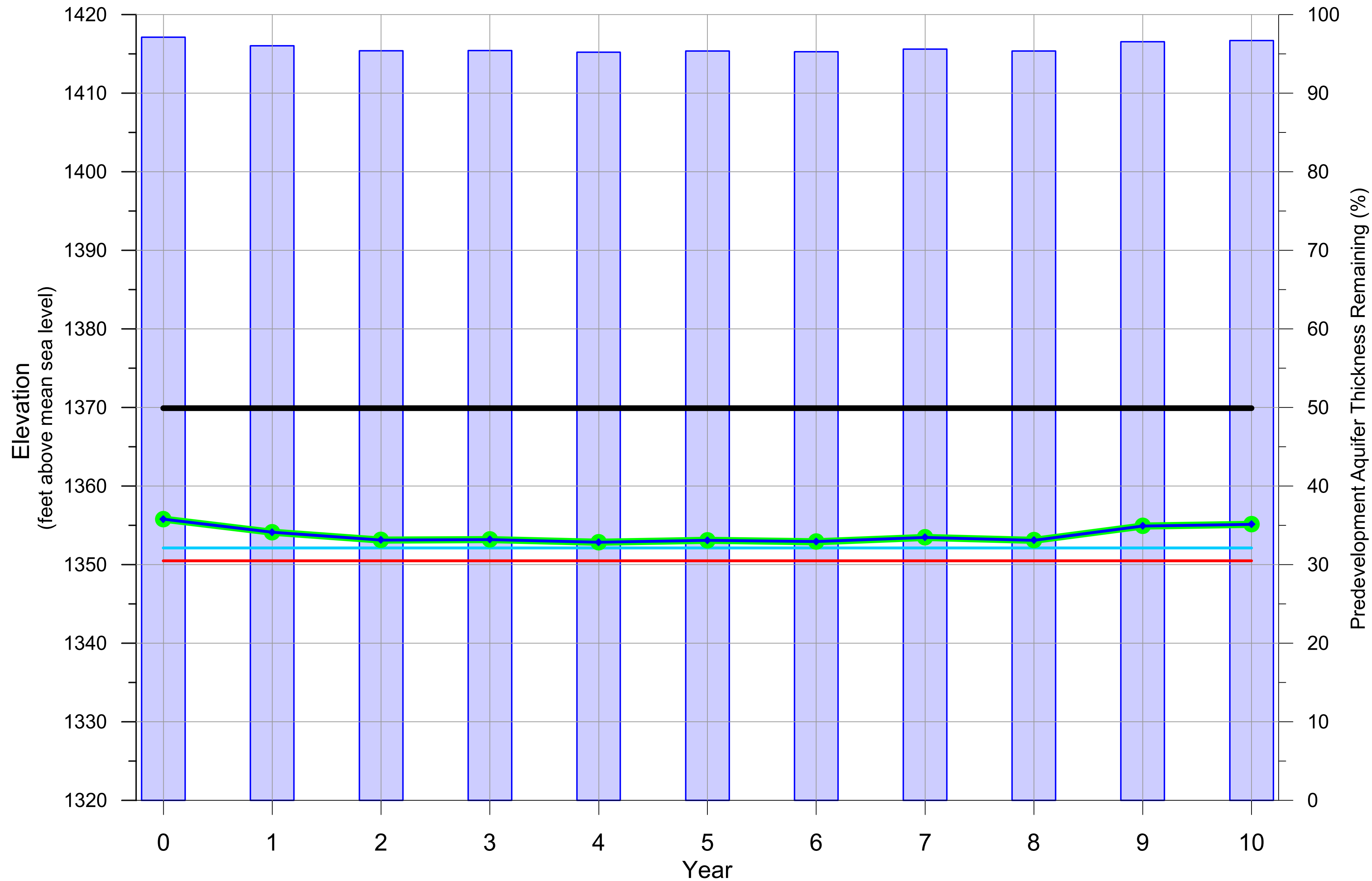


LEGEND

IW-36A
IW-36C
Ground Surface Elevation
1993 Upper Aquifer Groundwater Elevation
1993 Lower Aquifer Groundwater Elevation
Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 36
Index Well Hydrographs
IW-36A & IW-36C
Stress Periods 1 through 10

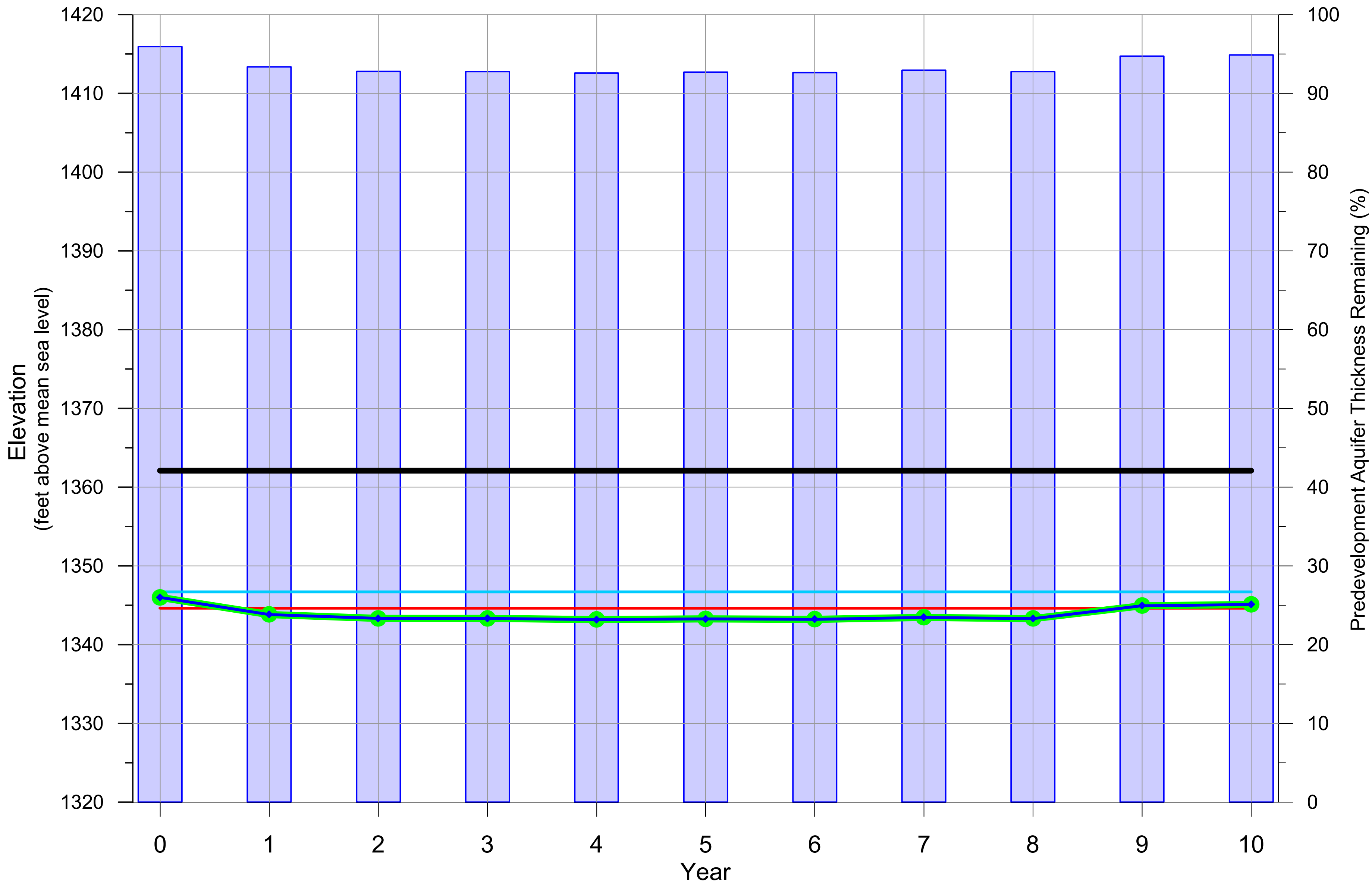


LEGEND

- IW-37A
- IW-37C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 37
Index Well Hydrographs
IW-37A & IW-37C
Stress Periods 1 through 10

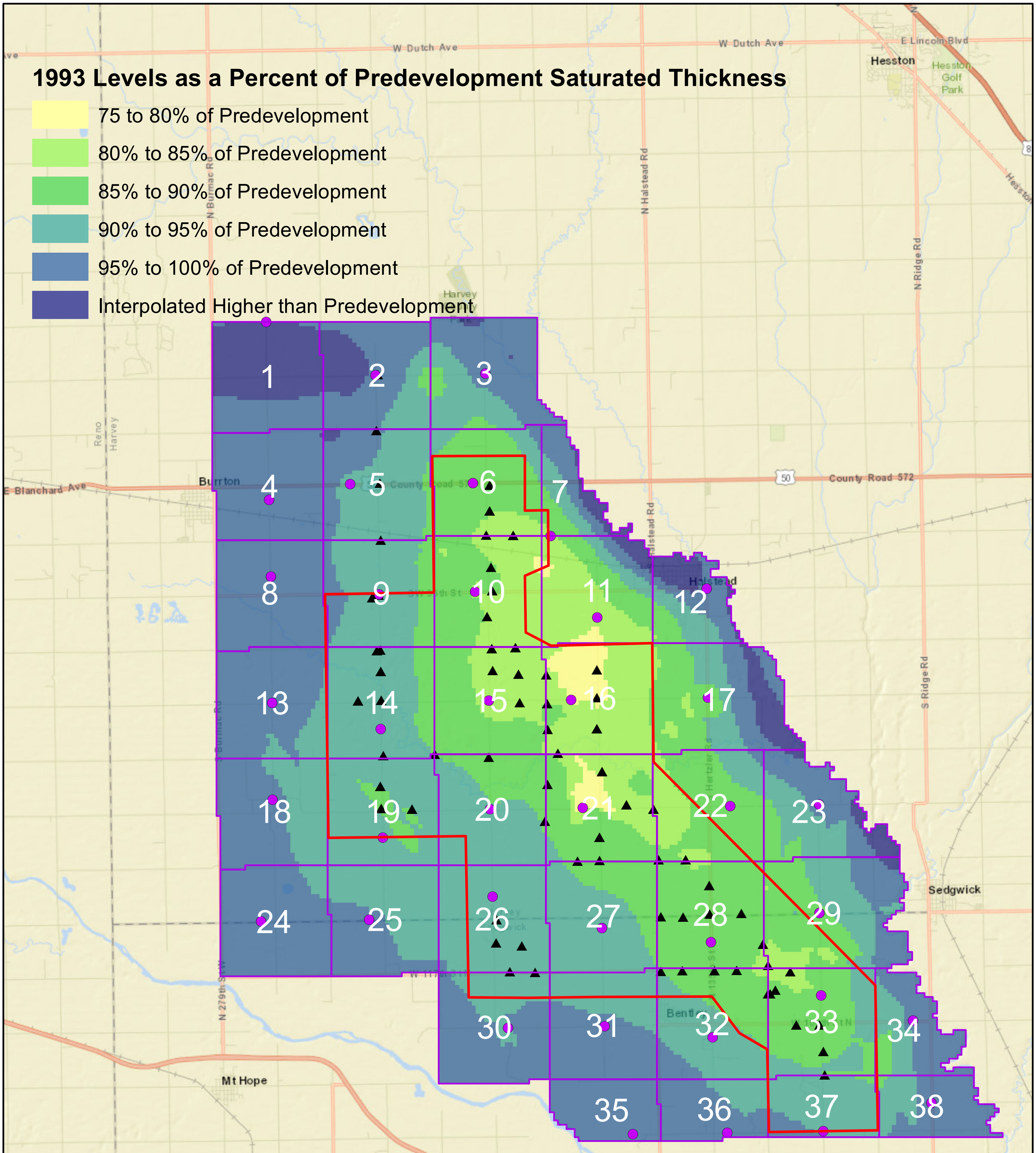


LEGEND

- IW-38A
- IW-38C
- Ground Surface Elevation
- 1993 Upper Aquifer Groundwater Elevation
- 1993 Lower Aquifer Groundwater Elevation
- Percent of Predevelopment Aquifer Thickness Remaining

BURNS McDONNELL

Hydrograph 38
Index Well Hydrographs
IW-38A & IW-38C
Stress Periods 1 through 10



Legend

- Boundary of Active Groundwater Model
- USGS Central Wellfield Study Area
- ASR Index Cells (Numbered)
- ASR Index Cell Monitoring Wells
- City of Wichita Groundwater Wells

N

1:150,000

0 0.5 1 2

Miles

CITY OF WICHITA

BURNS McDONNELL

Figure 9
1993 Levels as a Percentage of Predevelopment Saturated Thickness Clipped to ASR BSA

within the BSA as a percentage of predevelopment saturated thickness (Figure 9). By contrast, at the end of the 8-year simulated drought, the average remaining saturated thickness as a percentage of predevelopment saturated thickness was 86% for model cells in the CWSA and 89% for model cells for the entire BSA (see Figure 10 and Table 2-9).

Table 2-9: *Groundwater Modeling Results for 1% Drought Simulation*

	Drought Years								Recovery Years	
EBGWM 1% Drought Simulation Statistics	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**	**SP8**	**SP9**	**SP10**
ASR BSA avg Water Level Change from Starting Conditions (ft)	-1.8	-3.4	-5.2	-6.1	-7.3	-7.7	-7.9	-8.2	-6.1	-4.6
CWSA avg Water Level Change from Starting Conditions (ft)	-2.1	-4.4	-7.7	-8.9	-11.0	-11.2	-11.4	-11.6	-8.6	-6.3
ASR BSA Aquifer Condition (% Full)	93%	92%	91%	90%	90%	90%	90%	89%	91%	91%
CWSA Aquifer Condition (% Full)	90%	89%	87%	87%	86%	86%	86%	86%	87%	88%

Hydrographs have been generated for the model cells belonging to each of the existing ASR Index Well (IW) sites to record simulated water levels (Attachment I - Hydrographs 1 through 38). Further review of the hydrographs relative to January 1993 aquifer conditions indicates that groundwater levels within the EBWF are projected to fall below the current ASR minimum index levels during the simulated drought. Tables and maps illustrating when and where the January 1993 conditions are encountered have also been included within Attachment I.

2.6 Proposed Modifications to ASR Minimum Index Water Levels

The results of EBGWM 1% drought simulation confirm that after the drought, pumping demands will cause groundwater levels within the majority of the EBWF to drop below the currently permitted ASR minimum index level restrictions (Attachment I). This requires the City to seek reasonable alternative minimum index water levels for the existing ASR project that ensure recharge credits are available throughout periods of drought. The results of the EBGWM 1% drought simulation were utilized to calculate the lowest groundwater elevation for each IW site throughout the eight-year simulated drought.

within the BSA as a percentage of predevelopment saturated thickness (Figure 9). By contrast, at the end of the 8-year simulated drought, the average remaining saturated thickness as a percentage of predevelopment saturated thickness was 86% for model cells in the CWSA and 89% for model cells for the entire BSA (see Figure 10 and Table 2-9).

Table 2-9: *Groundwater Modeling Results for 1% Drought Simulation*

	Drought Years								Recovery Years	
EBGWM 1% Drought Simulation Statistics	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**	**SP8**	**SP9**	**SP10**
ASR BSA avg Water Level Change from Starting Conditions (ft)	-1.8	-3.4	-5.2	-6.1	-7.3	-7.7	-7.9	-8.2	-6.1	-4.6
CWSA avg Water Level Change from Starting Conditions (ft)	-2.1	-4.4	-7.7	-8.9	-11.0	-11.2	-11.4	-11.6	-8.6	-6.3
ASR BSA Aquifer Condition (% Full)	93%	92%	91%	90%	90%	90%	90%	89%	91%	91%
CWSA Aquifer Condition (% Full)	90%	89%	87%	87%	86%	86%	86%	86%	87%	88%

Hydrographs have been generated for the model cells belonging to each of the existing ASR Index Well (IW) sites to record simulated water levels (Attachment I - Hydrographs 1 through 38). Further review of the hydrographs relative to January 1993 aquifer conditions indicates that groundwater levels within the EBWF are projected to fall below the current ASR minimum index levels during the simulated drought. Tables and maps illustrating when and where the January 1993 conditions are encountered have also been included within Attachment I.

2.6 Proposed Modifications to ASR Minimum Index Water Levels

The results of EBGWM 1% drought simulation confirm that after the drought, pumping demands will cause groundwater levels within the majority of the EBWF to drop below the currently permitted ASR minimum index level restrictions (Attachment I). This requires the City to seek reasonable alternative minimum index water levels for the existing ASR project that ensure recharge credits are available throughout periods of drought. The results of the EBGWM 1% drought simulation were utilized to calculate the lowest groundwater elevation for each IW site throughout the eight-year simulated drought.

To account for variability in actual drought conditions such as initial water resource conditions (both of Cheney reservoir and the EBWF), an additional contingency was subtracted from the calculated lowest groundwater elevations encountered during the groundwater modeling simulation for each IW site to develop the proposed ASR minimum index levels (see Table 2-10). Table 2-11 contains the proposed ASR minimum index elevations, and a comparison to the existing index levels. In addition, Figure 11 illustrates the average remaining aquifer saturated thickness for each Index Cell under the proposed levels as a percentage of predevelopment aquifer thickness. The City is requesting that the proposed minimum index levels be applied to all existing ASR Phase II infrastructure, currently pending ASR applications, and potentially future ASR infrastructure. Modifications to the minimum index level on permits covering ASR Phase I infrastructure are not being requested at this time.

2.7 Summary

The City of Wichita developed the ASR project with the goal of improving long-term aquifer sustainability and lowering drought vulnerability. Through extensive data analysis and groundwater modeling, the City has confirmed that groundwater levels will drop below the currently permitted ASR minimum index water levels during a prolonged drought, preventing the withdrawal of ASR credits when they are needed most. The groundwater modeling results indicate that at the end of a simulated 1% drought the aquifer will be approximately 86% full across the EBWF area and 89% full across the entire project basin storage area. To address the concern of recharge credits becoming unavailable during drought the proposed ASR minimum index water level elevations illustrated in Table 2-11 are being submitted for consideration.

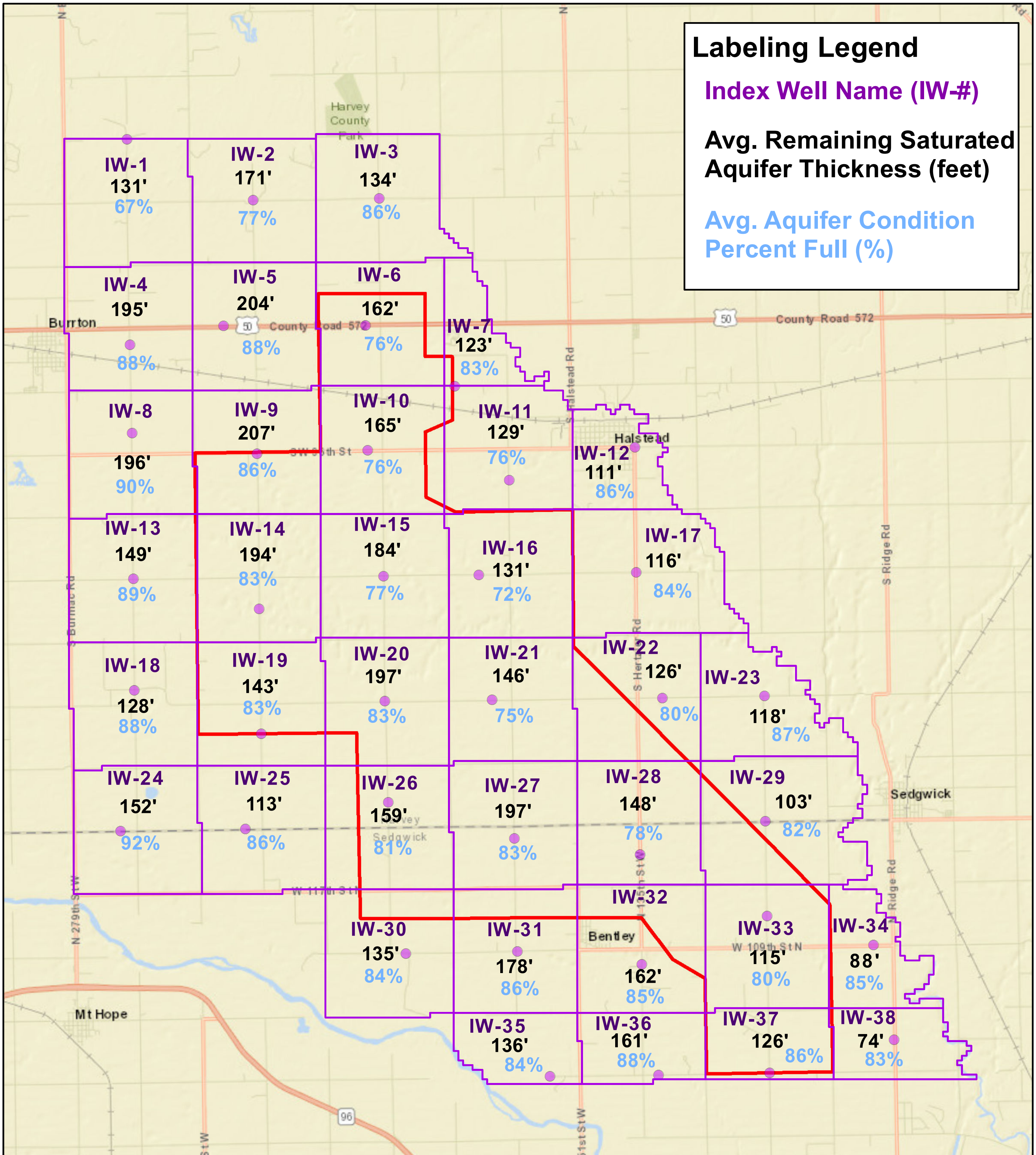
Table 2-10: *Development of Proposed ASR Minimum Index Levels*

		Minimum Index Level Elevations			
Index Well No.	Minimum Drought Model Elevation (feet)	Existing Level (1993 Level) (feet)	Basis for Proposed Level[1]	Contingency Added (feet)	Proposed Levels[2] (feet)
IW01C	1429.14	1413.42	Existing	20	1390
IW02C	1407.96	1410.52	Existing	10	1390
IW03C	1389.76	1396.93	Modeled	10	1380
IW04C	1420.35	1417.6	Existing	10	1407
IW05C	1408.21	1407.23	Modeled	10	1398
IW06C	1380.42	1388.74	Modeled	10	1370
IW07C	1372.79	1369.95	Existing	10	1360
IW08C	1418.06	1417.56	Modeled	10	1408
IW09C	1394.74	1394.1	Modeled	10	1385
IW10C	1368.08	1375.09	Modeled	10	1358
IW11C	1365.27	1363.75	Existing	10	1354
IW12C	1370.6	1365.78	Existing	10	1355
IW13C	1417.21	1418.27	Modeled	10	1407
IW14C	1386.6	1396.56	Modeled	10	1377
IW15C	1364.07	1369.75	Modeled	10	1354
IW16C	1354.11	1360.21	Modeled	10	1344
IW17C	1363.16	1360.59	Existing	10	1351
IW18C	1417.28	1421.4	Modeled	10	1407
IW19C	1396.07	1398.95	Modeled	10	1386
IW20C	1373.34	1376.05	Modeled	10	1363
IW21C	1352.12	1363.04	Modeled	10	1342
IW22C	1353.79	1354.92	Modeled	10	1344
IW23C	1356.94	1355.55	Existing	10	1345
IW24C	1416.31	1418.96	Modeled	10	1406
IW25C	1403	1407.27	Modeled	10	1393
IW26C	1380.64	1374.89	Existing	10	1364
IW27C	1363.16	1360.92	Existing	10	1350
IW28C	1343.8	1349.14	Modeled	10	1334
IW29C	1350.36	1349.51	Modeled	10	1340
IW30C	1386.13	1379.77	Existing	10	1370
IW31C	1376.18	1366.06	Existing	10	1356
IW32C	1362.86	1356.51	Existing	10	1346
IW33C	1348.93	1344.68	Existing	10	1334
IW34C	1344.62	1344.24	Modeled	10	1335
IW35C	1373.74	1366.76	Existing	10	1356
IW36C	1363.02	1360.13	Existing	10	1350
IW37C	1352.85	1350.51	Existing	10	1340
IW38C	1343.19	1344.65	Modeled	10	1333

[1] Existing refers to the Existing 1993 Level, Modeled refers to the Minimum Drought Model Elevation.
[2] Values were rounded to the nearest foot.

Table 2-11: *Proposed ASR Minimum Index Levels*

	Minimum Index Level Elevations				
Index Cell No.	Existing Level (1993 Level) (feet)	Proposed Level (feet)	Existing versus Proposed (feet)	Proposed Level - Remaining Aquifer Saturated Thickness (feet)	Proposed Level as a Percentage of Predevelopment Saturated Thickness (%)
1	1413.42	1390.00	-23.42	131	67%
2	1410.52	1390.00	-20.52	171	77%
3	1396.93	1380.00	-16.93	134	86%
4	1417.60	1407.00	-10.60	195	88%
5	1407.23	1398.00	-9.23	204	88%
6	1388.74	1370.00	-18.74	162	76%
7	1369.95	1360.00	-9.95	123	83%
8	1417.56	1408.00	-9.56	196	90%
9	1394.10	1385.00	-9.10	207	86%
10	1375.09	1358.00	-17.09	165	76%
11	1363.75	1354.00	-9.75	129	76%
12	1365.78	1355.00	-10.78	111	86%
13	1418.27	1407.00	-11.27	149	89%
14	1396.56	1377.00	-19.56	194	83%
15	1369.75	1354.00	-15.75	184	77%
16	1360.21	1344.00	-16.21	131	72%
17	1360.59	1351.00	-9.59	116	84%
18	1421.40	1407.00	-14.40	128	88%
19	1398.95	1386.00	-12.95	143	83%
20	1376.05	1363.00	-13.05	197	83%
21	1363.04	1342.00	-21.04	146	75%
22	1354.92	1344.00	-10.92	126	80%
23	1355.55	1345.00	-10.55	118	87%
24	1418.96	1406.00	-12.96	152	92%
25	1407.27	1393.00	-14.27	113	86%
26	1374.89	1364.00	-10.89	159	81%
27	1360.92	1350.00	-10.92	197	83%
28	1349.14	1334.00	-15.14	148	78%
29	1349.51	1340.00	-9.51	103	82%
30	1379.77	1370.00	-9.77	135	84%
31	1366.06	1356.00	-10.06	178	86%
32	1356.51	1346.00	-10.51	162	85%
33	1344.68	1334.00	-10.68	115	80%
34	1344.24	1335.00	-9.24	88	85%
35	1366.76	1356.00	-10.76	136	84%
36	1360.13	1350.00	-10.13	161	88%
37	1350.51	1340.00	-10.51	126	86%
38	1344.65	1333.00	-11.65	74	83%



Legend

- ASR Index Cells (Numbered)
- USGS Central Wellfield Study Area
- ASR Index Well Locations

N

1:130,000

0 0.5 1 2

Miles

Figure 11

Average Aquifer Conditions by Index Cell at Modified ASR Minimum Index Level Elevations

To account for variability in actual drought conditions such as initial water resource conditions (both of Cheney reservoir and the EBWF), an additional contingency was subtracted from the calculated lowest groundwater elevations encountered during the groundwater modeling simulation for each IW site to develop the proposed ASR minimum index levels (see Table 2-10). Table 2-11 contains the proposed ASR minimum index elevations, and a comparison to the existing index levels. In addition, Figure 11 illustrates the average remaining aquifer saturated thickness for each Index Cell under the proposed levels as a percentage of predevelopment aquifer thickness. The City is requesting that the proposed minimum index levels be applied to all existing ASR Phase II infrastructure, currently pending ASR applications, and potentially future ASR infrastructure. Modifications to the minimum index level on permits covering ASR Phase I infrastructure are not being requested at this time.

2.7 Summary

The City of Wichita developed the ASR project with the goal of improving long-term aquifer sustainability and lowering drought vulnerability. Through extensive data analysis and groundwater modeling, the City has confirmed that groundwater levels will drop below the currently permitted ASR minimum index water levels during a prolonged drought, preventing the withdrawal of ASR credits when they are needed most. The groundwater modeling results indicate that at the end of a simulated 1% drought the aquifer will be approximately 86% full across the EBWF area and 89% full across the entire project basin storage area. To address the concern of recharge credits becoming unavailable during drought the proposed ASR minimum index water level elevations illustrated in Table 2-11 are being submitted for consideration.

1. Physical recharge activities will continue to occur during periods when aquifer conditions facilitate adequate physical recharge capacity defined by an annual ASR Operations Plan.
2. The rate of accrual of all recharge credits cannot exceed the constructed physical diversion capacity of the ASR system including direct surface water diversions and future bank storage wells, and will be limited to the rate and quantity authorized by Water Right No. 46627.
3. ASR Phase I RRW's are not eligible to receive AMCs, only physical recharge at Phase I RRW's or recharge basins will result in the development of an ASR recharge credit.
4. The estimated aquifer storage volume in the CWSA during initial implementation of the ILWSP by the City and during the conceptual development of the ASR program is estimated at 120,000 AF (see Attachment H, page 13) therefore the combined total quantity of AMCs and physical recharge credits cannot exceed 120,000 AF. The proposed 120,000 AF limit on the combined total quantity of AMCs and physical recharge credits represents an estimated 11.7% of total available aquifer storage within the CWSA
5. The fundamental differences between the processes used to generate physical recharge credits and AMCs will require an alternative or modified accounting process for AMCs.
6. AMCs would be accumulated based on the metered quantity of water diverted from the Little Arkansas River via direct surface water diversions or water captured via bank storage wells and sent directly to the City.
7. A straight-forward spreadsheet accounting process will be adopted similar to other existing water management conservation programs in the State.
    a. A uniform and equal annual distribution throughout the EBWF to all authorized City points of diversion within the EBWF based on the annual quantity of water diverted from the Little Arkansas River sent directly to the Wichita MWTP.
    b. Uniform distribution of AMCs to all authorized City points of diversion within the wellfield reasonably reflects historic wellfield operations at locations where groundwater has effectively been left in storage within the aquifer due to the development and utilization of Little Arkansas River flows.
    c. After distribution and assignment of AMC quantities by point of diversion, an acceptable AMC accounting process will track the quantity of AMCs stored within each Index Cell.

3.5 ASR Physical Recharge & ASR Operations Plan

To illustrate the City's commitment to conducting physical recharge activities during periods when the aquifer permits physical recharge capacity, the City is proposing the use of an annual ASR Operations

Plan. The operations plan will utilize groundwater level monitoring and the calculated recharge capacity of the ASR recharge well network to determine the quantity and eligibility to accumulate AMCs. The ASR Phase II Water Treatment Plant (ASR WTP) can operate at either 15 or 30 MGD. The City is proposing that if the available physical recharge capacity of the ASR recharge well network drops below a cumulative total of 5 MGD that all water from the ASR WTP sent to town would be considered eligible for conversion to an AMC. The 5 MGD minimum for physical recharge capacity is considerate of the operational limitations at lower flows (pipeline residence times, well redevelopment frequency, pipeline flushing requirements, and system startup and shutdown requirements). During periods where the calculated physical recharge capacity of the ASR recharge well network exceeds 5MGD, the physical recharge capacity of the recharge well network would be subtracted from total production of the ASR WTP to calculate the quantity of water eligible for conversion to an AMC (see examples below).

Example 1 – High Groundwater Levels Limited Recharge Capacity

ASR Physical Recharge Capacity – 4 MGD

ASR WTP Running at 15 MGD – 15 MGD being sent to City to meet demands

Amount of ASR WTP water eligible for AMC **– 15 MGD**

Example 2 – Moderate Groundwater Levels with Moderate Recharge Capacity

ASR Physical Recharge Capacity – 10 MGD

ASR WTP Running at 15 MGD – 5 MGD being sent to City to meet demands

Max amount of ASR WTP water eligible for AMC **– 5 MGD**

Example 3 – Lowered Groundwater Levels with Available Recharge Capacity

ASR Physical Recharge Capacity – 15 MGD

ASR WTP Running at 30 MGD – 15 MGD being sent to City to meet demands

Max amount of ASR WTP water eligible for AMC **– 15 MGD**

To determine the physical recharge capacity of the ASR recharge well network, the City proposing the implementation of an annual water level monitoring program in conjunction with a recharge capacity calculation table. For each of the City’s ASR recharge wells, the individual sustainable recharge capacity is a function of static groundwater elevation, the maximum feasible limiting groundwater elevation below land surface, constructed wellhead infrastructure, and specific injectivity. During January of each year, the City will measure and document static groundwater levels at each of the existing ASR Index Wells and at each of the City’s ASR recharge wells. The static groundwater elevations obtained from the ASR recharge well network during January of each year will be used to generate an annual operations table that will calculate the available recharge capacity for each individual ASR recharge well and the cumulative capacity of the ASR recharge well network system. The annual operations table will utilize the following variables and terms:

i. *Static Groundwater Elevation* – Groundwater elevation will be gathered at each ASR recharge well location during January of each year when the well is off to eliminate or mitigate the effects of observing drawdown.

ii. *Maximum Groundwater Elevation* – The City's ASR operations protocols prevents recharge when groundwater levels reach ten feet below ground surface to protect wellhead equipment and surrounding infrastructure.

iii. *Sustainable Specific Injectivity* – During recharge operations, the long term sustainable recharge rate of a well can be divided by the rise in water level in the well column from static groundwater conditions to calculate a maximum sustained long term specific injectivity value in the units of gallons per minute per foot. This number is sourced from historic observations at each well during actual ASR recharge well operations.

iv. *Maximum Calculated Sustainable Recharge Rate* - The maximum sustainable recharge rate for each ASR well can be calculated as (Maximum Groundwater Elevation - Static Groundwater Elevation) x (Sustainable Specific Injectivity).

v. *Maximum Well Infrastructure Recharge Rate* – The City's recharge wells utilize recharge down tubes of various sizes to inject water below static groundwater level. The variety in sizes of the down tubes allows for recharge operations at various rates and pressures to best match the current recharge capacity of each well. The maximum recharge rate for each of the City's ASR wells is governed by the size and total number of recharge down tubes which have been designed and constructed to match the maximum anticipated recharge capacity of the well during depleted aquifer conditions.

vi. *Minimum Well Infrastructure Recharge Rate* – The City's recharge wells utilize recharge down tubes of various sizes to inject water below static groundwater level. The variety in sizes of the down tubes allows for recharge operations at various rates and pressures to best match the current recharge capacity of the well. The minimum recharge rate for each of the City's ASR wells is therefore limited by the rate available by using the smallest diameter recharge downtube available at each wellhead.

During periods where the maximum calculated sustainable recharge rate is less than the minimum well infrastructure recharge rate it is not practical to conduct physical recharge at the wellhead therefore the available physical recharge rate of the well is effectively zero. In addition, groundwater levels are above the maximum groundwater elevation (10 feet below land surface) the available physical recharge rate of the well is zero. Alternatively, if the maximum calculated sustainable recharge rate exceeds that of the minimum limits of the recharge well infrastructure, the available physical recharge capacity for each recharge well will be considered the maximum calculated sustainable recharge rate (see examples below).

Example 1 – High Groundwater Levels - No Available Physical Recharge Capacity

Well A – Land Surface Elevation – 1,420 feet

Well A – Static Groundwater Elevation – 1,395 feet (25 feet bls)

Well A – Maximum Groundwater Elevation - 1,410 feet (10 feet bls)

Well A – Sustainable Specific Injectivity – 6 gpm/foot

Well A – Maximum Calculated Sustainable Recharge Rate

(1410 – 1395) x (6 gpm/foot) = 90 gpm

Well A – Minimum Well Infrastructure Recharge Rate = 125 gpm

Well A – Available Physical Recharge Capacity = **0 gpm**

Since the Maximum Sustainable Injection of 90 gpm is less than the Minimum Infrastructure Injection Capacity of 125 gpm the Available Recharge Capacity is 0 gpm.

Example 2 – Lowered Groundwater Levels - Physical Recharge Capacity Available

Well B – Land Surface Elevation – 1,420 feet

Well B – Static Groundwater Elevation – 1,385 feet (35 feet bls)

Well B – Maximum Groundwater Elevation - 1,410 feet (10 feet bls)

Well B – Sustainable Specific Injectivity – 10 gpm/foot

Well B – Maximum Calculated Sustainable Recharge Rate

(1410 – 1385) x (10 gpm/foot) = 250 gpm

Well B – Minimum Well Infrastructure Recharge Rate = 125 gpm

Well B – Available Physical Recharge Capacity = **250 gpm**

Since the Maximum Sustainable Injection Rate of 250 gpm is greater than the Minimum Infrastructure Injection Capacity of 125 gpm the Available Recharge Capacity is 250 gpm.

The available physical recharge capacities for each of the recharge wells included in the ASR recharge well network will then be totaled to represent the physical recharge capacity of the ASR system. The City will assemble and submit an operations table as a part of the accounting process each year as the formal estimate of the total physical recharge capacity of the ASR system so that the quantity of water eligible for AMCs can be considered during the AMC accounting process. The operations table is intended as a guide to estimate the amount available physical recharge capacity available in the ASR recharge well network. Actual ASR recharge operations will need to remain flexible, and the operations table will be a living document that allows for improved representation of the ASR recharge well network (changes in the number of recharge wells, the availability of recharge well equipment, increases or decreases in specific injectivity, improvements to recharge well infrastructure, etc.). An example of a proposed operations table has been completed based on January 2016 groundwater levels (see Figure 13).

3.6 Outcome Based Management of Water Resources

The City's long-standing history of responsible water resources management and the continued outcome based management of available water supplies merits an alternative procedure for establishing ASR recharge credits during periods of high groundwater levels. This proposal for the consideration of AMCs presents a unique opportunity to achieve sustainable management of multiple high value regional water resources (Table 3-1).

The added flexibility granted by AMCs would City would reinforce the City's commitments outcome based management of water resources:

- The City of Wichita remains committed to optimizing the use of all available water supply resources both in times of abundance and times of drought.
- The City remains committed to making water resource management practices that are governed by outcome based results focused on the long-term sustainability of all available water supplies.
- The City will continue to maintain an ASR operational priority focused on generation of physical recharge credits where and when possible.
- The ability to develop and recover AMCs results in an aquifer management strategy focused on maintaining the maximum quantity of water possible in aquifer storage within the EBWF.

The capacity to maintain aquifer levels as full as possible during normal periods provides multiple local and regional water quality benefits by limiting migration of the Burrton chloride plume, limiting natural

Figure 14 - Example ASR Operations Plan
Based on 2016 City of Wichita Groundwater Level Measurements

Recharge Well Name	Static Groundwater Level Measured Below Top of Well Casing January 2016	Static Groundwater Elevation Measured January 2016	Maximum Groundwater Elevation at 10' Below Ground Surface	Water Column Available for Recharge	Sustainable Specific Injectivity	Maximum Calculated Sustainable Recharge Rate	Maximum Well Infrastructure Recharge Rate	Minimum Well Infrastructure Recharge Rate	Available Physical Recharge Capacity
	(feet)	(feet)	(feet)	(feet)	gpm/ft	gpm	gpm	gpm	gpm
MR02 (MK61)	37.60	1396.90	1420.3	23.40	5	117	1,000	125	0
MR04 (MK80)	37.69	1393.97	1418.42	24.45	8	196	1,000	125	196
MR06 (MK62)	34.45	1401.45	1421.7	20.25	8	162	1,200	150	162
MR08 (MK63)	28.61	1397.19	1411.6	14.41	12	173	1,100	150	173
MR10 (MK56)	29.96	1395.94	1411.7	15.76	8	126	1,000	125	126
MR11 (MK11)	28.96	1393.84	1409.65	15.81	8	126	700	150	0
MR13 (MK57)	23.30	1395.9	1405.1	9.20	15	138	1,200	250	0
MR14 (MK14)	29.00	1390.2	1405.51	15.31	11	168	800	225	0
MR18 (MK64)	23.04	1384.99	1390.7	5.71	10	57	1,000	150	0
MR19 (MK19)	25.16	1378.72	1391.68	12.96	7	91	350	150	0
MR20 (MK65)	25.00	1376.2	1384.4	8.20	7	57	1,200	150	0
MR22 (MK66)	25.41	1371.79	1381.1	9.31	6	56	700	150	0
MR23 (MK67)	27.60	1368.6	1377	8.40	7	59	700	100	0
MR26 (MK58)	23.89	1382.57	1391.3	8.73	13	113	1,200	150	0
MR42 (MK68)	26.54	1404.72	1416.4	11.68	6	70	700	100	0
MR43 (MK69)	18.67	1412.59	1414.1	1.51	8	12	700	100	0
MR44 (MK70)	16.20	1415.06	1415	0.00	7	0	625	50	0
MR45 (MK71)	17.34	1409.46	1412.6	3.14	14	44	400	125	0
MR47 (MK60)	17.88	1405.82	1409.5	3.68	5	18	500	50	0
MR48 (MK59)	25.94	1383.76	1395.5	11.74	10	117	1,100	175	0
MR50 (MK50)	24.94	1385.24	1398.25	13.01	4	52	325	250	0
MR51 (MK51)	20.37	1391.13	1399.34	8.21	4	33	200	100	0
MR55 (MK73)	15.31	1391.89	1393	1.11	30	33	1,200	225	0
MR56 (MK74)	15.96	1410.24	1412	1.76	13	23	525	75	0
MR57 (MK75)	25.62	1398.08	1409.5	11.42	4	46	500	50	0
MR58 (MK76)	23.98	1394.65	1402.6	7.95	12	95	1,200	125	0
MR59 (MK77)	24.74	1388.97	1396.6	7.63	7	53	650	100	0
MR60 (MK78)	32.27	1389.93	1408	18.07	9	163	1,200	150	163
MR61 (MK79)	25.02	1389.62	1399.9	10.28	11	113	1,000	150	0
					Total (GPM)	**2,513**	**23,975**	**3,975**	**819**
					Total (MGD)	**3.62**	**34.52**	**5.72**	**1.18**

BURNS McDONNELL

August 21, 2019

Brian McLeod
Deputy City Attorney
City of Wichita
455 N. Main, 13th Floor
Wichita, KS 67202

Re: Review of ASR Permit Modification Expert Report submitted by Carl E Nuzman P.E., P.Hg

Introduction and Purpose
Burns & McDonnell has been retained by the City of Wichita (City) to provide expert witness hearing testimony in the matter of the City's ASR Permit Modification Proposal (Proposal). Also, at the request of the City a review and critique of the technical expert report submitted by Carl E Nuzman P.E., P.Hg has been completed and summarized below:

Review of the Expert Report submitted by – Carl E Nuzman P.E., P.Hg:

Expert Report, page 2 - *During extended drought conditions, artificial recharged [sic] is needed for the City to use its allocated appropriation quantity of water established under senior water rights. As precipitation returns to more normal annual precipitation and streamflow's are available, the need for artificial recharge becomes limited.*

It is assumed that in the statement described above "*senior water rights"* the Expert Report is referring to the City's existing base 40,000 Acre-Feet of groundwater appropriations under Water Right HV006, 388, and 1006. The statement that "*During extended drought conditions, artificial recharged [sic] is needed for the City to use its allocated appropriation quantity of water established under senior water rights"* is incorrect. Artificial recharge is not required for the City to pump water from the base groundwater appropriations under HV006, 388, and 1006.

Expert Report, page 2 - *The City is now asking the Chief Engineer of the Division of Water Resources, KDA, to approve special groundwater recharge credits, now called Alternative Maintenance Credits (AMC) to the Equus Beds Aquifer for the direct use of surface water from Little Arkansas River directly to a water treatment plant for public consumption. This action if approved would have the effect of illegally increasing the available appropriation of water under existing senior water rights of the City of Wichita to the potential detriment of other appropriators from the same local source of supply.*

The nomenclature applied to AMCs by the Expert Report does not match that within the Proposal, mainly the use of "Alternative Maintenance Credit" rather than Aquifer Maintenance Credit (AMC). For the purpose of this review it is assumed the Expert Report intentions were to refer to the Proposal definition AMCs. It is also assumed that the Expert Report when referring to the City's "*senior water rights"* is referring to the City's existing base 40,000 Acre-Feet of groundwater appropriations under Water Right HV006, 388, and 1006.

The conclusion that the Proposal *"would have the effect of illegally increasing the available appropriation of water under existing senior water rights of the City"* is incorrect. There is no statement or request within the Proposal that submits a request for an increase in the authorized quantity of HV006, 388, or 1006. The establishment and recovery of ASR credits is managed by an annual ASR Accounting

Burns & McDonnell

process and individual ASR recharge and recovery permits managed by the Division of Water Resources (DWR). The recovery of ASR credits is specifically authorized by these separate DWR water permits which do not overlap the priority to pump water under the City's base water rights.

Regarding the conclusion that "*This action if approved would have the effect of illegally increasing the available appropriation of water under existing senior water rights of the City of Wichita to the potential detriment of other appropriators from the same local source of supply.*" An evaluation of this finding was not feasible as there were no mathematical calculations, analyses, or statistics found within the Expert Report in support of the conclusion. The finding that the Proposal would cause "*detriment of other appropriators from the same local source of supply.*" was not supported by any additional documentation to define "*same local source of supply*" or what "*appropriators*" would receive such "*detriment*", or to what magnitude such "*detriment*" was predicted to occur.

Burns & McDonnell appreciates the opportunity to be of service to the City. Should you have any questions on the review of the Expert Report please feel free to contact me directly.

Sincerely,

Daniel Clement, P.G.
Senior Hydrogeologist

DWC/dwc