Impact of Proposed SNWA Wells on CPB Water Rights in Northern Spring Valley, Nevada

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August 26, 2011

Submitted to:

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Introduction

Corporation of the Presiding Bishop of The Church of Jesus Christ of Latter-day Saints (CPB), a Utah corporation sole, owns and operates a cattle ranch in northern Spring Valley, Nevada. The ranch includes three deeded ranches: the 4,760 acre Cleveland Ranch, the 1,480 acre Rogers Ranch, and the 160 acre Negro Creek Homestead (Figure 1). The ranch headquarters are located on the Cleveland Ranch. The Ranch also grazes cattle on three Bureau of Land Management (BLM) grazing allotments. The public grazing allotments include the 13,527 acre Negro Creek Allotment, the 12,436 acre Cleveland Ranch Allotment, and the 13,445 acre Bastian Creek Allotment. All ranching operations are herein known collectively as “the ranch”. As part of the ranching operation the CBP has 2082 acre feet annually (AFA) of supplemental groundwater irrigation rights, 26,400 AFA of claims of vested irrigation surface water rights and 5,071 AFA or certified or deeded surface water rights, and numerous stockwater rights that allow the ranch to utilize springs on the BLM allotments as an integral part of cattle grazing.

The names and locations of the CPB water rights are shown in Figure 2 and Table 1. The water rights are described in detail in exhibits CPB_001 and CPB_006. The CPB water rights in Table 1 are divided into two categories: numbers 1-36 (shown in green on Figure 2) represent existing permitted water rights and numbers 37-56 (shown in light blue in Figure 2 and labeled “vested claims”) are springs and wells for which CPB recently filed claims for vested water rights. At the time that this study was performed, the sites did not have permit numbers and the identifiers “PXX” in the permit column of Table 1 were used for internal referencing in the model files and in this report. Just prior to printing and delivery of this report, the claims were processed by the Nevada State Engineer and permit numbers were issued for 16 of the vested claims. These claims are identified in the addendum immediately following Table 1. The first two columns of the addendum list the interim name and ID used to identify each of 16 sites in the first part of Table 1 and in all subsequent text, figures, and tables in the remainder of this report and in the model input files contained on the data disc submitted as exhibit CPB_012. The last two columns of the addendum contain the newly registered names and permit numbers.

The Southern Nevada Water Authority (SNWA) has made application to appropriate 91,224 AFA from 19 points of diversion in Spring Valley, Nevada. CPB has protested 12 of these points of diversion, because these diversions will impact existing CPB water rights and will have a deleterious impact on the ranching operation. Of these 12, four (shown in red in Figure 2) were previously denied by the State Engineer in 2007.

This document has been prepared in support of the CPB protest. To this end this report contains the following sections: the geologic and hydrogeologic setting, a review of existing groundwater budgets including recharge, ET and perennial yield, an analysis of SNWA water rights applications relative to ET distribution and perennial yield, and an analysis of SNWA’s numerical groundwater flow model.

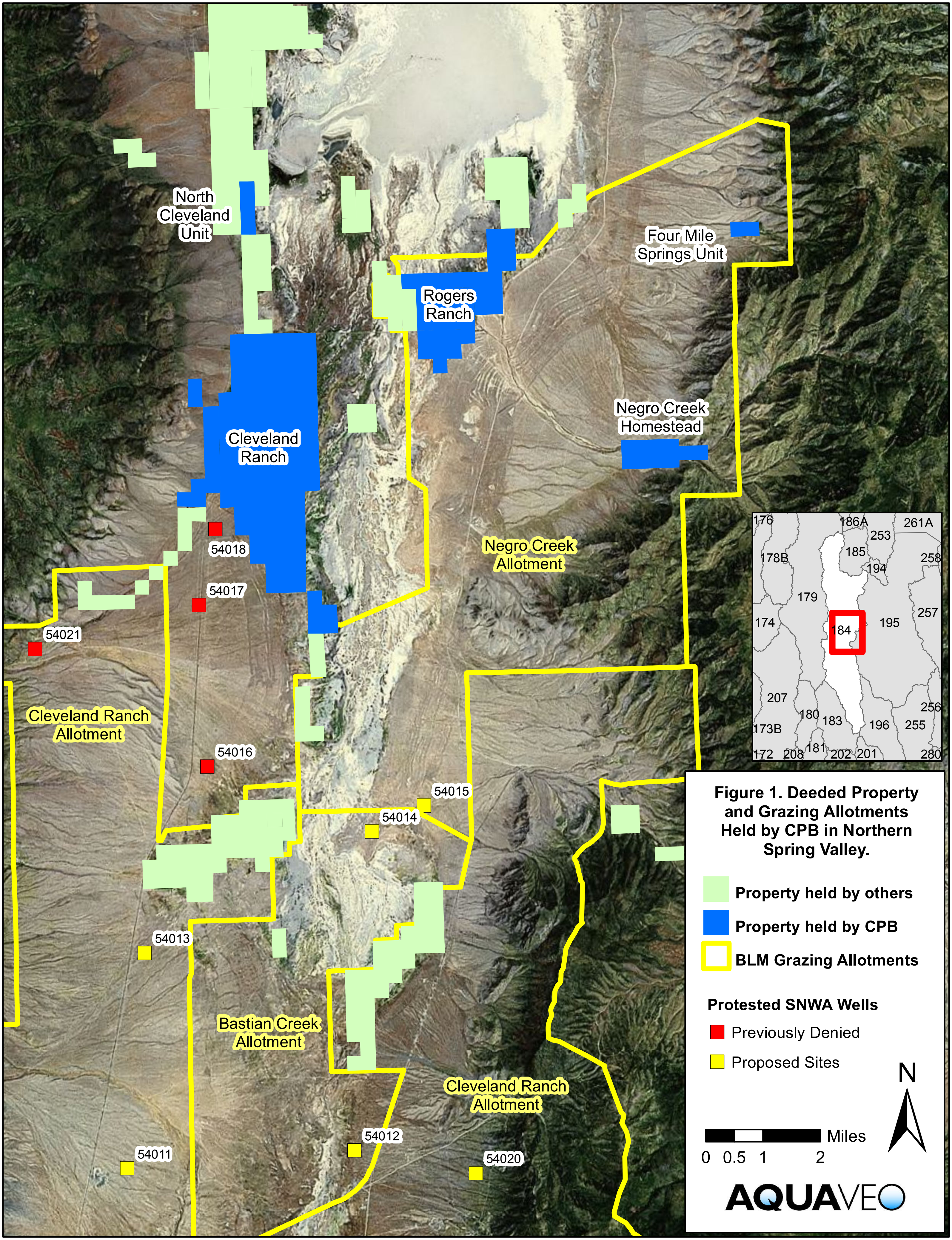

Figure 1. Deeded Property and Grazing Allotments Held by CPB in Northern Spring Valley.

Table 1 Summary of CPB water rights in northern Spring Valley, Nevada.

#	Name	Permit	Type	Location	UTM X	UTM Y	Elev [ft]
1	Six Mile Spring	1724	Spring	mountain block	731605.4	4357838.7	6885.9
2	Cleveland Creek; Winter	2852	Stream	alluvial fan	715785.9	4346688.8	5751.4
3	Negro Creek	3186	Stream	valley floor	723819.2	4352260.1	5607.3
4	Choke Cherry Spring	3793	Spring	mountain block	731832.9	4347539.3	6840.8
5	Smudge Spring	3926	Spring	mountain block	730495.7	4346734.6	6760.6
6	Four Mile Spring	3927	Spring	mountain block	732052.1	4354638.1	6793.2
7	Mud Springs 1,2, and 3	3973	Spring	valley floor	721791.3	4349492.7	5585.6
8	Four Mile Spring	5028	Spring	mountain block	732052.1	4354638.1	6793.2
9	Granite Spring	5713	Spring	mountain block	728268.9	4343714.1	6798.1
10	Negro Creek	8393	Stream	valley floor	724595.3	4351469.7	5664.3
11	South Millick Spring	8721	Spring	valley floor	725119.3	4353625.7	5584.0
12	Negro Creek	10487	Stream	valley floor	724506.0	4351523.4	5662.7
13	Bastian Creek Allotment	18841	Well	valley floor	718357.2	4336457.8	5643.6
14	Bastian Creek Allotment	18842	Well	valley floor	718370.4	4334117.9	5675.9
15	Bastian Creek Allotment	18843	Well	valley floor	718244.7	4335320.9	5652.8
16	Cleveland Creek Supp	54204	Well	valley floor	717635.2	4346715.8	5654.7
17	Cleveland Creek Supp	54205	Well	valley floor	715830.6	4346880.9	5739.8
18	T Property	67333	Well	valley floor	722431.7	4352040.6	5571.1
19	Rogers Area Supp	69726	Well	valley floor	723646.7	4352064.3	5606.6
20	Rogers Area Supp	69727	Well	valley floor	724034.6	4352483.7	5604.5
21	Cleveland Creek	V00790	Stream	alluvial fan	715210.8	4345126.6	5899.6
22	Negro Creek	V01080	Stream	mountain block	730532.9	4348603.8	6364.4
23	Cleveland Creek, Springs	V01217	Stream	alluvial fan	715582.1	4346189.4	5797.4
24	Stevens Creek	V01218	Stream	a. fan/valley floor	717119.5	4351447.5	5643.3
25	Murphy Springs	V02817	Spring	valley floor	717462.1	4347893.3	5604.6
26	Big Reservoir Springs No. 1	V02818	Spring	valley floor	717983.1	4347638.8	5594.0
27	Big Reservoir Springs No. 2	V02819	Spring	valley floor	717891.2	4347507.5	5600.0
28	Big Reservoir Springs No. 3	V02820	Spring	valley floor	718221.5	4347194.8	5593.8
29	Big Reservoir Springs No. 4	V02821	Spring	valley floor	718037.7	4346578.0	5625.5
30	Big Reservoir Springs No. 5	V02822	Spring	valley floor	718413.9	4346971.7	5593.0
31	Big Reservoir Springs No. 6	V02823	Spring	valley floor	718479.5	4346680.8	5593.7
32	Big Reservoir Springs No. 7	V02824	Spring	valley floor	718177.7	4345939.3	5645.8
33	Big Reservoir Springs No. 8	V02825	Spring	valley floor	718263.0	4346368.0	5620.6
34	Big Reservoir Springs No. 9	V02826	Spring	valley floor	718389.9	4346223.7	5619.1
35	Big Reservoir Springs No. 10	V02827	Spring	valley floor	718442.4	4346024.6	5621.5
36	Big Reservoir Springs No. 11	V02828	Spring	valley floor	718993.5	4346271.8	5593.8
37	South Bastian Spring 2	*P01*	Spring	valley floor	718344.1	4334407.1	5672.1
38	South Bastion Spring	*P02*	Spring	valley floor	718344.1	4334814.6	5663.1
39	Cleveland Ranch Spring - North	*P03*	Spring	valley floor	718646.0	4345297.0	5628.0
40	Cleveland Ranch Spring - South	*P04*	Spring	valley floor	719532.0	4343655.0	5618.0

Table 1, cont.

#	Name	Permit	Type	Location	UTM X	UTM Y	Elev [ft]
41	Cleveland Well	*P05*	Well	alluvial fan	716362.2	4342684.1	5862.7
42	Fera Well	*P06*	Well	valley floor	723173.1	4344252.4	5612.6
43	Layton Spring	*P08*	Spring	valley floor	720060.8	4331758.4	5692.2
44	North Cleveland Unit Spring	*P09*	Spring	valley floor	717483.0	4355319.8	5563.9
45	North Millick Spring	*P10*	Spring	valley floor	725678.2	4353967.4	5584.0
46	Rogers Ranch Spring	*P11*	Spring	valley floor	722711.3	4351754.3	5582.2
47	Unnamed Spring #1.1	*P13*	Spring	valley floor	719014.5	4342583.6	5642.3
48	Unnamed Spring #1.2	*P14*	Spring	valley floor	719110.8	4342404.1	5640.7
49	Unnamed Spring #2.1	*P15*	Spring	valley floor	719392.0	4342120.5	5625.0
50	Unnamed Spring #2.2	*P16*	Spring	valley floor	719525.9	4342005.7	5618.7
51	Unnamed Spring #3.1	*P17*	Spring	valley floor	719553.9	4341845.3	5618.4
52	Unnamed Spring #3.2	*P18*	Spring	valley floor	719550.5	4341705.4	5620.7
53	Unnamed Spring #3.3	*P19*	Spring	valley floor	719461.0	4341562.6	5625.4
54	Unnamed Spring #4	*P20*	Spring	valley floor	718909.3	4340638.0	5643.1
55	Unnamed Spring #7	*P21*	Spring	alluvial fan	716280.2	4335145.3	5757.8
56	Unnamed Spring #8	*P22*	Spring	alluvial fan	716127.1	4334268.8	5796.3

Table 1 – Addendum

Interim Name	Interim ID	Registered Name	Permit
North Cleveland Unit Spring	P09	North Cleveland Unit Spring	V010086
Unnamed Spring #1.1	P13	Cleveland Ranch Allotment Spring - North	V010082
Unnamed Spring #1.2	P14	Cleveland Ranch Allotment Spring - South	V010083
Unnamed Spring #2.1	P15	Fenceline Spring - North	V010084
Unnamed Spring #2.2	P16	Fenceline Spring - South	V010085
Rogers Ranch Spring	P11	Rogers Ranch Spring	V010087
North Millick Spring	P10	North Millick Spring	V010088
Unnamed Spring #3.1	P17	Triple Spring - North	V010078
Unnamed Spring #3.2	P18	Triple Spring – Middle	V010079
Unnamed Spring #3.3	P19	Triple Spring – South	V010080
Unnamed Spring #4	P20	Big Water Spring	V010081
Unnamed Spring #7	P21	West Bastian Allotment Spring	V010074
Unnamed Spring #8	P22	West Bastian Allotment Spring 2	V010075
South Bastion Spring	P02	South Bastion Spring	V010076
South Bastion Spring 2	P01	South Bastion Spring 2	V010077
Layton Spring	P08	Layton Spring	V010073

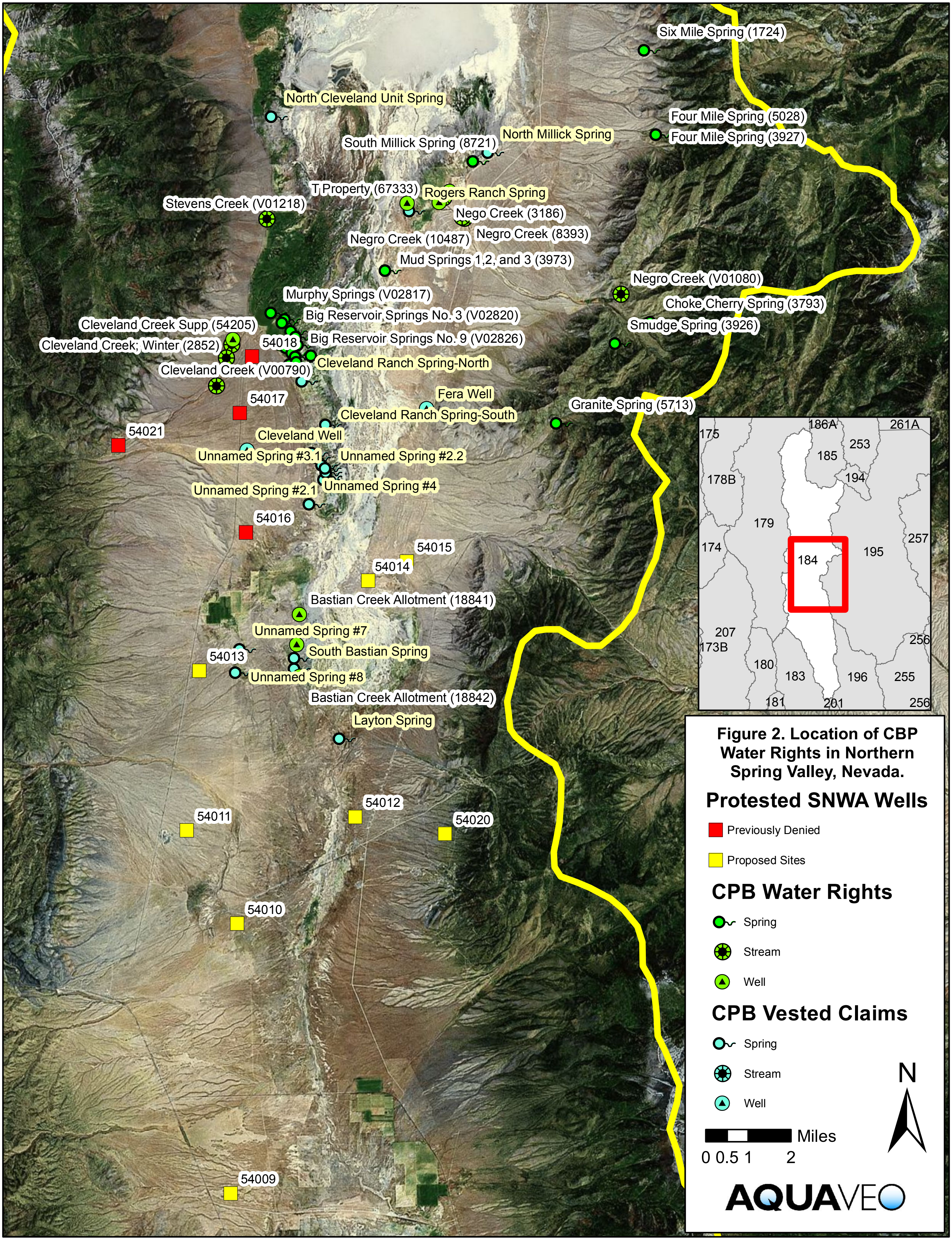

Figure 2. Location of CBP Water Rights in Northern Spring Valley, Nevada.

Geologic and Hydrogeologic Setting

Spring Valley is a closed basin, the northern portion of which drains to Yelland Playa which is located about seven miles northeast of the Cleveland Ranch. South of U.S. Highway 6 is a small playa which is the local terminus of ephemeral drainages in southern Spring Valley. In the vicinity of the Cleveland and Rogers Ranches the bounding mountain ranges support several perennial streams including Cleve, Indian, and Stephens Creeks that originate in the Schell Creek Range and Negro Creek that originates in the Snake Range (Figure 3). In addition to the perennial drainages hundreds of ephemeral drainages and braided streams channels issue from the mountain fronts and traverse mountain front alluvial fans along the entire length of both the Schell Creek and Snake Ranges.

The Spring Valley groundwater flow system is one of 39 major groundwater flow systems that have been identified in the Great Basin (Harrill and Purdic, 1998). The geology and hydrogeology of the Great Basin including Spring Valley has been the subject of numerous investigations (Clancy, 1968; Horse and Blake, 1970; Horse et al., 1976; Hess and Mifflin, 1978; Lopes, and Evetts, 2004; Nichols, 2000; Pavelko, 2007; Prudic et al., 1993; Welch and Bright, 2008, Southern Nevada Water Authority, 2009a, 2011a). Results of the previous investigations and the geology of Spring Valley will not be described in detail here. Instead this report focuses on the hydrogeology of northern Spring Valley and its relationship to the perennial groundwater safe yield. The quantity and the spatial distribution of perennial yield are critical factors in the evaluation of the SNWA Spring Valley groundwater appropriation applications.

The Spring Valley groundwater flow system consists of three primary interconnected hydrogeologic regimes: 1) bedrock highlands that surround the valley to the east and west, 2) alluvial fan deposits that flank the mountain fronts and slope to the valley-floor, and 3) the relatively flat-lying valley floor that has periodically supported pluvial lakes (Figure 4). The alluvial fans and valley floor sediments are underlain by carbonate and siliciclastic bedrock at depths as great as thousands of feet. In addition to the three groundwater regimes, interbasin groundwater flow, both into and out of the valley, has been described by some authors as contributing to the groundwater budget. Interbasin flow is the transfer of groundwater from one basin to another, largely through the so-called Carbonate Aquifer that underlies portions of the valley floor. In northern Spring Valley, all SNWA proposed well-sites are located on alluvial fans and it is our understanding that the wells would be screened entirely in alluvial-fan sediments.

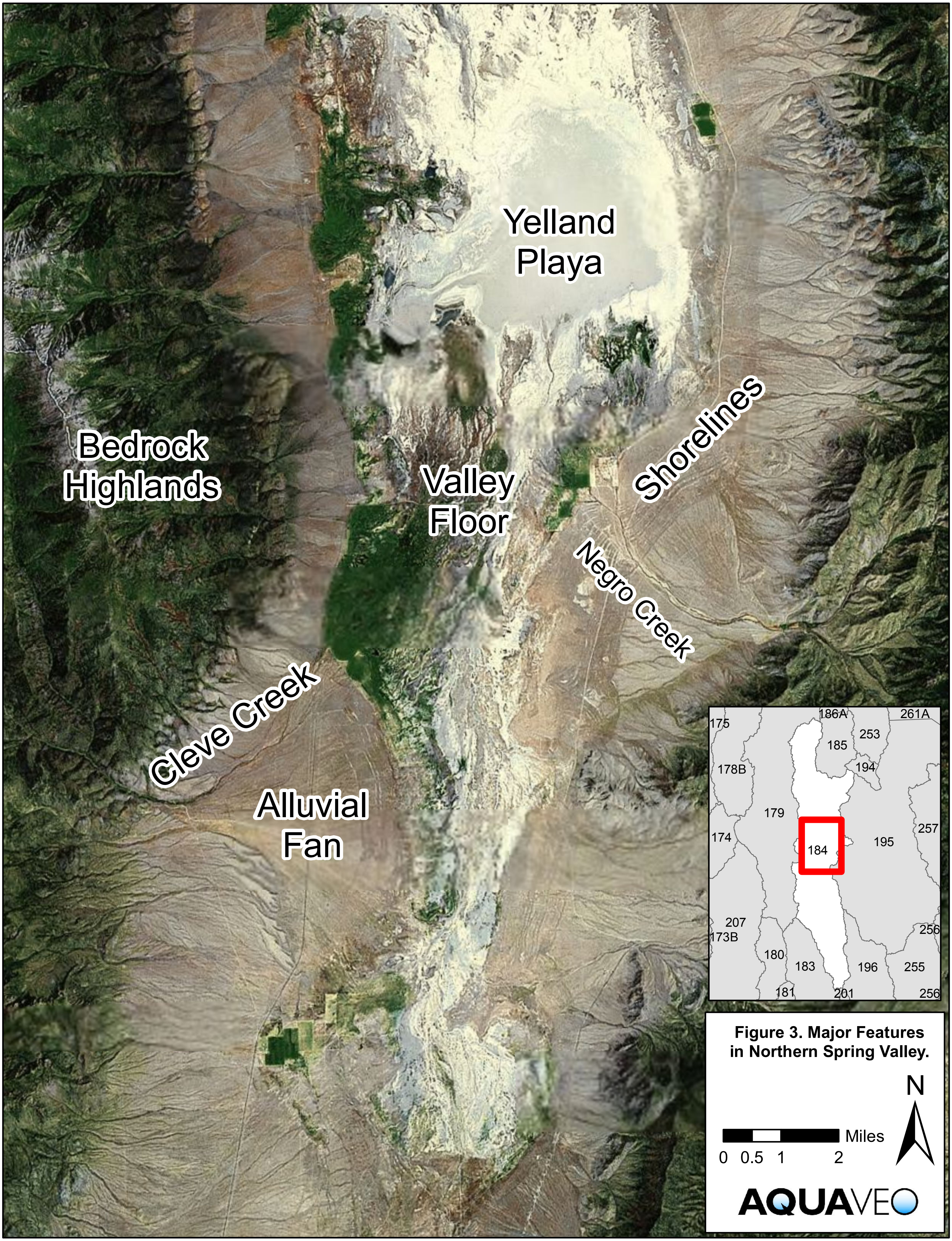

Figure 3. Major Features in Northern Spring Valley.

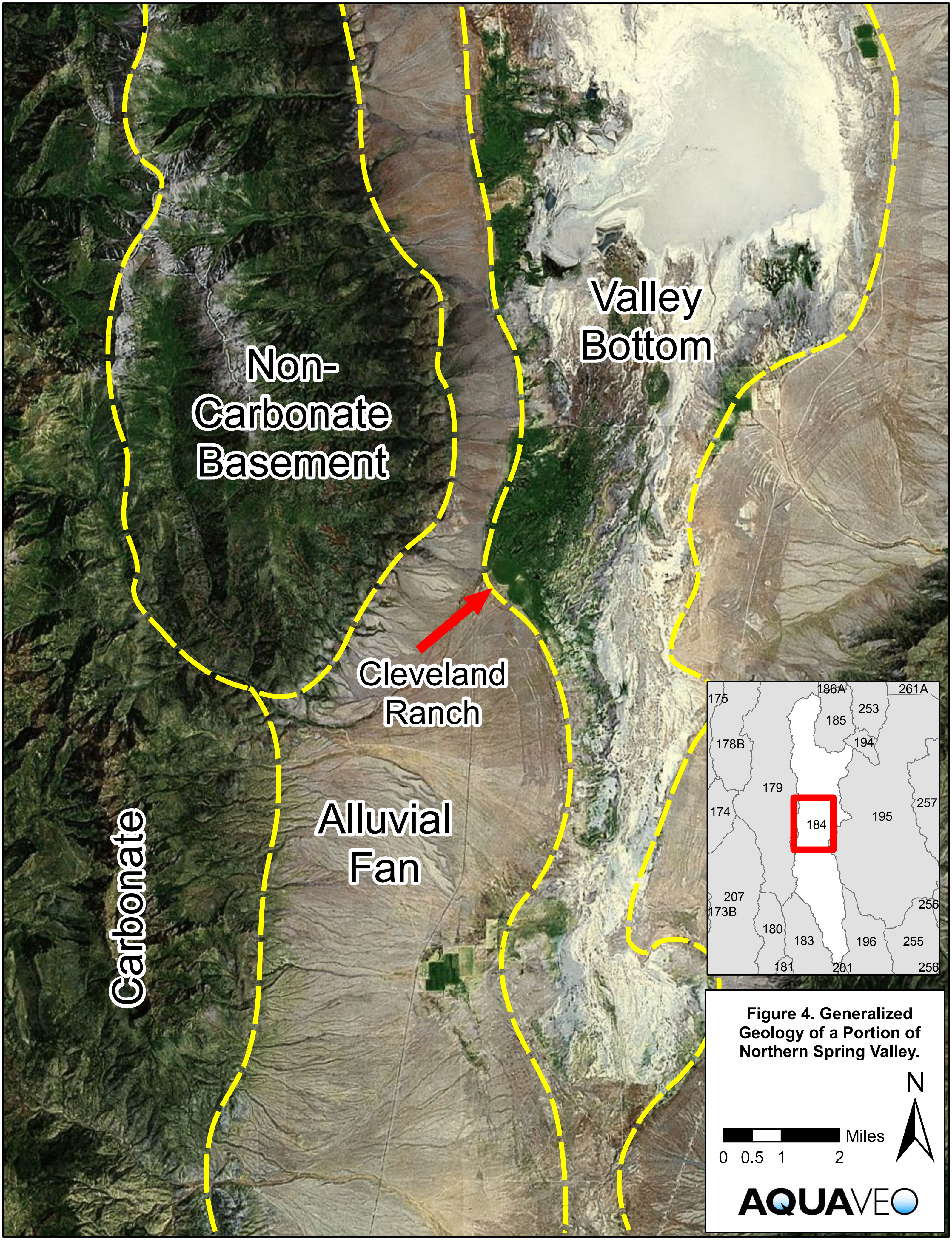

Figure 4. Generalized Geology of a Portion of Northern Spring Valley.

Bedrock Highlands

The bedrock highlands include the Schell Creek Range to the west and the Snake Range to the east. Both ranges rise as much as 6,000 feet above the valley floor and they receive considerable precipitation and accumulate winter snow pack. The high relief of the mountain ranges is due to mountain block bounding faults that are covered by alluvial fan debris. Bordering Spring Valley, the Schell Creek Range consists mostly of upper and lower carbonate bedrock (Mississippian to Permian and Cambrian to Devonian age, respectively) south of Cleve Creek and lower siliciclastic rocks (early Cambrian and older) north of Cleve Creek. The siliciclastic rocks have been designated by SNWA (2009a) as Basement Rock (Figure 4). The basement rocks are a regional confining unit (SNWA 2009a, 2011a) and do not support appreciable groundwater flow. The carbonate rocks have greater hydraulic conductivity than the siliciclastic rocks (SNWA, 2011a, Appendix C), which means the carbonate rocks have a greater capacity to recharge, store, and transmit groundwater than do the siliciclastic basement bedrock.

The high elevations of the bedrock highlands receive most of the Spring Valley precipitation, and this precipitation has been assigned by SNWA (2009a, 2011a) as the primary recharge source. The large mass of high elevation, low permeability, non-carbonate bedrock (basement rock) in the Schell Creek Range contributes to the large base flow of Cleve Creek. Although the basement rock has been characterized as an aquitard, SNWA (2009a, Plate 1) indicates that five plus inches of groundwater recharges annually into this mass of rock.

Alluvial Fans

The mountain front alluvial fan deposits are not mapped as separate units by SNWA (2009a, 2011a) but are lumped as upper valley fill (UVF), which also includes playa deposits. In northern Spring Valley the alluvial fan deposits are hydrogeologically significant in that: 1) almost all of the proposed SNWA wells would be completed in alluvial fan deposits (Figure 5), 2) the fans are important groundwater recharge locations via mountain front recharge, and 3) groundwater discharge from the fans supports most of the valley springs after which the valley was named.

Although the data are limited, the Cleve Creek alluvial fan supports at least two groundwater flow regimes: 1) a shallow flow system that is recharged by mountain front recharge and discharges from springs located at the base of the fan, and, 2) a deeper confined systems that may be recharged by a combination of mountain front and mountain block underflow. The deeper system is manifested in flowing artesian wells. Evidence for a multilayer alluvial fan system is described below. The three-dimensional geometry of the two systems is unknown due to insufficient data. Similar multilayer aquifer systems likely exist in other alluvial fans that flank the valley mountain ranges.

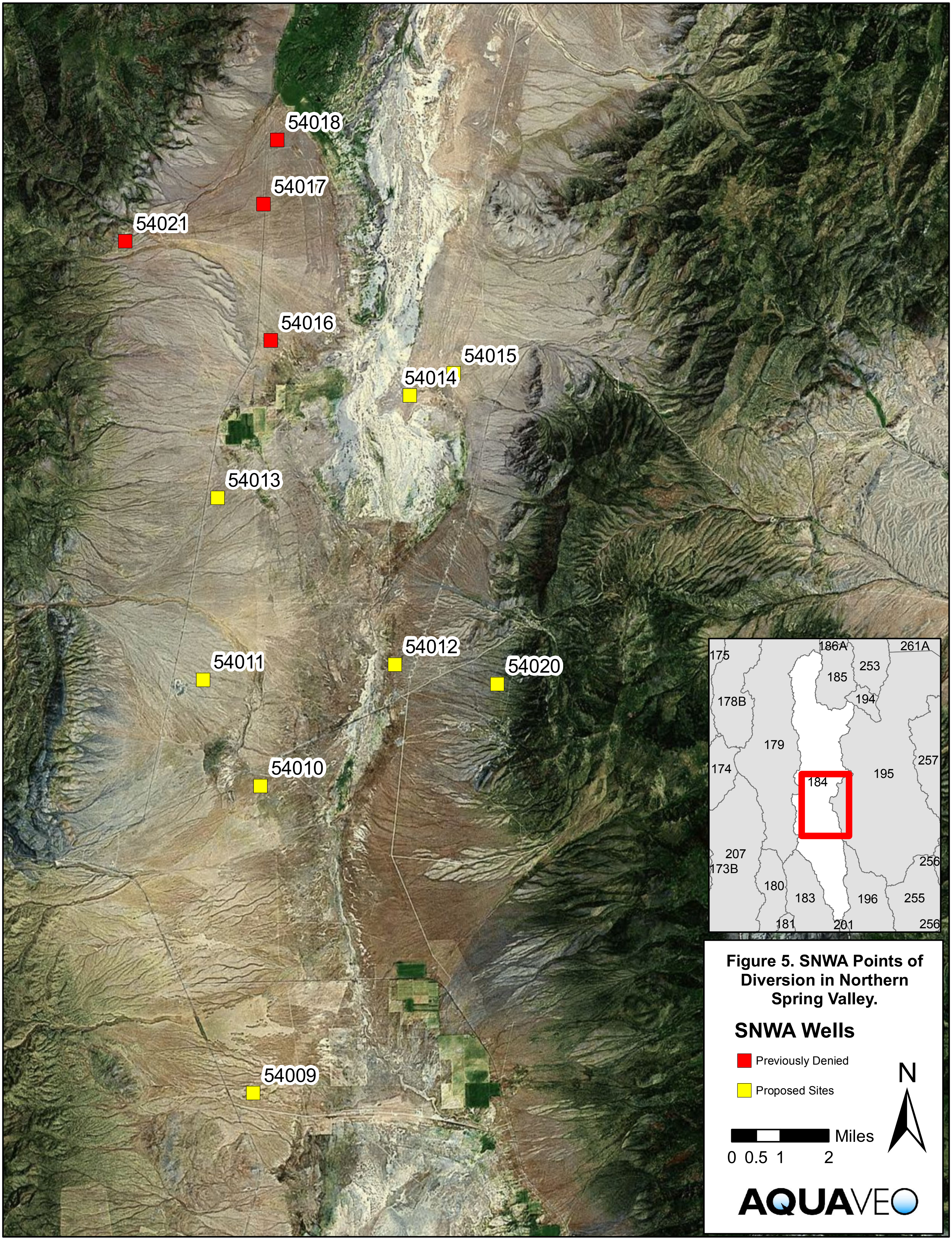

Figure 5. SNWA Points of Diversion in Northern Spring Valley.

An appreciable but unquantified portion of the Spring Valley groundwater recharge occurs as mountain front recharge by the infiltration of surface flows on the mountain front alluvial fans. Evidence for mountain front recharge includes: 1) measured stream infiltration from perennial streams, 2) the abundance of braided ephemeral alluvial fan stream channels, and 3) the location of most spring discharges at either the toe of alluvial fans or where pluvial lake shorelines resulted in subtle breaks in slope near the alluvial fan/lake bed interface (Figure 6 and Figure 7). The springs shown in Figure 7 discharge at the distal end of the low gradient Cleve Creek alluvial fan. Indian Creek flows across the steep alluvial fan in the far ground. The spring discharges are largely controlled by two factors: 1) groundwater recharge from Cleve Creek infiltration, and 2) the break in slope caused by a pluvial lake wave-cut terrace. Similar but smaller volume spring discharges issue from the distal end of the southern portion of Cleve Creek fan (unnamed springs), Negro Creek alluvial fan (unnamed and north and south Millick springs), and the Bastian Creek alluvial fan (Bastian Creek springs).

Mountain front (i.e., alluvial fan) stream losses were measured on the perennial Negro Creek (Snake Range) in 2008 (CPB Exhibit 001) and on Cleve, Indian and Stephens Creeks (Schell Creek Range) on August 15, 2010, as part of this investigation. A summary of the measurements is shown in Table 2 and the measurement locations and raw measurement data are contained in Appendix A. The purpose of the gain-loss measurements was to help document the relationship between surface water infiltration and the groundwater recharge sources of the springs that are critical to the operation of Cleveland and Rogers Ranches.

Measured infiltration rates ranged from about 31 to 93% of total perennial stream flows. The groundwater recharge rate into west side alluvial fans (Cleve and Stephens Creek fans) was about 40% of total stream flow during August 2010. Under natural conditions the net infiltration rate would be greater than measured because the measure rates only include the stream reaches up gradient of Cleveland Ranch points of diversion. Indian Creek is a small discharge tributary to Cleve Creek. The groundwater recharge rate from Negro Creek into the Negro Creek alluvial fan, located at the base of the Snake Range on the west side of the valley (Figure 3), was typically more than 70% during the seven month 2008 study. The higher infiltration rate of Negro Creek may be due to the fact that the creek free flows along its entire reach for approximately three miles from the canyon sources to the ranch. The Negro Creek data demonstrates that appreciable groundwater recharge continues during low flow months when most of the stream flow is lost to groundwater recharge and suggests that much of the water in ephemeral streams is also lost to groundwater recharge. Using unpublished data from Pilot Valley (Nevada-California) we have found a similar recharge mechanism from ephemeral mountain front alluvial fan systems.

The largest number and total discharge volume of alluvial fan springs in Spring Valley issue from the distal end of the Cleve Creek alluvial fan. This concentration of springs and spring discharge volume is consistent with the fact that Cleve Creek is the largest perennial stream in the Valley. The average monthly flow of Cleve Creek between 1960 and 2010 ranged from 6.5 to 23 cfs and the average annual flow ranged from 5.6 to 22.2 cfs (waterdata.usgs.gov, 2011).

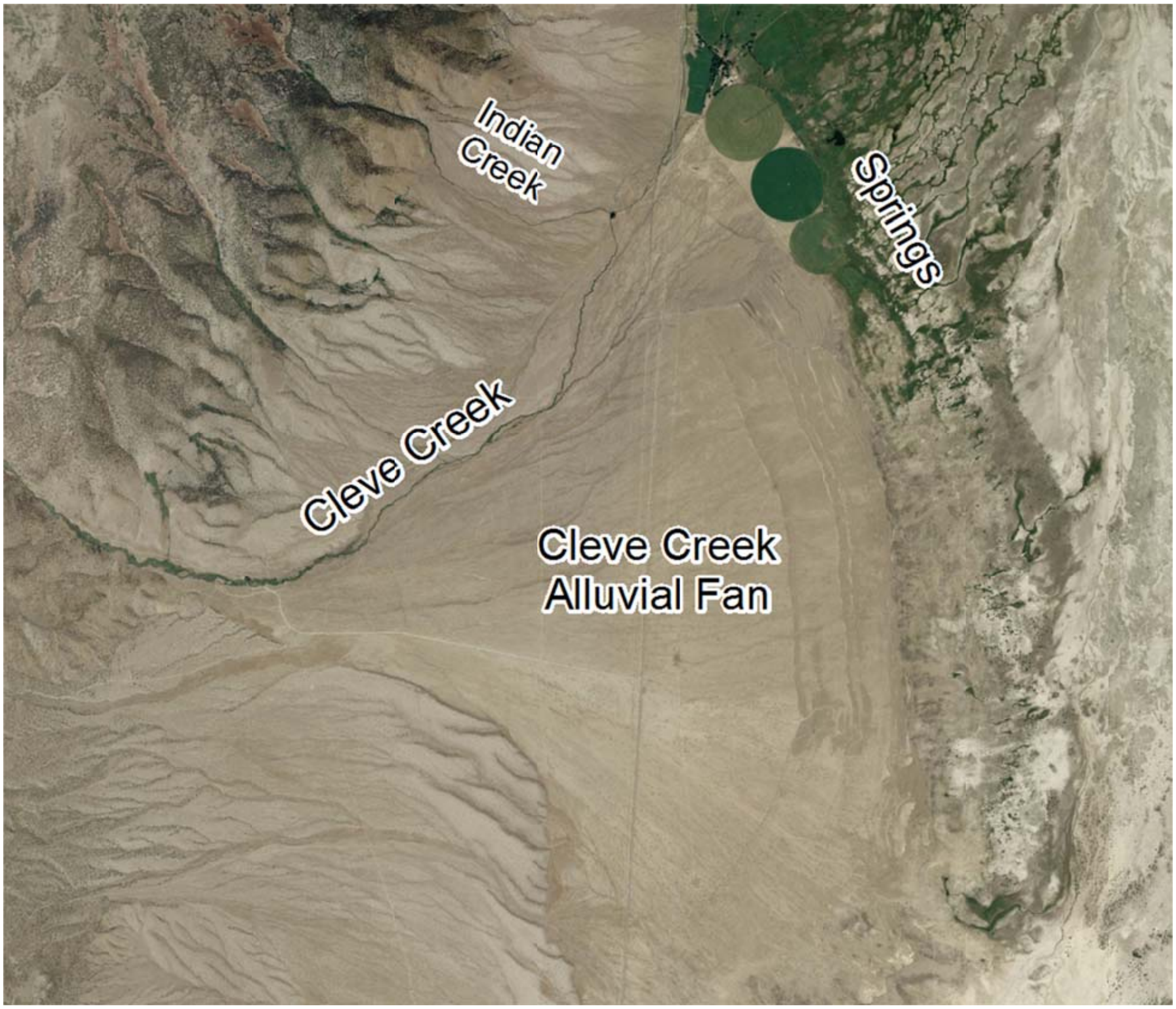

Figure 6 **Cleve Creek Alluvial Fan.**

Figure 7 **Southwest-Looking View of Murphy and Big Reservoir Springs #1-11.**

Table 2 Alluvial Fan Gain-Loss Stream Measurements.

Cleve Creek		Discharge [cfs]	Reach [miles]	Loss [cfs]	Infiltration [%]	Loss/Mile [cfs]
	Mountain Front	15.98	0		0.0	
	USGS gauging Station	15.35	0.7	0.63	4.0	
	USGS 10243700 Cleve Creek[1]	15	0.7			
	Mid alluvial fan	10.95	3	5.03	32.0	
	Just before holding pond	9.69	4.1	6.29	39.0	1.53
Indian Creek						
	Mountain front	1.51	0		0.0	
	Just before holding pond	1.04	1.3	0.47	31.0	0.36
Stephens Creek						
	Mountain front	1.73	0		0.0	
	Sprinkler system inlet	0.98	0.5	0.75	44.0	1.50

Negro Creek[2]		Discharge [AF]	Reach [miles]	Loss [AF]	Infiltration [%]	Loss/Mile [AF]
April	Homestead	**199**	**0**			
	Downstream diversion	52	3.6	147	73.9	40.83
May	Homestead	184	0			
	Downstream diversion	50	3.6	134	72.8	37.22
June	Homestead	223	0			
	Downstream diversion	99	3.6	124	55.6	34.44
July	Homestead	128	0			
	Downstream diversion	26	3.6	102	79.7	28.33
August	Homestead	81	0			
	Downstream diversion	6	3.6	75	92.6	20.83
September	Homestead	94	0			
	Downstream diversion	13	3.6	81	86.2	22.50
October	Homestead	114	0			
	Downstream diversion	32	3.6	82	71.9	22.78

1 Preliminary data from USGS website (waterdata.usgs.gov, 2011)

2 2008 measurements (CPB Exh-001, 2011)

The relationship between surface water infiltration into the Cleve Creek alluvial fan and the Big Reservoir springs is further evidenced by a groundwater age investigation performed as part of this study. Carbon-14 ages and tritium analyses were performed on six surface and groundwater samples collected from northern Spring Valley (Table 3). The Stephens Creek sample which contains ~ 11 tritium units (TU) and the Negro Creek spring sample, collected from the bedrock spring at the mouth of Negro Canyon, indicate that recent recharge water contains about 10 TU. Ten TU for modern precipitation is consistent with the 15 year tritium precipitation record of rain and snowfall along the Wasatch Front (unpublished data). Because tritium has a half-life of about 12.5 years, groundwater in the western Great Basin that is older than about 60-75 years contains little or no measurable tritium. The Big Reservoir spring (1/2) water contains 77 percent modern carbon (pmc) which means the water has a modern recharge source. A modern recharge source is consistent with recharge from Cleve Creek and rapid groundwater flow toward the spring.

The Cleveland Ranch flowing-artesian well contains ~37.6 pmc and 3.9 tritium units (TU), which means the water has mixed recharge sources, including both modern and older groundwater recharge. The old component of recharge is appreciably older than the calculated Fontes 14C age of 2,500 years and the tritium content is a mixture of pre-atmospheric nuclear testing groundwater and more recent recharge water. Because the well is screened from about 100 feet to about 600 feet below ground surface, it is likely that the well acquires modern groundwater near the surface and older groundwater deeper in the alluvial fan. The fact that the well is a flowing artesian well indicates that the well penetrates a confining layer, and that there are at least two groundwater systems in the alluvial fan within 700 feet of the ground surface. The significance of the two groundwater systems with different groundwater travel times is that deeper alluvial fan groundwater is not rapidly replenished by annual groundwater recharge, whereas the overlying shallow alluvial system has an active hydrodynamic communication with surface water and annual recharge events. The importance of this to groundwater extraction by deep alluvial fan wells is that shallow alluvial fan groundwater will be readily replenished by annual recharge events, whereas the replenishment of the deeper groundwater will require hundreds to thousands of years.

The carbon-14 ages and tritium contents of the Bastian Creek spring and the Millick spring (Table 3) suggest that these spring discharges are also supported by young shallow and older deep groundwater. Both of the springs discharge at the distal ends of alluvial fans but not in direct line with the perennial surface water which contributes to alluvial fan recharge. Based on the limited isotopic data, it is not possible to determine the percentages of annual groundwater recharge vs. paleo-groundwater recharge that contribute to Spring Valley ET. It is clear, however, that annual groundwater recharge constitutes a major component of the Murphy and Big Reservoir Springs discharges that are critical to the operation of Cleveland Ranch.

Table 3 Summary of Northern Spring Valley Groundwater Age Data from the Vicinity of Cleveland and Rogers Ranches.

Sample ID	BYU lab #	Sampling Date	pH	^{14}C [pmc]	+/-	δ^{13}C	+/-	^{3}H [TU]	+/-	HCO3^{-} [mg/L]	Fontes calculate 14C age [years]
Bastian Creek Spring	9232	7/19/2011	8.01	44.39	0.15	-7.87	0.04			184	1200
Irrigation Well	9234	7/19/2011	8.11	37.56	0.13	-8.22	0.04	3.9	0.2	186	2500
Stephens Creek	9236	7/19/2011						11.1	0.4		
Big Resevoir Spring (#1/2)	9237	7/20/2011	7.93	77.12	0.22	-13.90	0.04			131	modern
Millick Spring	9238	7/20/2011	7.92	44.94	0.14	-8.63	0.04	2.0	0.1	270	1200
Negro Creek Spring	9239	7/19/2011						9.1	0.1		

Valley Floor

Northern Spring Valley was occupied by the Pleistocene age Lake Spring to an elevation of 6428 feet (Reheis, 1999). Many of the lake shorelines are visible on the alluvial fans (Figure 3) and some wave-cut terraces are the locations of alluvial fan spring discharges. Surficial deposits on the valley floor include recent playa muds, fine-grained pluvial lake sediments, and reworked alluvial fan sediments. Depth to bedrock may exceed 10,000 feet and the details of the deep stratification are unknown. Because the basin has periodically been closed during the past 11 million years or so, lake deposits interfingered with coarser grained alluvial fan sediments and possibly lava flows likely occur.

The basin is topographically closed, thus nearly all surface and groundwater, except for groundwater loss to interbasin flow, either discharges on the alluvial fan margins or upwells in the valley bottom. Yelland playa is the current location of the topographic low of the northern valley and, as such, all surface and groundwater in the valley bottom flows toward the playa (Figure 3). Because of the relatively low relief of the valley floor, upwelling groundwater and surface flows that reach the valley floor support a significant region of both surface water ponds and groundwater ET as characterized by the unusual grove of swamp cedars located below the Bastian alluvial fan, the sub-irrigated pasture land of the Cleveland Ranch, and the extensive wetlands located north of Cleveland Ranch. SNWA (2009a, 2011a) has mapped the ET zone in the valley floor.

The Nevada State Engineer has determined that in most Nevada basins groundwater discharge is primarily by evapotranspiration (ET) and that the perennial yield is approximately equal to the estimated groundwater ET (Nevada State Engineer, 2007). Because almost all Spring Valley groundwater ET occurs in the valley floor, SNWAs' application to appropriate groundwater is based on the idea that wells can be constructed so as to capture all unappropriated groundwater prior to potential ET loss. What this entails is either capturing the groundwater prior to entering the ET area and/or lowering the groundwater table below the root extinction depth without causing groundwater mining. The significance of ET capture relative to the SNWA application is discussed below.

Groundwater Budget

Establishing the groundwater budget is one of the critical factors in the groundwater appropriation process in that the budget, combined with existing appropriations, is the basis for determining the quantity of unappropriated water. Groundwater budgets are based on the simple continuity equation where inflow = outflow ± change in storage. In the case of perennial yield for a closed basin such as Spring Valley, inflow includes direct basin groundwater recharge plus interbasin inflow, and outflow includes groundwater ET plus interbasin outflow. Perennial or safe annual yield is based on the assumption that there is no change in storage (i.e., increasing water table or potentiometric elevations, or groundwater mining).

In the case of Spring Valley, more than a dozen estimates of a groundwater recharge, net groundwater ET and perennial yield, or net interbasin outflow have been published since 1965 (Table 4). Most groundwater recharge calculations have been based on a version of the well-established Maxey-Eakin method and some have used PRISM data to calculate precipitation for inclusion in the Maxey-Eakin method. ET estimates have been based on an analysis involving phreatophyte mapping and assigning groundwater consumption factors to various plant and bare land communities or by assuming that calculated net groundwater recharge equals ET. During the 2006 water rights hearing before the State Engineer, SNWA presented a revised groundwater budget that included 87,000 AFA of ET using the Maxey-Eakin method and an additional 12,000 AFA from stream flow and 2,000 AFA from underflow from Tippet Valley. Since then, SNWA (2009a, 2011a) has prepared reports that suggest net ET is 75,400 and 94,000 AFAA, respectively. During the State Engineers' hearing, numerous arguments were made regarding the validity of some assumptions used in many of the existing groundwater budget calculations. SNWA has prepared a new document (Exhibit 258, SNWA 2011a) which: 1) describes in detail various assumptions and variations of methodologies that can be used to calculate groundwater budget components, and 2) includes calculations of groundwater budget components using various assumptions and methodologies. The most recent SNWA methodology has resulted in the largest perennial yield estimate to date (94,800 AFA). In this calculation, SNWA assumes that groundwater ET equals perennial yield and that groundwater ET equals calculated groundwater recharge. SNWA calculated groundwater recharge using a version of Maxey-Eakin and PRISM data for precipitation values.

Table 4 Summary of Spring Valley Groundwater Budgets Based on Non-Geochemical Methods

Source	Groundwater Recharge [x1000 AFA]	Net ET or Perennial Yield [x1000 AFA]	Net Interbasin Flow [x1000 AFA]
Rush and Kazmi, 1965	75.0	70.0	
Watson et al., 1976	63.0		
Harill et al., 1988			-21.0
Dettinger, 1989	62.0		
Nicols,2000	104.0	90.0	-14.0
Flint et al., 2004	67.0		
Epststein, 2004	35.0		
Epststein, 2004	93.0		
Brothers et al., 1994	72.0	70.0	
Nevada State Engineer, 2007		80.0	
Welch and Bright, 2008	93.0	75.6	-15.0
SNWA, 2009a[1]	81.4	75.4	-12.0
SNWA, 2011a[2]	99.2	94.8	-4.4

[1] *Groundwater recharge (Table 9-2), groundwater ET volume (Table F3)*

[2] *Groundwater recharge (Table 6-2), groundwater ET volume (Table D6, average for period of record 2006-2010)*

There are several factors that make it clear that a definitive estimate of potential yield extending 200+ years into the future cannot be made. They include: 1) the complexity of the groundwater systems, 2) the uncertainty in estimating groundwater recharge rates relative to precipitation, 3) the relatively limited time record of measured precipitation, 4) the uncertainty in calculating groundwater ET, 5) the fact that Spring Valley groundwater recharge and net ET calculation results vary greatly based on the methodology and the assumptions used, and 6) other factors such as the potential effect of climate change. Because a definitive estimate of perennial yield extending 200+ years into the future cannot be made, the State Engineer’s approach in establishing a conservative estimate of perennial yield is appropriate.

SNWA has presented a moving target for estimated groundwater ET: 87,000 AFA at the 2006 State Engineers hearing, 75,600 AFA in 2009, and 94,800 AFA in 2011. The 2011 SNWA groundwater budget includes 84,800 AFA perennial yield (SNWA Exhibit 258, p. 10-1 and 10-2), 12,768 AFA or 10,429 AFA (excluding later priority) committed groundwater and 84,370.49 AFA unappropriated water (SNWA Exhibit 258, p. 10-4). Both the 2009 and 2011 estimates have been submitted as exhibits (Exhibit 88 and Exhibit 258, respectively). It appears that the SNWA is using the 2009 number (75,600 AFA) in the baseline groundwater model.

SNWA Application and Perennial Yield

Regardless of the State Engineer's final ruling on net groundwater ET, three critical groundwater budget issues need to be examined: 1) the total diversion rates from SNWA's points of diversion relative to reasonable estimates of perennial yield, 2) the feasibility of successfully accomplishing ET salvage based on the locations of the points of diversion relative to the spatial distribution of groundwater ET, and 3) the well design relative to ET salvage and groundwater mining.

The total SNWA Spring Valley application is for 91,224 AFA of unappropriated perennial yield (Table 5). Approval of all points of diversion at the requested diversion rate would result in groundwater mining. Existing consumptive use of vested and appropriated groundwater rights not owned by SNWA are about 14,000 AFA; thus, assuming the most optimistic estimate of perennial yield 94,800 AFA (SNWA, 2011a) only about 81,000 AFA of perennial yield is available. Based on the State Engineer's previous finding of 80,000 AFA perennial yield (Nevada State Engineer, 2007) and the most recent inventory of Spring Valley appropriated groundwater (Nevada Division of Water Resources, 2011) 14,202 AFA of groundwater is committed groundwater and only 65,797 AFA is available for appropriation.

Table 5 Summary of SNWA Spring Valley Points of Diversion.

Site ID	CFS	AFA
54003	6	4,344
54004	6	4,344
54005	6	4,344
54006	6	4,344
54007	6	4,344
54008	6	4,344
54009	6	4,344
54010	6	4,344
54011	6	4,344
54012	6	4,344
54013	6	4,344
54014	6	4,344
54015	6	4,344
54016	6	4,344
54017	6	4,344
54018	6	4,344
54019	10	7,240
54020	10	7,240
54021	10	7,240
	Total	**91,224**

Equally important as the final estimated perennial yield in Spring Valley is the spatial ET distribution relative to the location of the SNWA proposed points of diversion. The reason that this is critical is that SNWA is proposing an ET salvage project that will capture the entire unappropriated perennial yield from Spring Valley via a series of ET salvage wells. If successful, such an extensive ET salvage project would result in the loss of all Spring Valley phreatophytes, the drying up of almost all alluvial fan margin springs, and the loss of all Cleveland Ranch sub-irrigation. ET salvage projects have been successfully undertaken in places such as the San Luis Valley, Colorado, where 170 shallow wells (<125 feet deep) located on about a one-mile grid spacing were constructed to salvage ET from the topographic low of the closed basin (Mayo, 2010). Although well and well field designs are the keys to comprehensive ET salvage, SNWA has not proposed or designed a groundwater recovery plan that will achieve the proposed ET salvage.

In Spring Valley, groundwater recharge originates in all of the mountain blocks and alluvial fans that surround the valley floor. Because this groundwater generally flows perpendicular from the mountain front toward the valley, the ET salvage well design needs to include wells that will capture perennial yield before it can be lost to ET. The SNWA well-field layout is such that ET salvage will not occur in many locations of the valley (Figure 8) and much of the perennial yield will continue to be lost to ET including most of the area located north of the ranch headquarters. The points of diversion appear to be located along a pipeline design where the largest alluvial fans occur. In the northern portion of the valley, no wells are located north of Cleveland Ranch headquarters, and in the southern portion of the valley no points of diversion are located along much of the base of the Snake Range. Because of the well field layout some perennial yield would continue to be lost to ET at full project development.

The well-field layout (i.e., points of diversion) in Spring Valley is a good design to optimize groundwater withdrawal from selected alluvial fans, but will not capture a significant portion of the groundwater ET; thus, to withdraw the entire requested 91,224 AFA will require appreciable groundwater mining. Analysis of SNWA's groundwater model, described below, quantifies the ET salvage and groundwater mining that will occur at full project design and assuming the previously denied points of diversions will not be reinstated.

Each of the SNWA-proposed wells is projected to have screened intervals that extend 400 to 900 feet into the alluvial fans. These wells will intercept shallow alluvial fan and valley bottom groundwater that has direct contact with annual groundwater recharge and with deeper alluvial fan groundwater that recharged hundreds to thousands of years earlier. In alluvial fan systems, such as those that flank the Schell Creek and Snake Ranges, the small number of such long-screened wells is more appropriate for groundwater mining than for a comprehensive ET salvage plan.

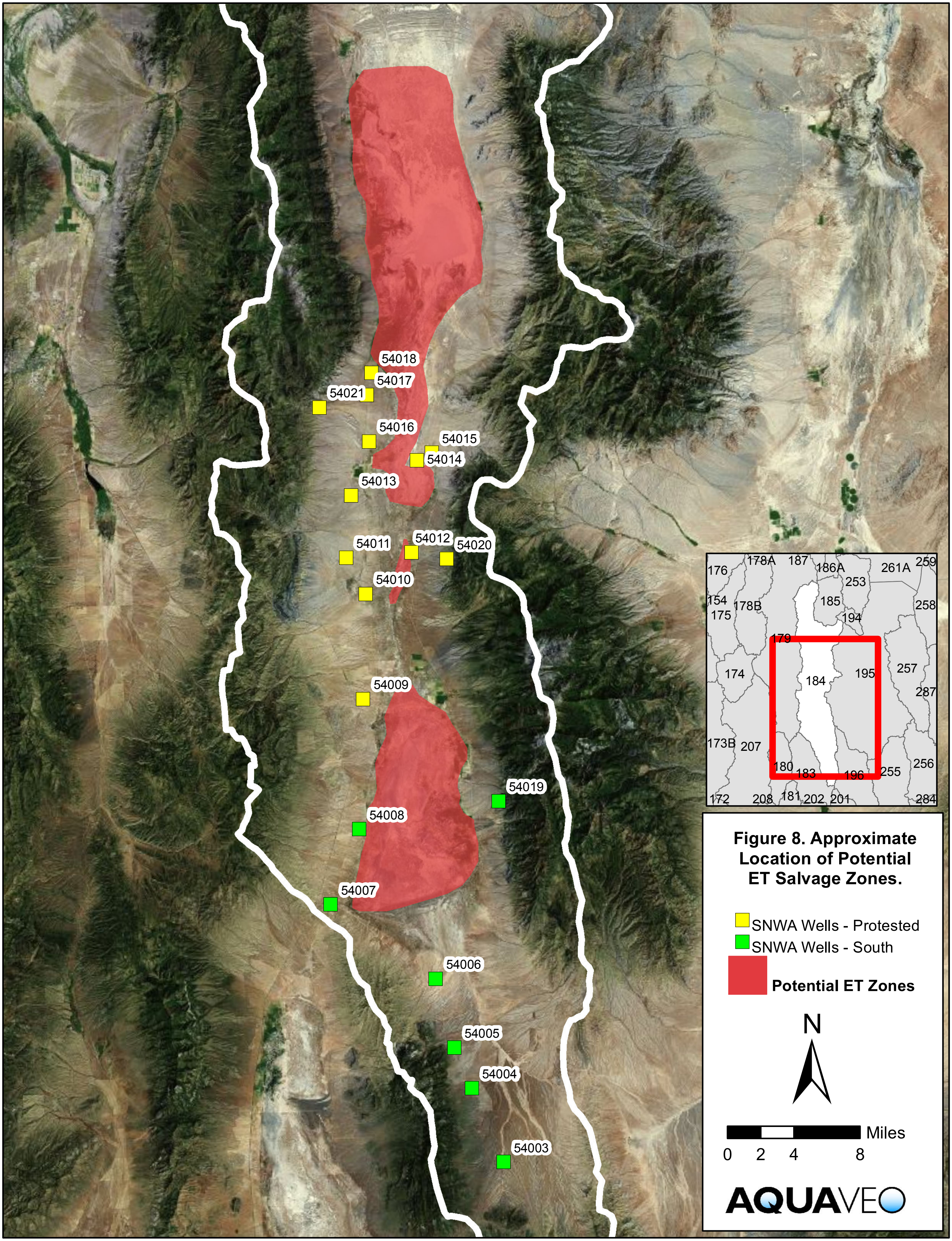

Figure 8. Approximate Location of Potential ET Salvage Zones.

Analysis of SNWA Groundwater Model

The following analysis is based on a series of MODFLOW models developed by SNWA. These models are based on a SNWA's conceptual model for a large region of Southeastern Nevada that includes a larger number of hydrographic areas in addition to Spring Valley (SNWA, 2009a). This conceptual model was used to develop a calibrated flow model for the entire region and the calibrated model was converted to a transient predictive model (SNWA 2009b). The predictive model was used by the SNWA to analyze the impact of the proposed SNWA wells on the water rights in four valleys, including Spring Valley. The results of this analysis are described in a report by Watrus and Drici (SNWA, 2011b) and the corresponding model input files were provided by the SNWA as part of the exhibits made public on July 1, 2011.

Watrus and Drici used two versions of the SNWA model to perform the analysis: one version without any of the SNWA wells representing baseline conditions and one version with the proposed SNWA wells in Spring, Delamar, Cave, and Lake valleys pumping at the full planned pumping rate. Both models cover a period from 2006 through 2254. The SNWA wells are introduced to the model according to a three-stage schedule with a preliminary pumping rate beginning in 2029, intermediate pumping rate beginning in 2038, and a full rate beginning in 2043. The wells are pumped at the full rate until 2243 and are turned off for the last nine years of the simulation.

Of the 19 wells proposed for Spring Valley, 12 are being protested by CPB (Figure 5). Accordingly, our analysis is restricted to these 12 wells. Of these 12 wells, four (54016, 54017, 54018, 54021) were previously denied by the State Engineer in 2007 (Nevada State Engineer, 2007). As part of our analysis, we modified the Watrus and Drici predictive model to perform two additional model runs: one where we removed the four protested wells denied in 2007, and one where we removed all twelve protested wells. No other changes were made to the model inputs for these model runs. In summary, the four model runs shown in Table 6 are discussed in this report:

Table 6 Model Runs Referenced in this Report.

Name	Description
Baseline	Transient model without any SNWA wells
Predictive-Full	Predictive model with all proposed SNWA wells turned on
Predictive-Minus4	The Predictive-Full model with SNWA wells 54016, 54017, 54018, 54021 removed from the simulation.
Predictive-Minus12	The Predictive-Full model with SNWA wells 54009, 54010, 54011, 54012, 54013, 54014, 54015, 54016, 54017, 54018, 54020, and 54021 removed from the simulation.

Drawdown of Water Table

In the Watrus and Drici report, impact at any Spring Valley water rights location was reported using a single criterion: whether or not the drawdown was greater than 50 ft at selected points in time during the simulation period. Drawdown is defined as the change in water table elevation for the predictive model run with the proposed SNWA wells active in the model vs. the baseline conditions. Actual simulated drawdown values at the water rights locations were not reported in SNWA (2011b). To obtain a more detailed understanding of predicted drawdown, we analyzed the output of the predictive models using drawdown maps and time series plots.

Drawdown Maps

Drawdown maps were developed by contouring the drawdown values at the model grid-cell centers. The head values corresponding to model layer 2 were used in the analysis. Since Layer 1 is not active in this region of the model, Layer 2 is the topmost active layer in Spring Valley. Layer 2 extends from the ground surface down to an elevation of 5085 ft. In the vicinity of the Ranch, the average thickness of layer 1 is approximately 500 ft. Since the hydraulic conductivity decreases with depth, most of the water withdrawn to the SNWA wells comes from layer 2.

Simulated drawdown results for the Predictive-Full model in the vicinity of the CPB-owned properties are shown in Figure 9-Figure 13 for years 2042, 2062, 2082, 2117, and 2242. A common color scale is used for the contours in each of the figures and the color scale shown in the map legends. The minimum contour level is 1 ft and regions with drawdown less than 1 ft are not contoured.

The contours illustrate a composite cone of depression created by the SNWA wells that grows deeper and larger over time. Many of the CPB water rights locations are impacted by the cone of depression by 2042 and virtually all are impacted by 2082. The three southernmost wells associated with the Bastian Creek allotment and the water rights locations in the vicinity of the Cleveland Ranch (adjacent to SNWA well 24018) are impacted most severely, with drawdown levels as great as 200 ft.

The cone of depression caused by the SNWA wells has a north-south longitudinal shape due to the manner in which the valley hydrogeology was represented in the model. The mountain ranges on the east and west sides of Spring Valley are dominated by low permeability bedrock (Basement Rock units) and the center of the valley is dominated by higher permeability valley fill and the underlying Carbonate aquifer. Furthermore, the SNWA model includes a low permeability fault running north and south along the west side of the valley. The fault is simulated with the Horizontal Flow Barrier (HFB) package in MODFLOW. As a result of the aquifer characterization and the fault, the drawdown is mostly confined to the center of the valley with a sharp demarcation on the west side at the presumed fault location.

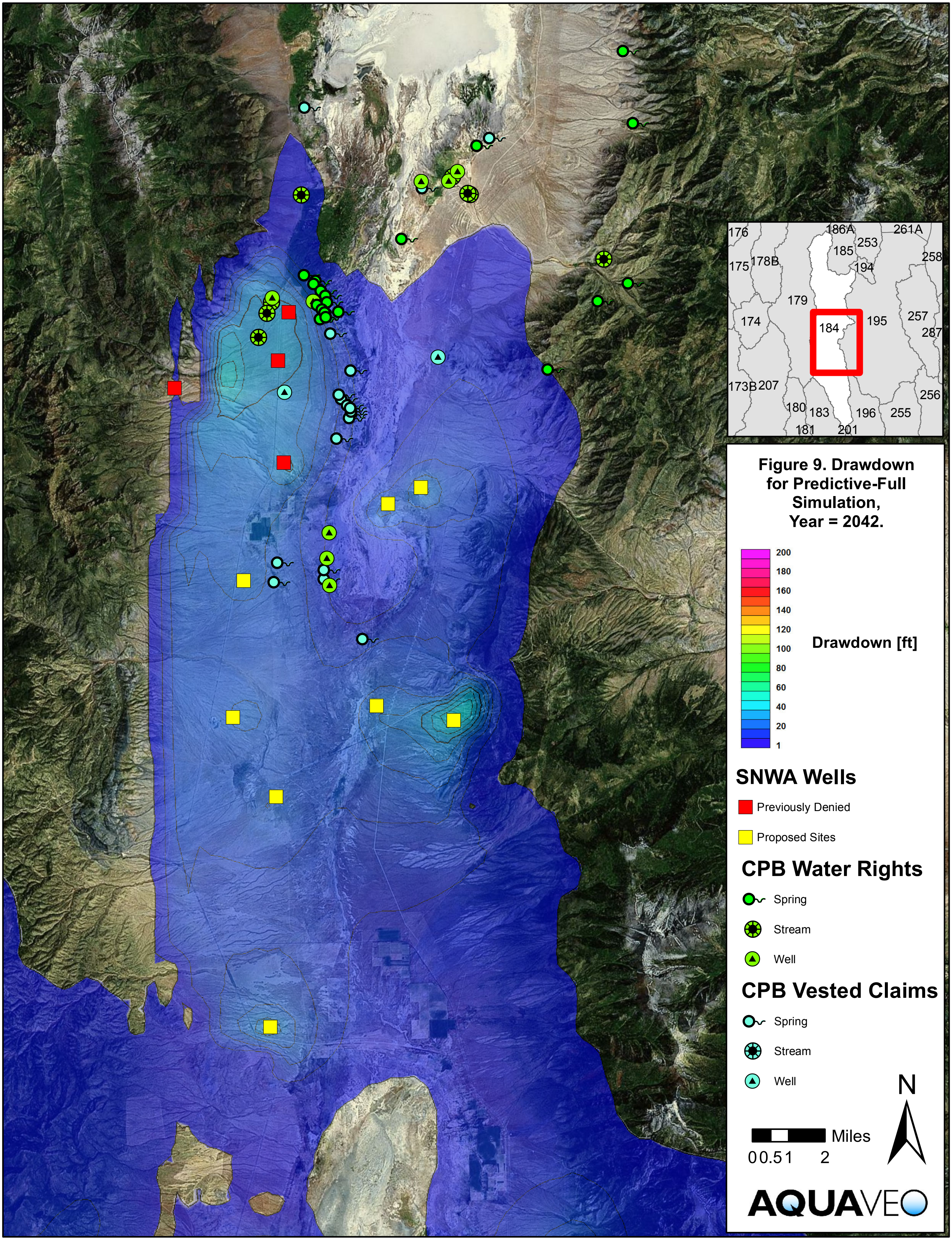

Figure 9. Drawdown for Predictive-Full Simulation, Year = 2042.

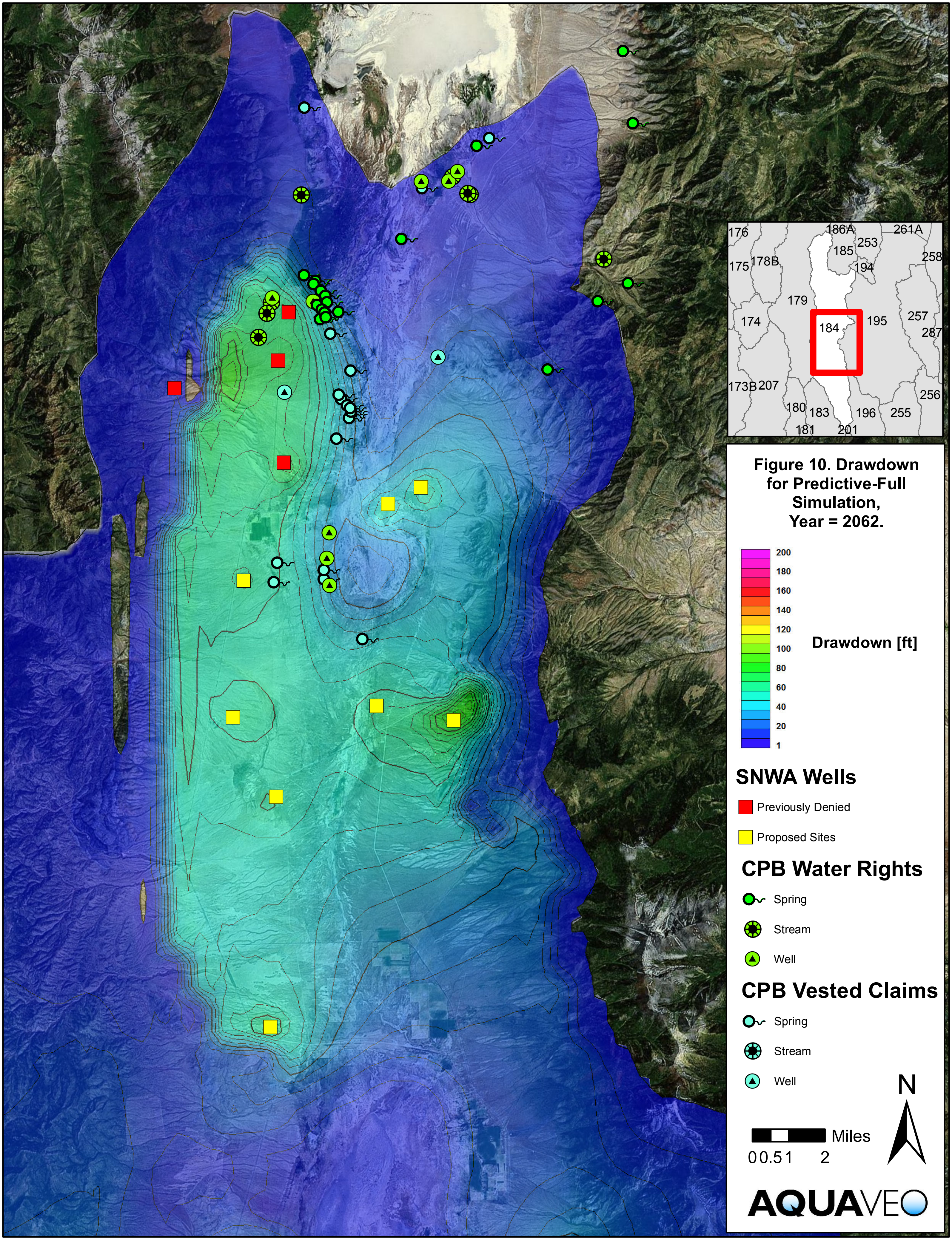

Figure 10. Drawdown for Predictive-Full Simulation, Year = 2062.

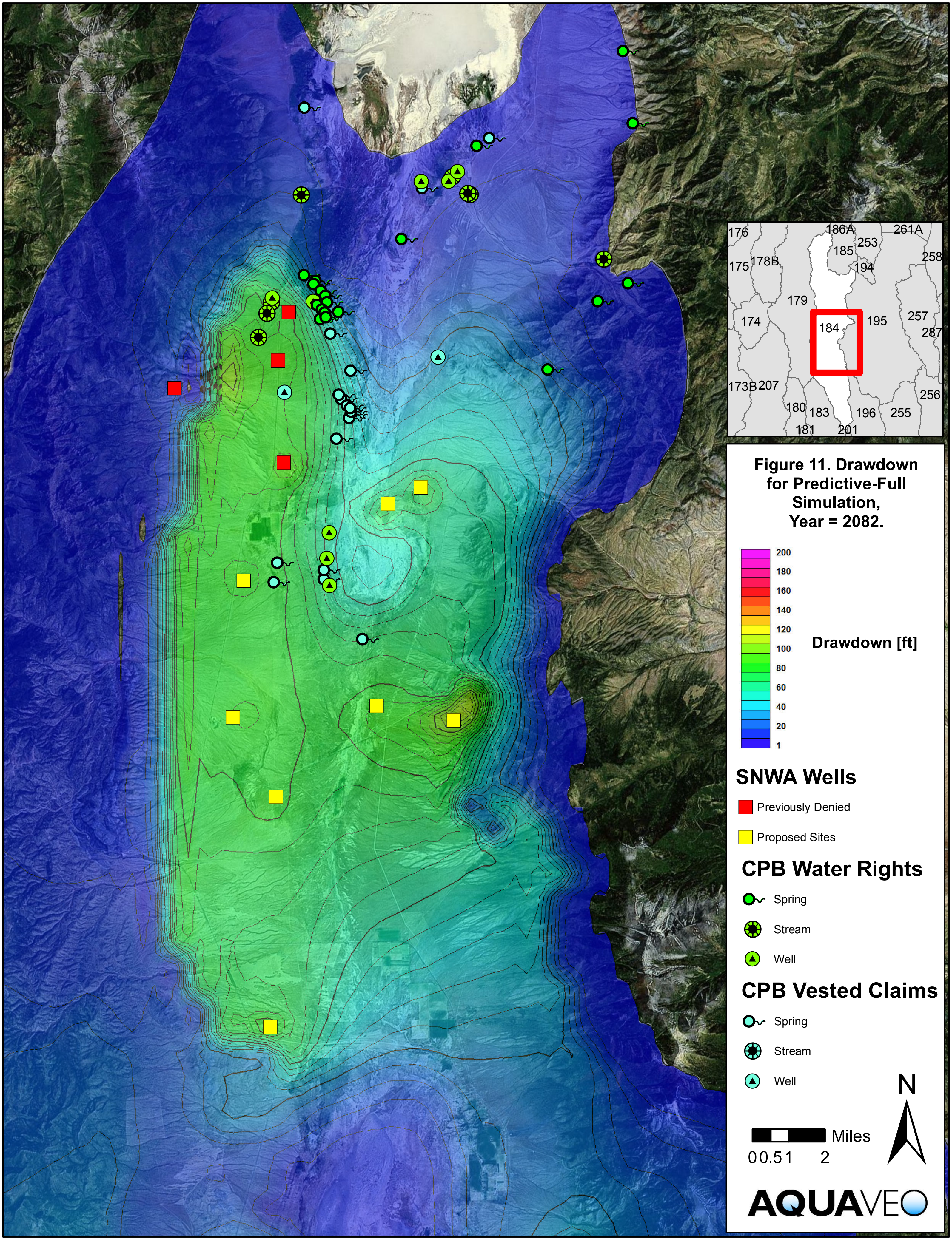

Figure 11. Drawdown for Predictive-Full Simulation, Year = 2082.

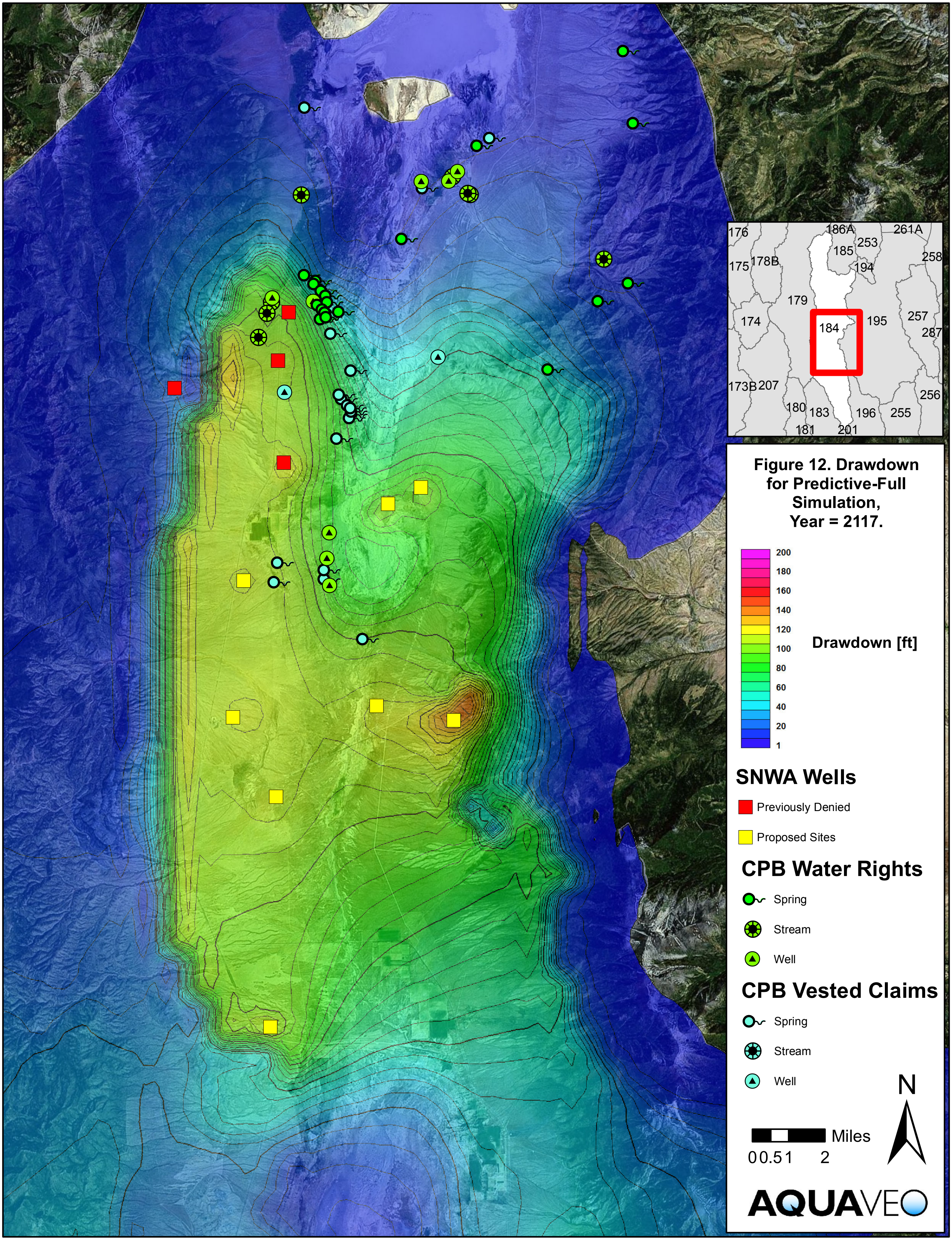

Figure 12. Drawdown for Predictive-Full Simulation, Year = 2117.

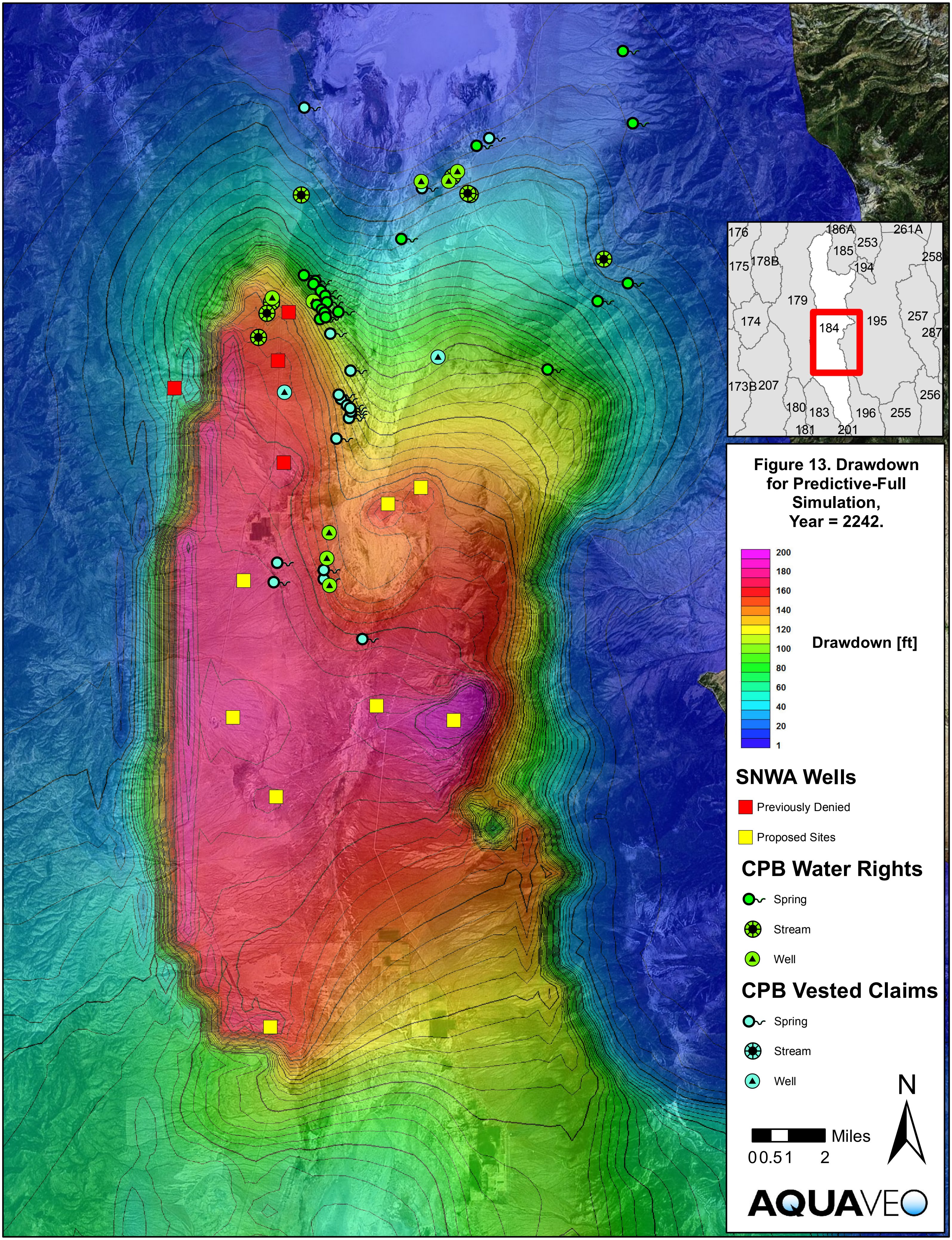

Figure 13. Drawdown for Predictive-Full Simulation, Year = 2242.

A set of drawdown maps for the same points of diversion at selected years based on the Predictive-Minus4 version of the model is shown in Figure 14-Figure 18. This version does not include the four wells denied by the State Engineer in 2007. As expected, the drawdown in the northern end of the aggregate cone of depression is less severe. Nevertheless, there is still substantial drawdown at many of the CPB water rights locations, particularly those adjacent to and south of the Cleveland Ranch.

A drawdown map for the Predictive-Minus12 version of the model is shown in Figure 19. This version omits the remaining eight wells that impact CPB water rights. In this case, the predicted impact at each of the CPB water rights locations is negligible.

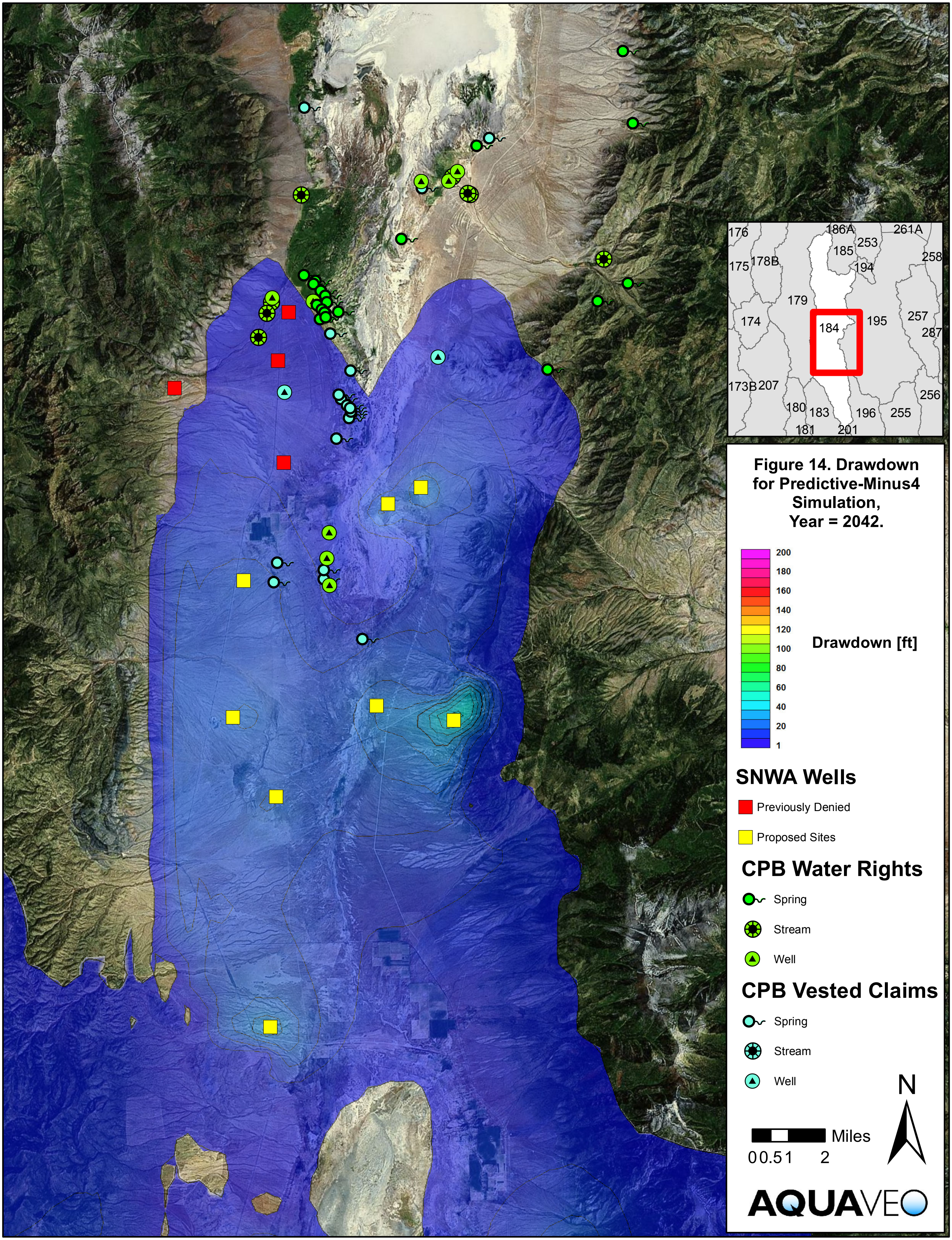

Figure 14. Drawdown for Predictive-Minus4 Simulation, Year = 2042.

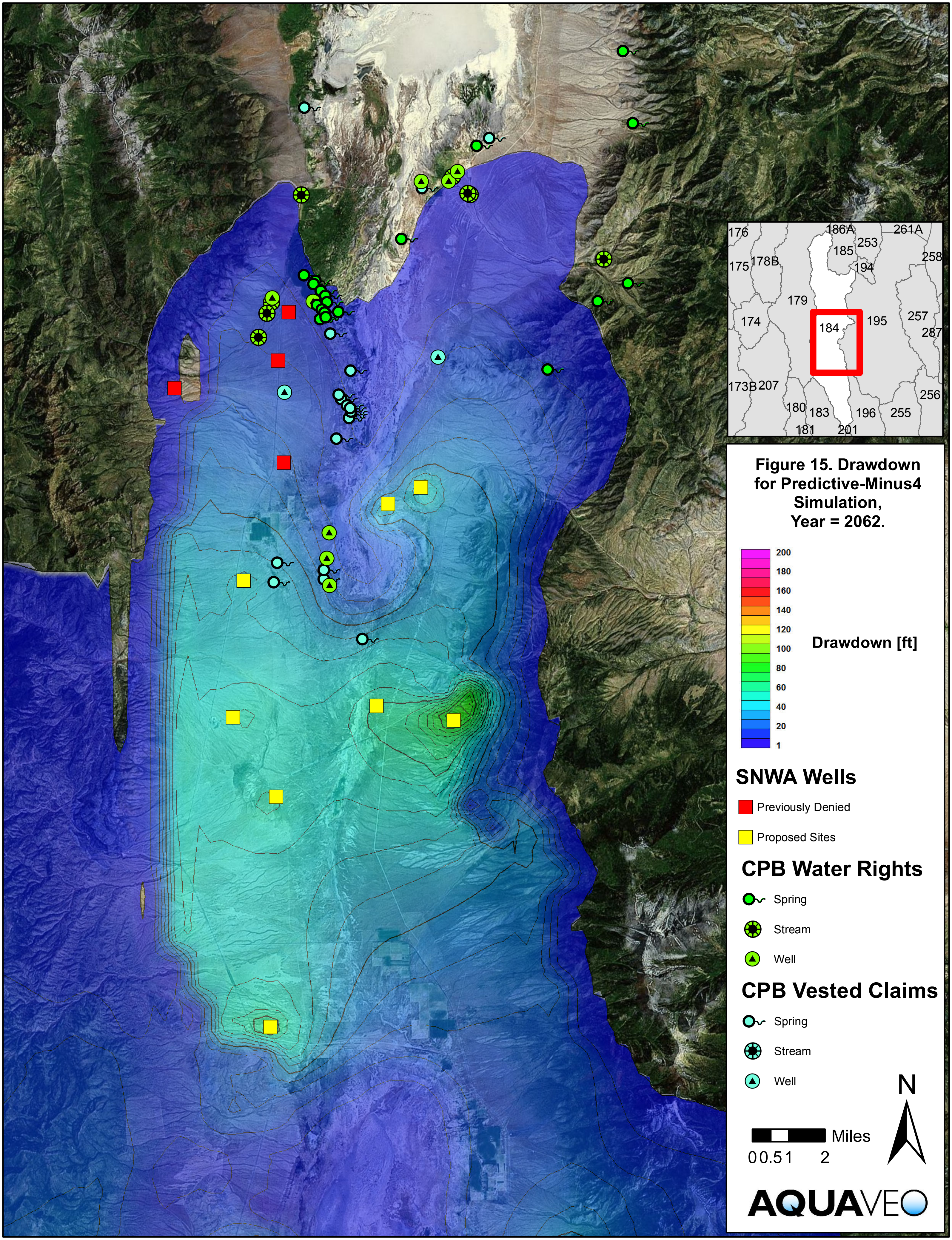

Figure 15. Drawdown for Predictive-Minus4 Simulation, Year = 2062.

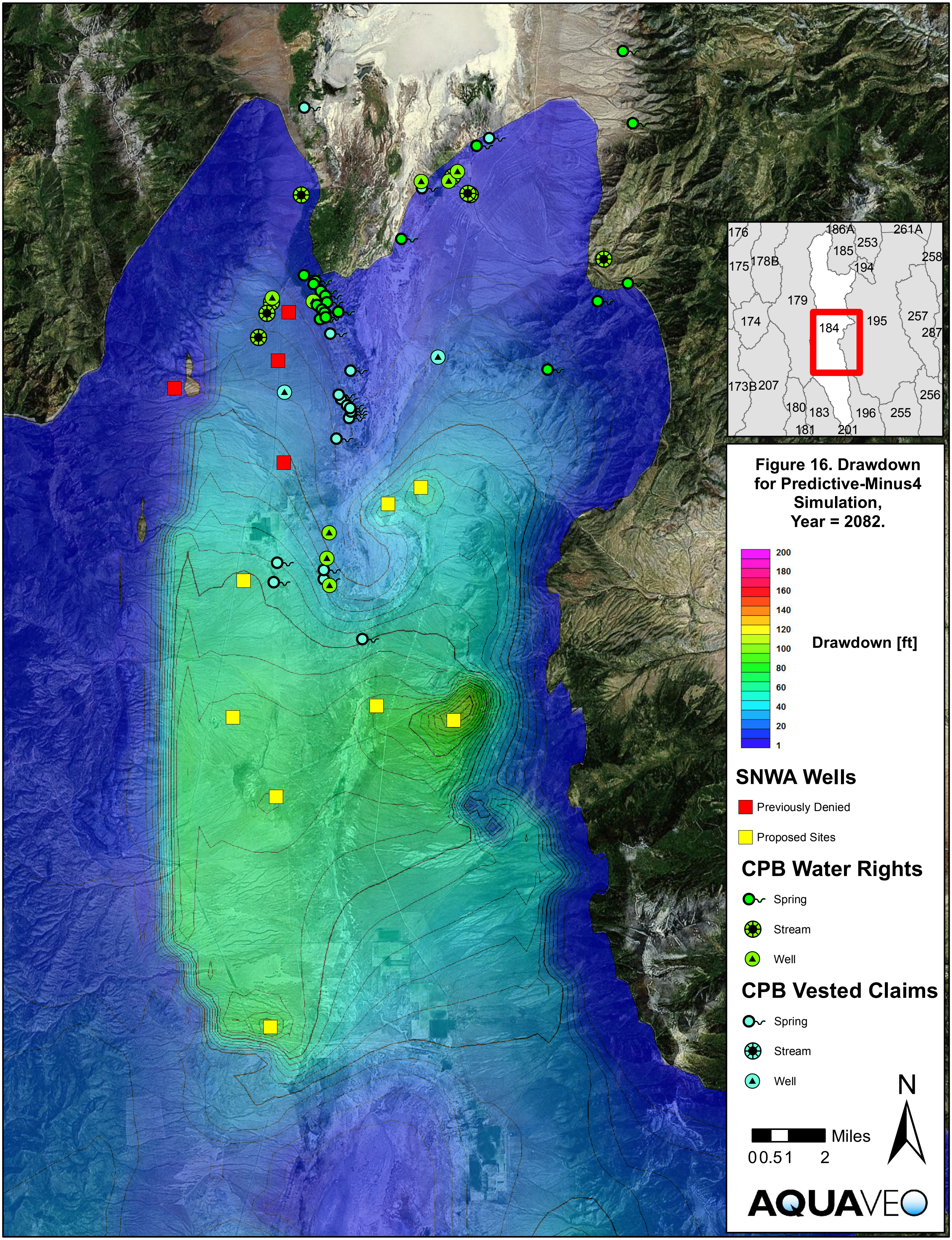

Figure 16. Drawdown for Predictive-Minus4 Simulation, Year = 2082.

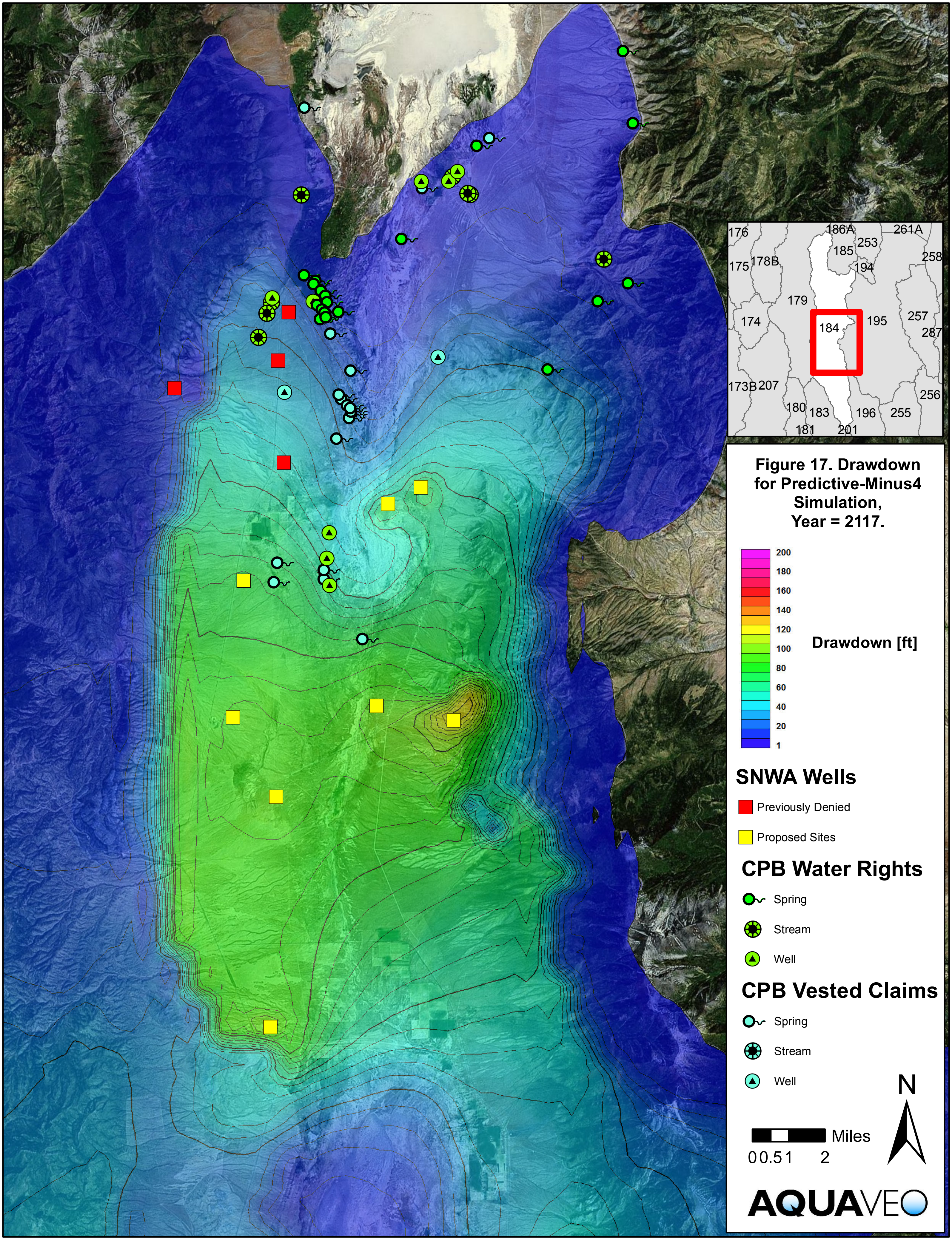

Figure 17. Drawdown for Predictive-Minus4 Simulation, Year = 2117.

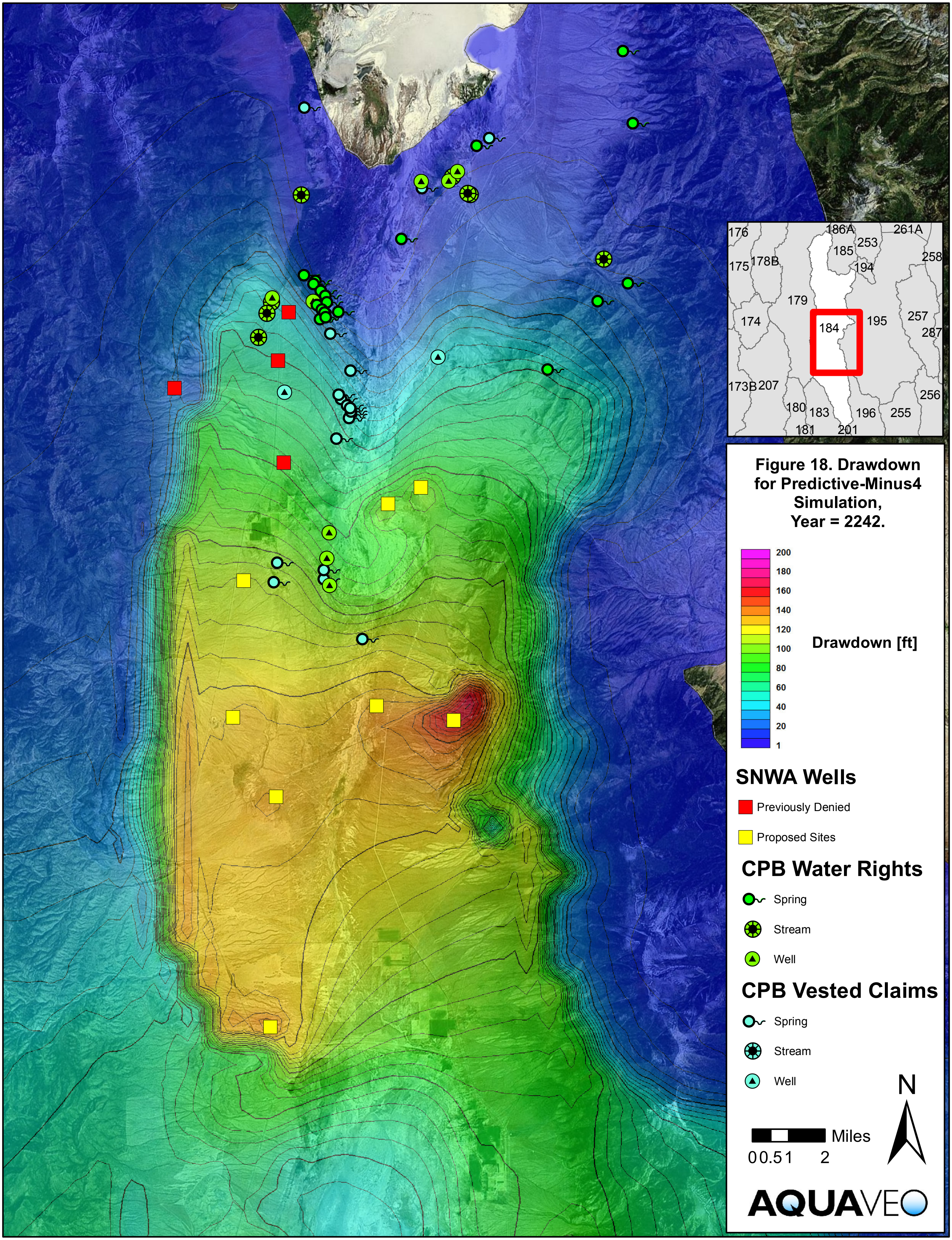

Figure 18. Drawdown for Predictive-Minus4 Simulation, Year = 2242.

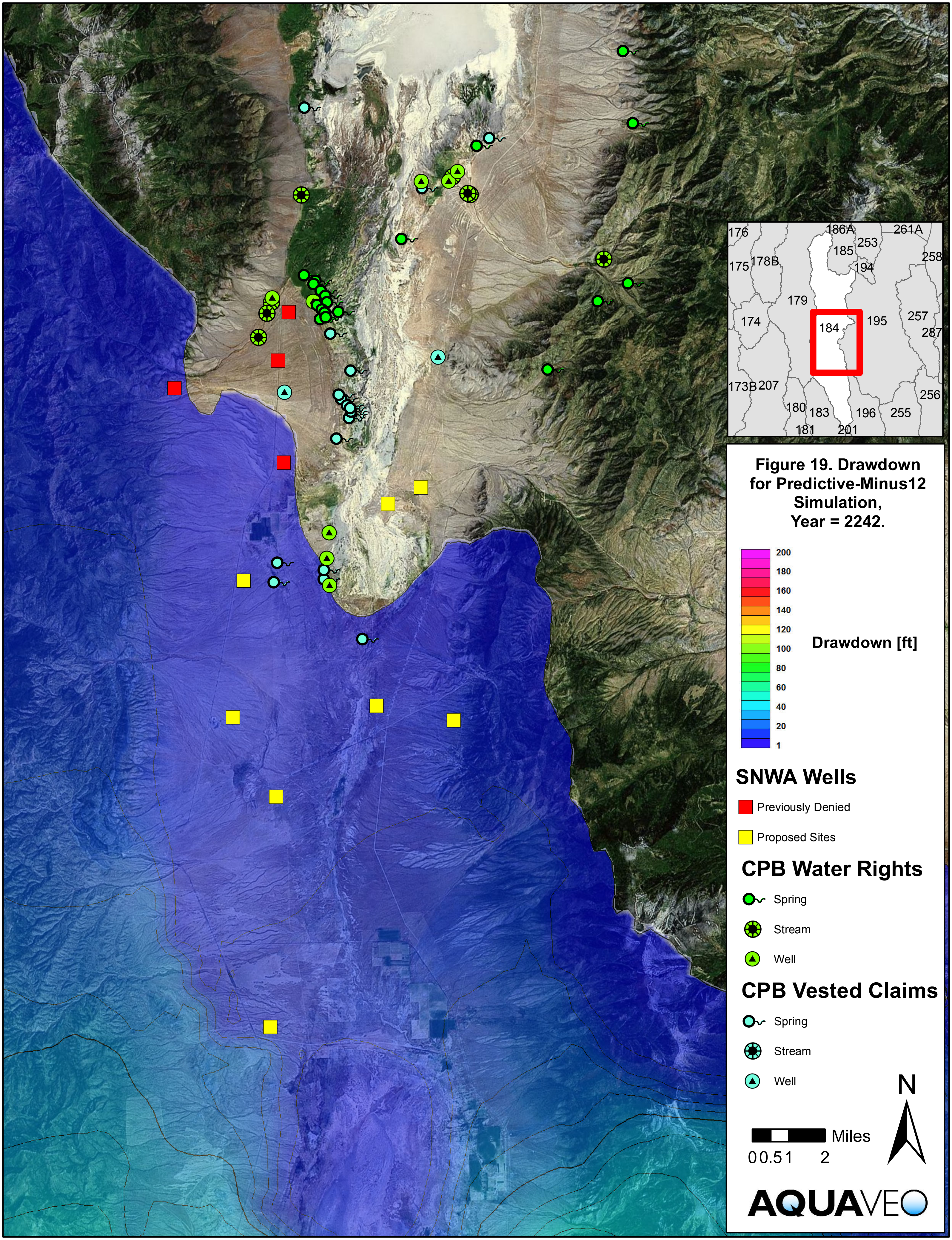

Figure 19. Drawdown for Predictive-Minus12 Simulation, Year = 2242.

Time Series

In addition to the drawdown maps, we performed a detailed analysis of the simulated drawdown vs. time at each of the CPB water rights locations. To do this, we used the Observation (OBS) Process in MODFLOW. The MODFLOW model calculates head (water table elevation) values at the centers of each of the grid cells at specific points in time corresponding to the model time steps. The OBS Process is used to calculate model-simulated head (water table elevation) values at selected locations in the model domain which may not coincide with grid-cell centers or the output time intervals. Head values are interpolated from grid cell centers to the selected locations using a bilinear interpolation algorithm. If necessary, head values are also interpolated in time. The spatial interpolation is especially important for the SNWA model because it is a regional model, and the grid-cell sizes used by the model are large relative to the distribution of water rights features of interest in Spring Valley as shown in Figure 20.

In addition to head interpolation, the OBS Process can also be used to calculate model-simulated discharges between grid cells and external sources and sinks including drains, lakes, and rivers. The OBS Process is typically used as part of the model calibration process in order to compare model-simulated heads and flows to field-observed heads and flows measured at monitoring wells and gauging stations. In this case, we use the OBS Process to interpolate the simulated heads from the cell centers to the CPB water rights locations. No temporal interpolation is necessary; rather, we evaluate the simulated values at all of the model output time steps.

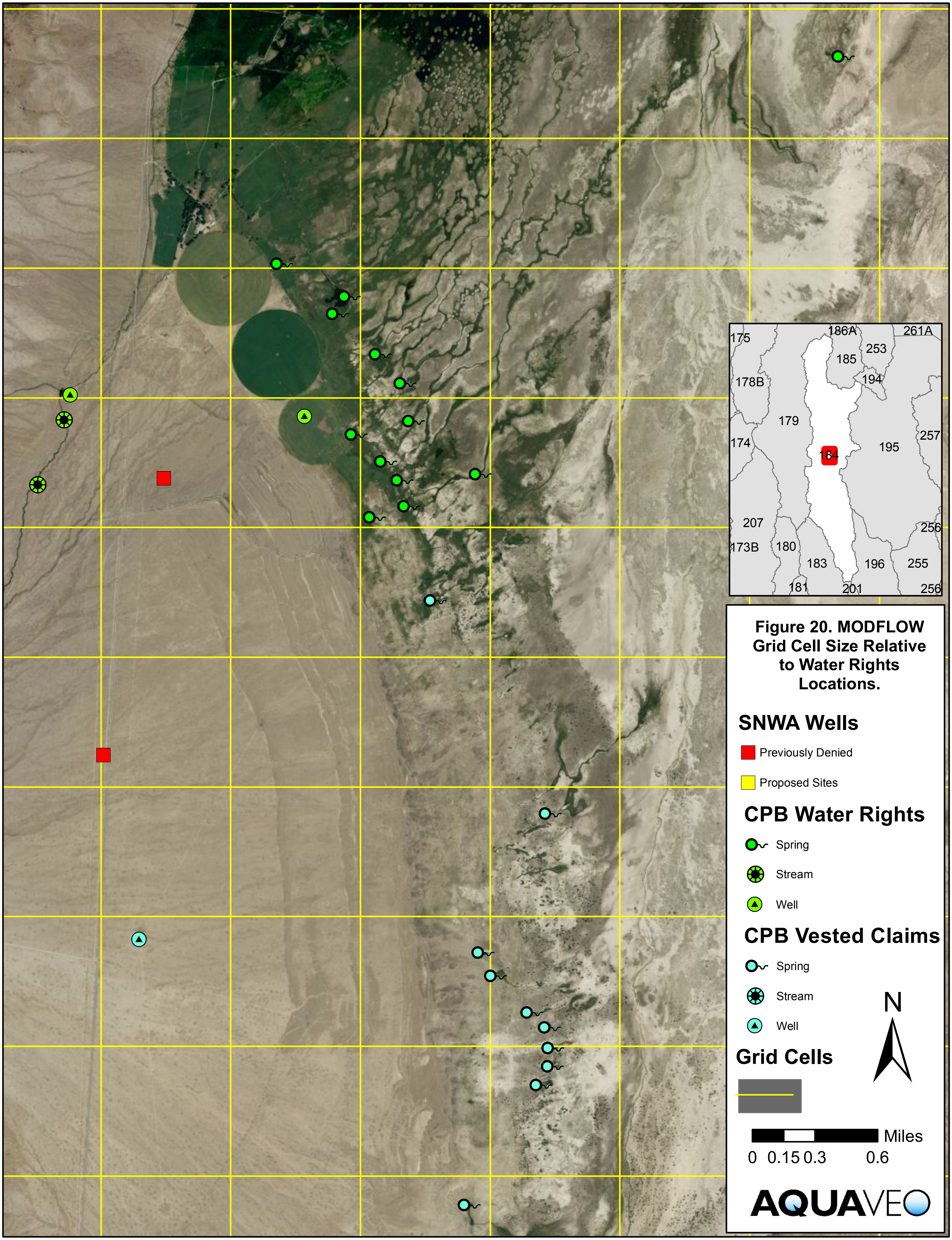

Figure 20. MODFLOW Grid Cell Size Relative to Water Rights Locations.

To utilize the OBS process, we created an HOB file containing the locations of the CPB water rights and re-ran each of the four models (Baseline, Predictive-Full, Predictive-Minus4, and Predictive-Minus12) with the OBS Process active. Running the OBS Process does not affect any of the other MODFLOW inputs and does not alter the model results. It simply generates a more detailed set of model outputs for analysis. The resulting OBS Process output files were imported to Excel and drawdown was computed at each of the CPB water rights locations by subtracting the baseline heads from the heads for each of the predictive model runs. A representative chart of head vs time is shown in Figure 21. The baseline head is shown in blue and the head associated with the Predictive-Full simulation at the location of the spring is shown in red. The difference between the predicted and baseline head represents the drawdown. As can be seen, the chart shows a steady downward trend and **the drawdown never reaches a steady-state condition** representing sustainable conditions. A full set of drawdown charts for all of the CPB water rights locations corresponding to wells and springs can be found in Appendix B. Each of the plots indicates the same type of steady decrease in water level over the entire duration of the simulation.

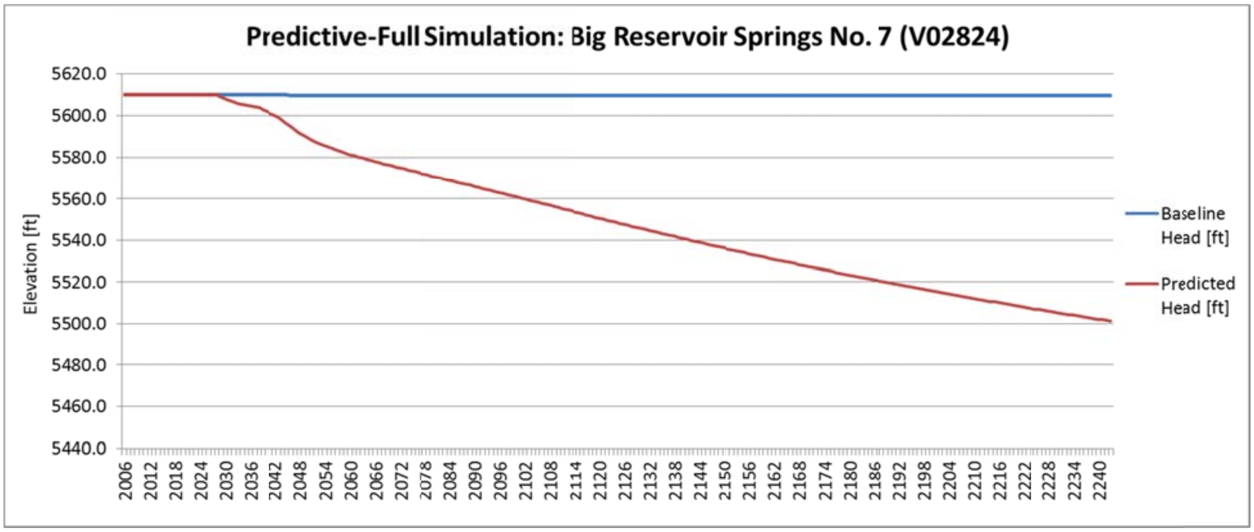

Figure 21 Simulated Head vs. Time for Big Reservoir Springs No. 7.

A summary of the maximum drawdown values at each of the CPB water rights locations corresponding to wells and springs located in the alluvial fan or valley floor is shown in Table 7. The drawdown values from the Predictive-Full simulation exceed the arbitrary 50 ft threshold used by Watrus and Drici for most of the water rights locations, including several locations for the Predictive-Minus4 simulation. In some cases, the drawdown exceeds 180 ft.

Table 7 Maximum Predicted Drawdown at Wells and Springs Located in the Alluvial Fan or Valley Floor.

		Max Drawdown [ft]		
Name	**Permit**	**Full**	**Minus4**	**Minus12**
Mud Springs 1,2, and 3	3973	-35.7	-4.7	0.0
South Millick Spring	8721	-15.6	-4.0	0.0
Bastian Creek Allotment	18841	-159.7	-78.8	-0.5
Bastian Creek Allotment	18842	-167.4	-94.1	-1.0
Bastian Creek Allotment	18843	-163.5	-86.4	-0.8
Cleveland Creek Supp	54204	-102.2	-19.3	-0.3
Cleveland Creek Supp	54205	-141.6	-37.6	-0.6
T Property	67333	-18.3	-3.0	0.0
Rogers Area Supp	69726	-23.2	-5.4	0.0
Rogers Area Supp	69727	-21.2	-5.1	0.0
Murphy Springs	V02817	-72.9	-8.9	-0.1
Big Reservoir Springs No. 1	V02818	-68.8	-7.3	-0.1
Big Reservoir Springs No. 2	V02819	-72.1	-8.1	-0.1
Big Reservoir Springs No. 3	V02820	-75.6	-9.4	-0.1
Big Reservoir Springs No. 4	V02821	-97.6	-17.3	-0.2
Big Reservoir Springs No. 5	V02822	-78.5	-10.3	-0.1
Big Reservoir Springs No. 6	V02823	-84.3	-12.0	-0.1
Big Reservoir Springs No. 7	V02824	-108.4	-22.2	-0.3
Big Reservoir Springs No. 8	V02825	-97.9	-17.0	-0.2
Big Reservoir Springs No. 9	V02826	-97.1	-16.8	-0.2
Big Reservoir Springs No. 10	V02827	-99.3	-18.1	-0.2
Big Reservoir Springs No. 11	V02828	-84.4	-12.0	-0.1
South Bastian Spring 2	P01	-166.6	-92.5	-1.0
South Bastion Spring	P02	-164.7	-89.3	-0.9
Cleveland Ranch Spring - North	P03	-107.9	-22.9	-0.2
Cleveland Ranch Spring - South	P04	-113.2	-29.3	-0.2
Cleveland Well	P05	-167.9	-57.5	-0.9
Fera Well	P06	-102.1	-38.6	-0.3
Layton Spring	P08	-178.3	-114.7	-2.0
North Cleveland Unit Spring	P09	-8.7	-1.5	0.0
North Millick Spring	P10	-14.4	-3.8	0.0
Rogers Ranch Spring	P11	-21.8	-4.1	0.0
Unnamed Spring #1.1	P13	-133.8	-42.2	-0.4
Unnamed Spring #1.2	P14	-133.6	-42.5	-0.4
Unnamed Spring #2.1	P15	-129.9	-41.5	-0.3
Unnamed Spring #2.2	P16	-128.1	-40.9	-0.3
Unnamed Spring #3.1	P17	-128.7	-41.7	-0.2
Unnamed Spring #3.2	P18	-129.8	-42.7	-0.2
Unnamed Spring #3.3	P19	-132.2	-44.4	-0.3
Unnamed Spring #4	P20	-145.1	-53.8	-0.4
Unnamed Spring #7	P21	-183.0	-102.6	-2.0
Unnamed Spring #8	P22	-185.8	-108.3	-2.3

Subsidence

The drawdown maps and the time series analysis illustrate that the SNWA model predicts extreme amounts of drawdown will occur in central Spring Valley in the vicinity of the CPB water rights. When an aquifer dewaters to this extent, the soil and rock particle in the aquifer lose the buoyancy effect of the water and are subjected to a greatly increased inter-particle stress. This stress causes the aquifer matrix to consolidate leading to ground subsidence. With drawdown levels as high as 185 ft, the subsidence levels are likely to be severe. In addition to subsidence, aquifer consolidation results in a permanent loss of storage capacity. Since soils are inelastic and exhibit hysteresis, the void space in the aquifer prior to dewatering would never be fully recovered, even if the water levels were allowed to rebound to pre-pumping conditions.

Effect of Coarse Grid Resolution

As mentioned above, the SNWA model is a regional model covering an extensive part of Southeastern Nevada, of which Spring Valley is only a small part. As a result, the grid cells used in the simulation are large relative to the distribution of the water rights locations. This fact leads to uncertainty when analyzing simulated water levels at specific points. The region of the SNWA model in the vicinity of the ranch property is shown in Figure 22. The colored lines are drawdown contours from year 2242 for the Predictive-Full simulation. The contours illustrate a large degree of drawdown in the coarse-grained alluvial deposits to the south and west of the ranch. The center of Spring Valley is filled with fine-grained deposits and playas that have a lower hydraulic conductivity than the coarse-grained alluvial deposits.

Many of the CPB water rights are wells and springs located on the edge of alluvial fan deposits near the Cleveland Ranch. The transition from high-permeability coarse-grained deposits to low-permeability fine-grained deposits results in a rapid change in head/drawdown as indicated by the closely-packed contours. Since the water rights locations are located on the boundary of the transition, they are extremely sensitive to the location of the boundary in the model marking the transition between the coarse-grained alluvial fan and the finer-grained playa materials.

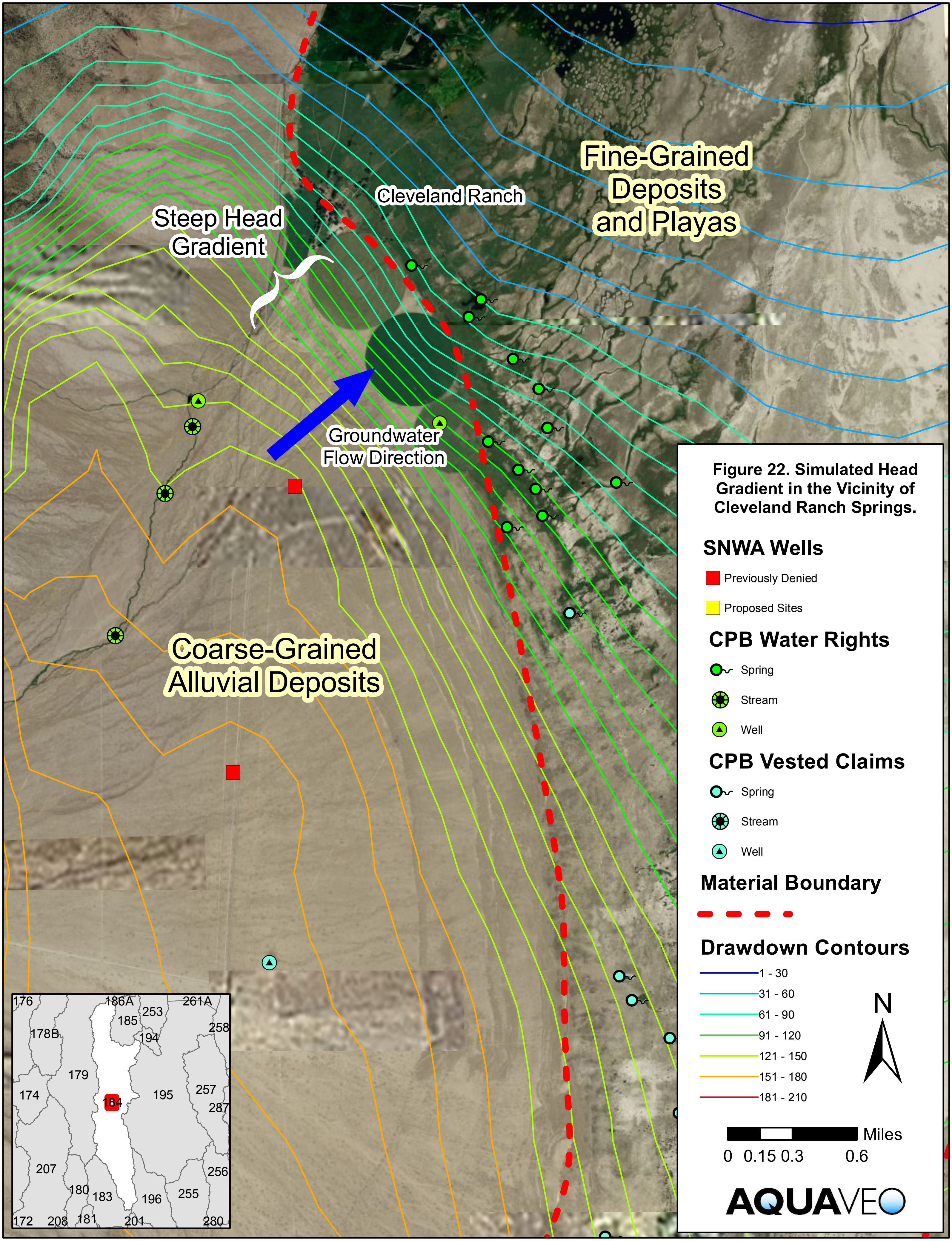

Figure 22. Simulated Head Gradient in the Vicinity of Cleveland Ranch Springs.

The hydraulic conductivity (K) values used by the SNWA model are associated with the inputs to the Hydrogeologic Unit Flow (HUF) Package. The HUF package is an alternative to the Block-Centered Flow (BCF) and Layer Property Flow (LPF) Packages in MODFLOW. For both the BCF and LPF packages, the user directly inputs K values on a cell-by-cell basis. The HUF package allows the user to represent the vertical layering and spatial distribution of the hydrogeologic units separately from the model grid cells. The cell-by-cell K values are then calculated by overlaying the hydrogeologic units with each grid cell and calculating an aggregate vertical and horizontal K for the cell. These calculations are performed internally to the MODFLOW code at run time. The hydrogeologic units used by the HUF Package in the SNWA model are based on the conceptual model described in SNWA (2009a) and a set of multiplier arrays that define a lateral variation of hydraulic conductivity in each unit.

The MODFLOW code distributed with the SNWA July 1, 2011 exhibits contained a set of modifications made to the code. The modifications included a utility to export the aggregate K values computed internally to the HUF Package. We used this utility to export the HUF K values for layer 2 so that we could examine the distribution of K values in the vicinity of the ranch. The resulting K values are shown in Figure 23. In valley systems such as this with substantial alluvial deposits, one normally expects to find the highest K values on extreme edges of the alluvial deposits near the base of the mountains and the K values gradually decrease towards the center of the valley. This is a result of the coarser and heavier materials depositing first, following by increasingly finer materials as the mountain runoff moves to the valley center. However, the green-colored cells indicate that the SNWA model includes a set of cells (marked in green) with a low K value directly between the higher K alluvial deposits (dark red) and lower K deposits in the valley center (yellow). These cells have a lower K value than the valley fill materials in the center and do not follow the typical grain size trend described above. This set of lower K values results in a barrier that causes a large head gradient near the ranch. This gradient results in a significantly lower set of simulated drawdown values at the CPB water rights locations at the fringe of the alluvium. The actual drawdown levels in these locations are likely to be greater than the simulated drawdown levels predicted by the model.

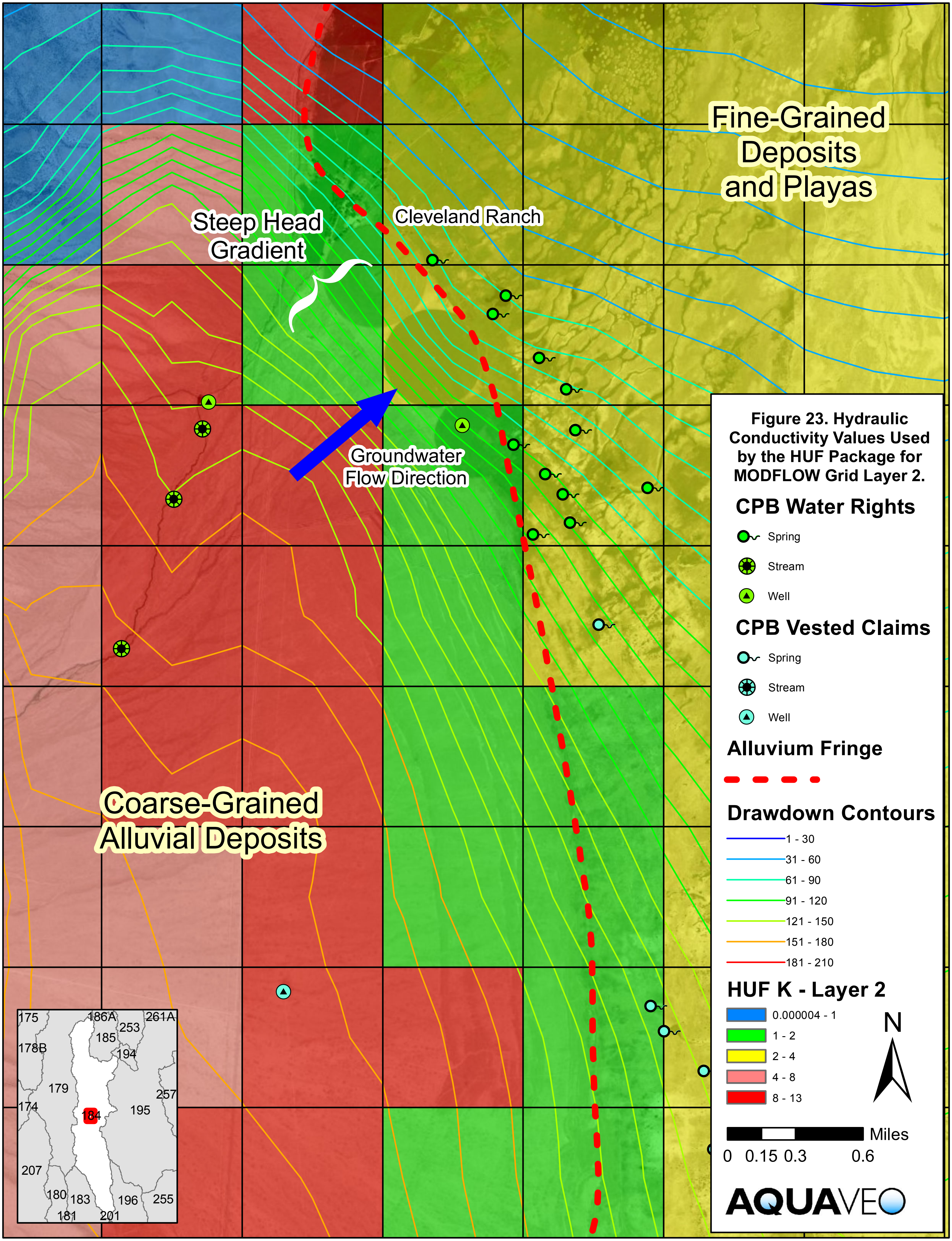
Figure 23. Hydraulic Conductivity Values Used by the HUF Package for MODFLOW Grid Layer 2.

Impact on Springs

Of the 56 CPB-owned water rights and vested claims in Spring Valley, 48 are associated with wells and springs (Table 1). Of this number, 38 are associated with springs. Of this number 20 are associated with existing water rights and 18 are associated with vested claims. Most of the springs occur at the edge of the alluvial fans. In the previous section it was shown that the SNWA wells will cause substantial drawdown at the well and spring locations. In this section, we examine the impact that the drawdown will have on the springs.

Springs are typically simulated in the MODFLOW model using the Drain Package. The inputs and equations used by the Drain Package are illustrated in Figure 24. Since the Drain Package is often used to simulate discharge through agricultural drains, it is often conceptualized as shown in Figure 24 by a pipe and a set of lower permeability materials (shown in yellow) between the aquifer at the drain. A conductance value (CD) is associated with the intermediate materials that is a function of the geometry (thickness, length) and the hydraulic conductivity of the materials. The term Delev represents the elevation of the drain and H_{ijk} is the simulated head value at the model grid cell associated with the drain. If the simulated head value is above the elevation of the drain, water discharges from the aquifer to the drain at a rate equal to the conductance term times the difference in elevation between the drain elevation and the head (a negative sign on the discharge denotes water leaving the aquifer). However, if the simulated head is below the drain elevation, the discharge is zero and the drain has no effect on the aquifer system.

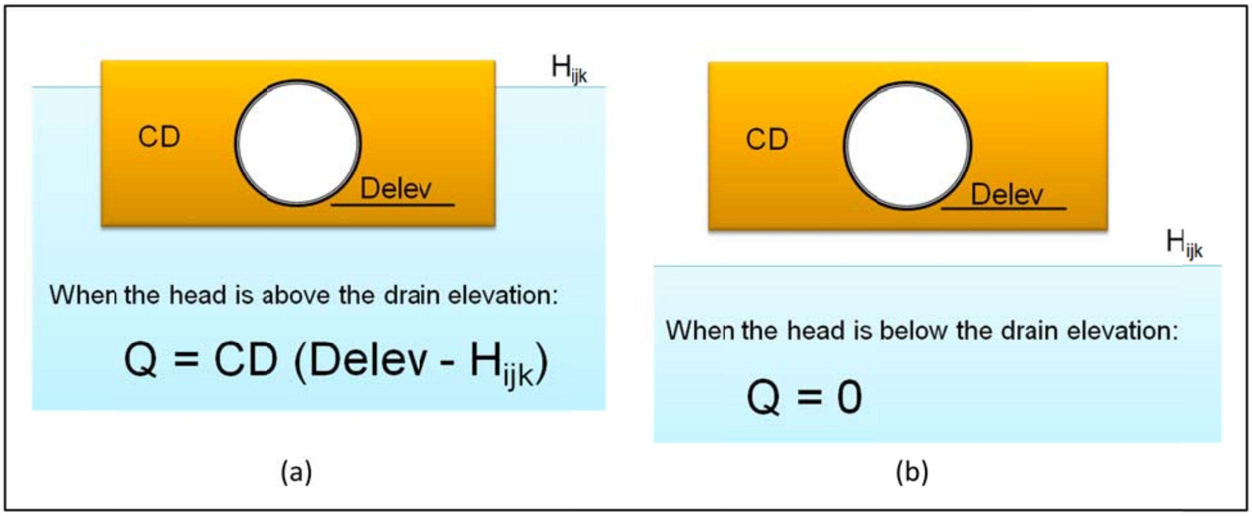

Figure 24 Drain Package Calculations when Simulated Head is (a) Above, and (b) Below the Drain Elevation.

One of the objectives of the study reported by Watrus and Drici (SNWA, 2011b) was to analyze the impact that the proposed SNWA wells will have on the springs in Spring Valley that are associated with existing water rights. Table B-1 of the SNWA report lists which of the CPB water rights were included in the model. According to this table, 14 of the 20 CPB-owned springs associated with existing water rights were included in the model (3973, 8721, V02817-V02828). Some springs were not included because they are located in mountain zones and are thought to be tied to perched bedrock aquifers. Of the 14 that were included, only one (8721 – South Millick Spring) was said to be calibrated during the regional calibration process. Calibration typically involves adjusting the drain conductance until the simulated discharge to the spring matches the field-observed discharge. The simulated head also contributes to the discharge, so adjusting other model features (hydraulic conductivity, recharge, etc.) in order to get more accurate simulated heads in the vicinity of the drain can also be part of the calibration process.

In addition to simulating springs, the Drain Package was used in the SNWA model to simulate evapotranspiration (ET) in the middle of Spring Valley as shown in Figure 25. For each cell in the ET zone, an elevation corresponding to the ET extinction depth was assigned as the drain elevation and a conductance value was assigned that was scaled to calculate an appropriate ET discharge value for the cell for cases where the simulated head is above the ET extinction depth.

With the Drain Package it is possible to associate multiple drain instances with a single cell. For example, both ET discharge and discharge to a spring could be simulated in the same cell by associating two drain objects with the cell, each with a unique set of conductance and elevation values. We examined the input to the Drain Package in the SNWA model to locate the 14 springs that were explicitly represented in the model according to Table B-1 in SNWA (2011b). Of these 14 springs, we were only able to locate one (8721 – South Millick Spring) that was simulated with a unique drain object. For each of the other 13 locations, the springs were located in an ET zone and there was a single drain object in each cell. The drain elevations in these cells were an average of 20 ft below the estimated ground surface elevations, indicating that the drain elevations were assigned based on ET extinction depths and not to simulate spring flow. For free-flowing springs, one would typically expect the elevation to be approximately equal to the ground surface elevation. The significance of this is that use of the drain package for springs does not explicitly model the impact of well pumping on springs.

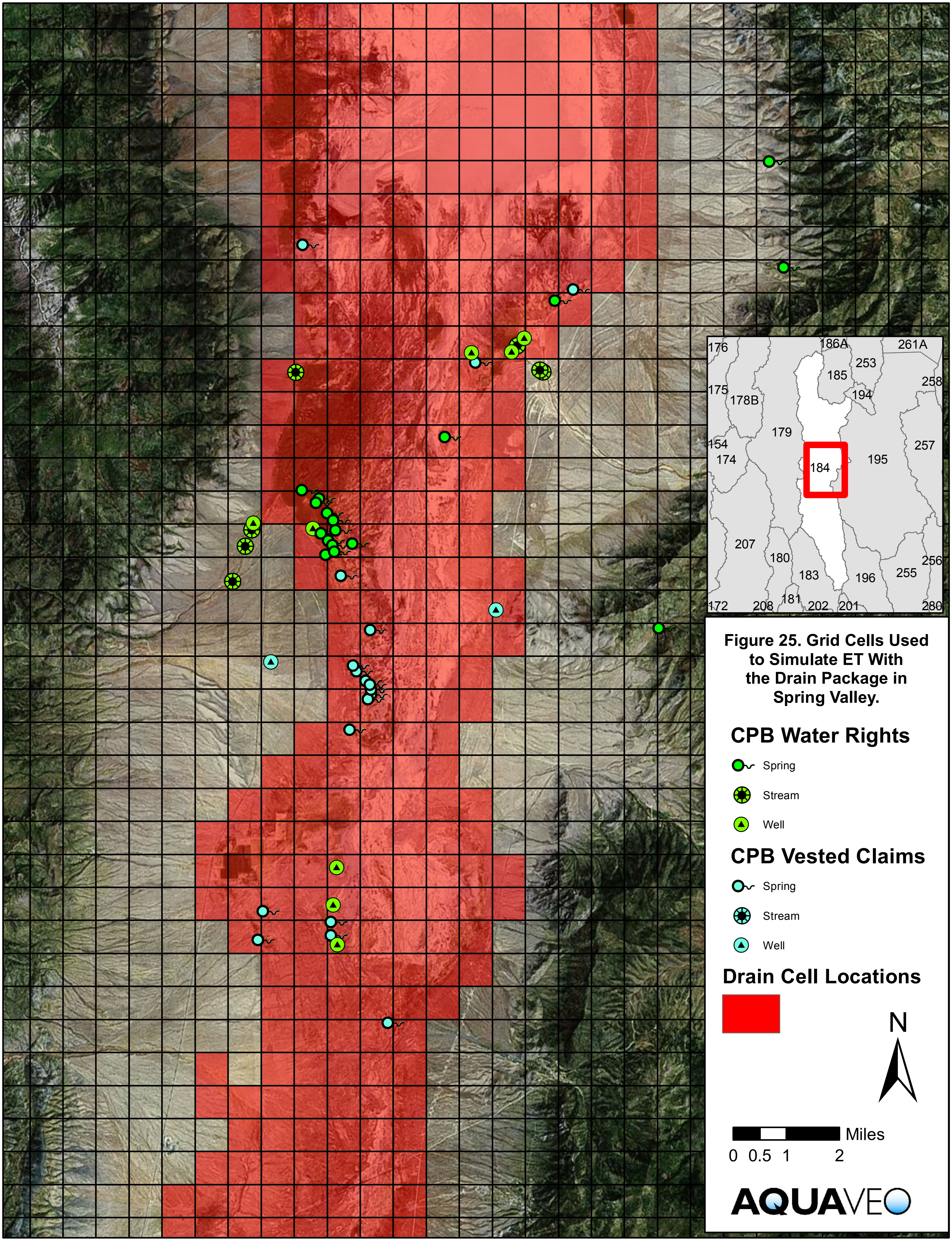

Figure 25. Grid Cells Used to Simulate ET With the Drain Package in Spring Valley.

The fact that most of the springs were not explicitly represented in the model means that we cannot use the OBS process to analyze the model simulated discharge to the springs. This discharge should go to zero once the simulated head drops below the spring elevation. However, if we examine the simulated heads at the water table locations output by the OBS process (as described in the previous section), we can compare these elevations to the spring elevations in an attempt to estimate when the springs will go dry. The springs will go dry when the head drops below the ground surface elevation as shown by the intersection of the solid red line and the dotted green line in Figure 26. When conducting this type of analysis, the emphasis should be on overall trends since there is considerable uncertainty with the data associated with individual sites. This uncertainty comes from a number of factors, including but not limited to the following:

- **Impact of coarse grid resolution**. The large grid cells used in the regional model can introduce significant error at individual locations even if the model is relatively accurate on a regional scale. This is especially true with springs since they are strongly impacted by local scale conditions such as fissures and localized confinement which leads to vertical head gradients. The model-simulated head represents an average value over the entire layer thickness, which is approximately 500 ft in this portion of the regional model.
- **Elevation error**. The ground surface elevations may not be precise. We obtained the elevations at each of the spring locations by interpolating from a one-arc-second USGS digital elevation model downloaded from the USGS website (seamless.usgs.gov, 2011). We checked these interpolated values with a site survey at selected locations and found good agreement.
- **Model calibration error**. No groundwater model is expected to precisely match field observations. A model may match overall trends in an aquifer while exhibiting a poor match between observed and simulated heads at certain locations in the model domain.

In other words, when looking at an individual spring the point in time at which the spring is predicted to go dry may be off by several years (either too early or too late), but the overall trends provides an estimate of when the springs will go dry.

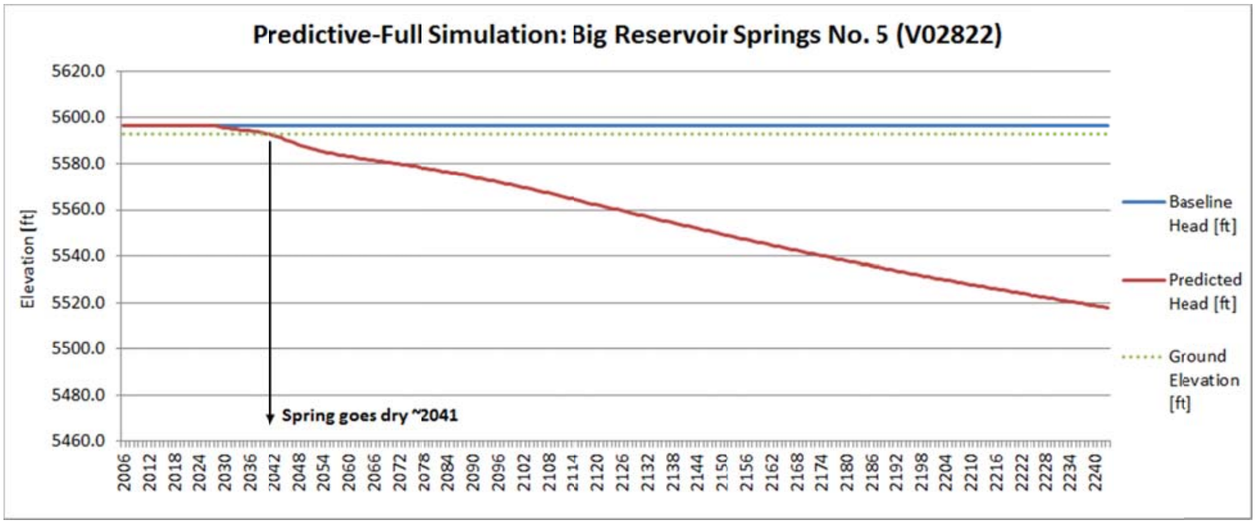

Figure 26 **Simulated Head Relative to Spring Elevation.**

Predictive-Full Simulation

We analyzed each of the CPB water rights and vested claims corresponding to springs on the alluvial fan or valley floor in this fashion based on the Predictive-Full simulation and the results are shown in Table 8. A corresponding timeline illustrating when each spring goes dry is shown in Figure 27. All 14 of the springs go dry after a short period of time. For 27 of the 32 springs, the simulated heads at the beginning of the simulation were at or below the ground surface elevation (typically by a few feet). Since the springs are all currently flowing, the simulated heads in this region of the model must be too low by some degree. This could be due to any of the uncertainty factors described above, but since we validated the elevations at spring locations, it is most likely due to model calibration error and coarse grid resolution as described above. Nevertheless, with the extreme drawdown values at these locations shown previously in Table 7 there is little question that the springs will rapidly go dry. Indeed, the SNWA application is based on the concept of ET-salvage, which by definition involves elimination of surficial discharge of groundwater.

Table 8 Impact to Alluvial Fan and Valley Floor Springs, Predictive-Full Simulation.

Name	Permit	Goes Dry?	Year
Mud Springs 1,2, and 3	3973	Yes*	2029
South Millick Spring	8721	Yes*	2029
Murphy Springs	V02817	Yes*	2029
Big Reservoir Springs No. 1	V02818	Yes*	2044
Big Reservoir Springs No. 2	V02819	Yes	2040
Big Reservoir Springs No. 3	V02820	Yes	2045
Big Reservoir Springs No. 4	V02821	Yes*	2029
Big Reservoir Springs No. 5	V02822	Yes	2041
Big Reservoir Springs No. 6	V02823	Yes	2041
Big Reservoir Springs No. 7	V02824	Yes*	2029
Big Reservoir Springs No. 8	V02825	Yes*	2029
Big Reservoir Springs No. 9	V02826	Yes*	2029
Big Reservoir Springs No. 10	V02827	Yes*	2029
Big Reservoir Springs No. 11	V02828	Yes*	2029
South Bastian Spring 2	P01	Yes*	2029
South Bastion Spring	P02	Yes*	2029
Cleveland Ranch Spring - North	P03	Yes*	2029
Cleveland Ranch Spring - South	P04	Yes*	2029
Layton Spring	P08	Yes*	2029
North Cleveland Unit Spring	P09	Yes*	2029
North Millick Spring	P10	Yes*	2029
Rogers Ranch Spring	P11	Yes*	2029
Unnamed Spring #1.1	P13	Yes*	2029
Unnamed Spring #1.2	P14	Yes*	2029
Unnamed Spring #2.1	P15	Yes*	2029
Unnamed Spring #2.2	P16	Yes*	2029
Unnamed Spring #3.1	P17	Yes*	2029
Unnamed Spring #3.2	P18	Yes*	2029
Unnamed Spring #3.3	P19	Yes*	2029
Unnamed Spring #4	P20	Yes*	2029
Unnamed Spring #7	P21	Yes*	2029
Unnamed Spring #8	P22	Yes*	2029

**Dry at beginning of simulation.*

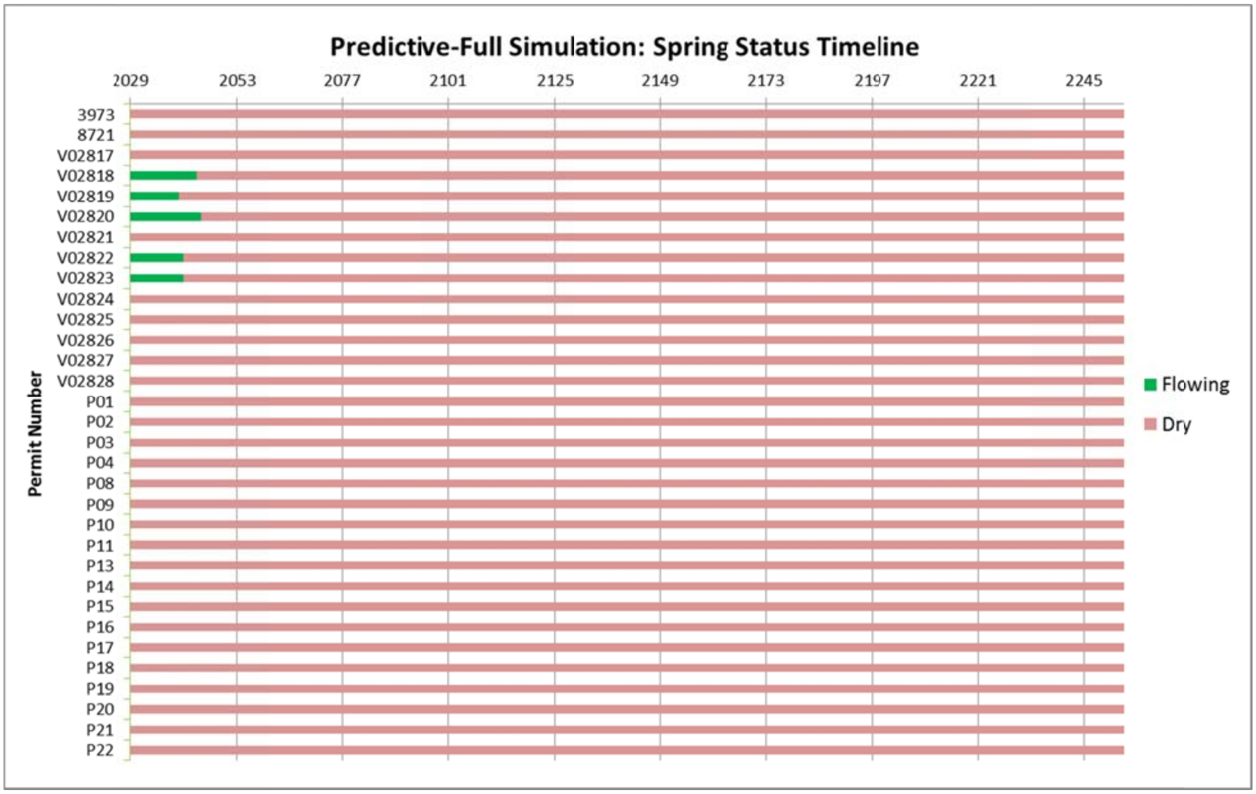

Figure 27 **Timeline Indicating When Valley Floor Springs go Dry, Predictive-Full Simulation.**

Predictive-Minus4 Simulation

We repeated the spring impact analysis for the Predictive-Minus4 simulation and the results are shown in Table 9 and Figure 28. Once again, the model results indicate that all of the springs go dry.

Table 9 Impact to Alluvial Fan and Valley Floor Springs, Predictive-Minus4 Simulation.

Name	Permit	Goes Dry?	Year
Mud Springs 1,2, and 3	3973	Yes*	2029
South Millick Spring	8721	Yes*	2029
Murphy Springs	V02817	Yes*	2029
Big Reservoir Springs No. 1	V02818	Yes	2044
Big Reservoir Springs No. 2	V02819	Yes	2040
Big Reservoir Springs No. 3	V02820	Yes	2045
Big Reservoir Springs No. 4	V02821	Yes*	2029
Big Reservoir Springs No. 5	V02822	Yes	2041
Big Reservoir Springs No. 6	V02823	Yes	2041
Big Reservoir Springs No. 7	V02824	Yes*	2029
Big Reservoir Springs No. 8	V02825	Yes*	2029
Big Reservoir SPrings No. 9	V02826	Yes*	2029
Big Reservoir Springs No. 10	V02827	Yes*	2029
Big Reservoir Springs No. 11	V02828	Yes*	2029
South Bastian Spring 2	P01	Yes*	2029
South Bastion Spring	P02	Yes*	2029
Cleveland Ranch Spring - North	P03	Yes*	2029
Cleveland Ranch Spring - South	P04	Yes*	2029
Layton Spring	P08	Yes*	2029
North Cleveland Unit Spring	P09	Yes*	2029
North Millick Spring	P10	Yes*	2029
Rogers Ranch Spring	P11	Yes*	2029
Unnamed Spring #1.1	P13	Yes*	2029
Unnamed Spring #1.2	P14	Yes*	2029
Unnamed Spring #2.1	P15	Yes*	2029
Unnamed Spring #2.2	P16	Yes*	2029
Unnamed Spring #3.1	P17	Yes*	2029
Unnamed Spring #3.2	P18	Yes*	2029
Unnamed Spring #3.3	P19	Yes*	2029
Unnamed Spring #4	P20	Yes*	2029
Unnamed Spring #7	P21	Yes*	2029
Unnamed Spring #8	P22	Yes*	2029

**Dry at beginning of simulation.*

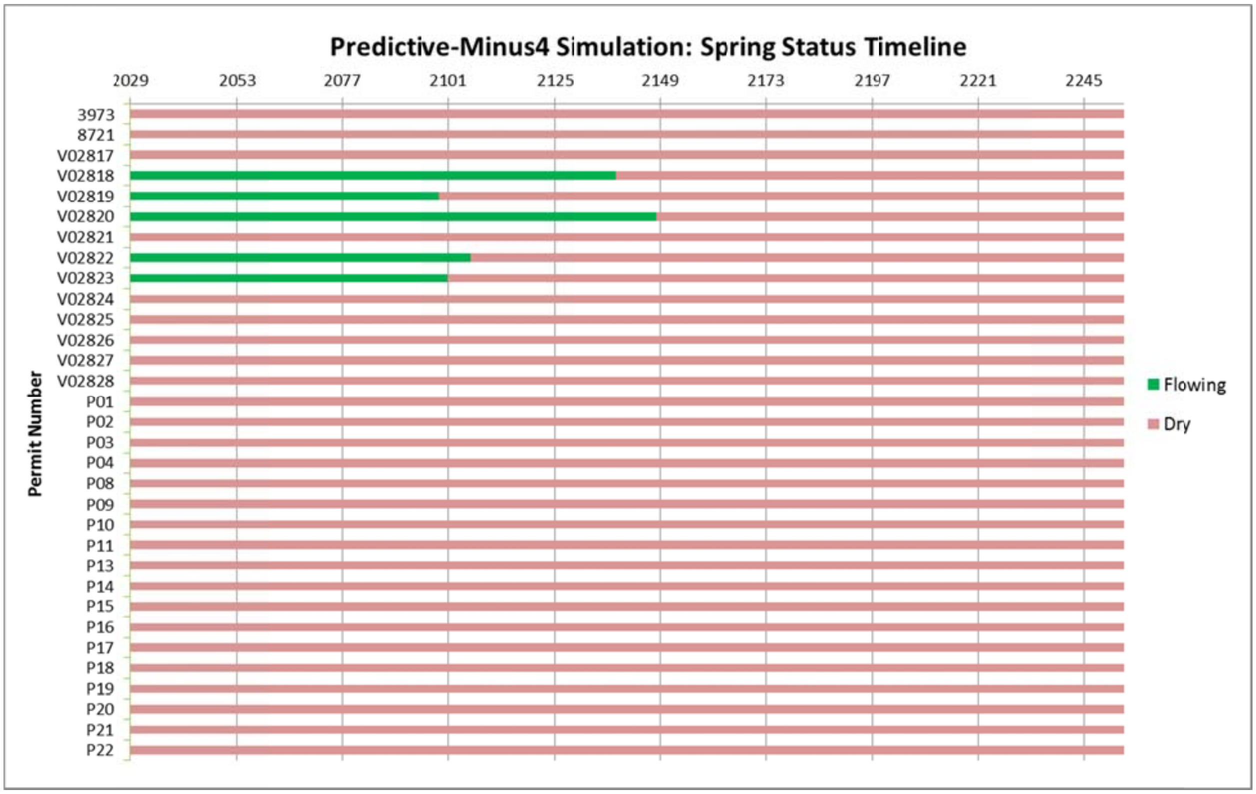

Figure 28 **Timeline Indicating When Valley Floor Springs go Dry, Predictive-Minus4 Simulation.**

Flow Budget Analysis and Groundwater Mining

Next, we analyze the flow budget for the regional model to determine the source of the water used by the proposed SNWA wells based on the SNWA model results. We took the output from each of the predictive models and processed it using a USGS utility called ZONEBUDGET (water.usgs.gov/nrp/gwsoftware/zonebud3/zonebudget3.html, 2011). ZONEBUDGET is used to compute flow budget summaries for selected subregions in the model. It calculates flowrates (both IN and OUT) for each type of source or sink object in a model at selected output time steps. Prior to running ZONEBUDGET we marked each of the MODFLOW grid cells inside of Spring Valley as a single zone and we created a zone for each of the valleys directly adjacent to Spring Valley as shown in Figure 29.

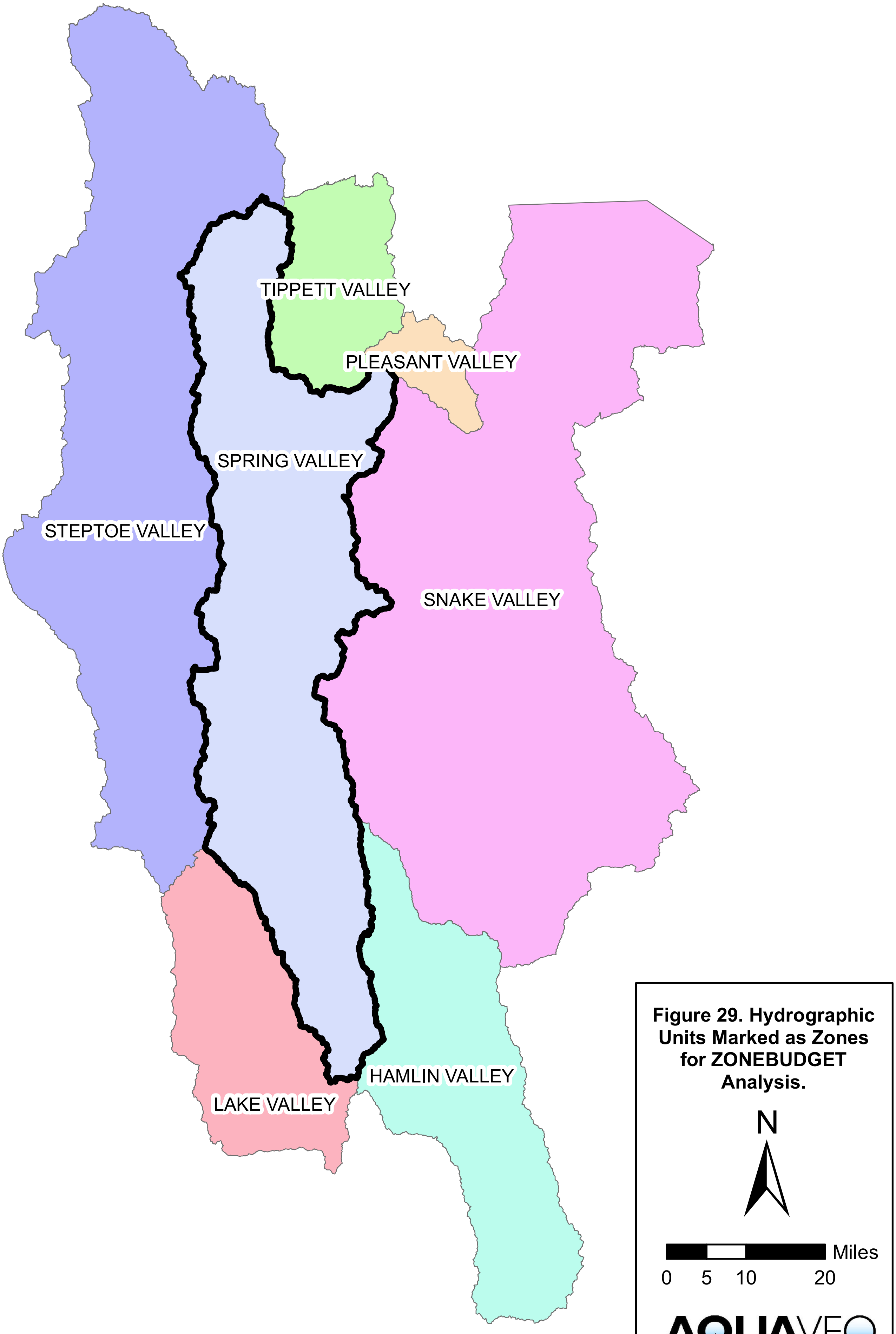

Figure 29. Hydrographic Units Marked as Zones for ZONEBUDGET Analysis.

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The output from ZONEBUDGET was aggregated on a yearly basis to determine an annual sum for each category for each year of the simulation period from 2006-2254. Our objective in this analysis is to determine the source of water extracted by the proposed SNWA wells and how those sources change over time. To do this, we take the flow budget amounts for the predictive simulation and subtract the flow budget amounts from the baseline simulation. The resulting numbers represent the net change in flow budget resulting from the proposed wells. Furthermore, the flow budgets sums are divided into two categories: IN and OUT. Some flow categories (interbasin flow for example) include both water coming into the zone and water leaving the zone. Since we are interested in net flows, we computed a total net flow for each instance representing IN-OUT. After doing so, there are four categories in the flow budget that exhibit a non-zero net change in flow:

1. **Storage**. This number represents change in water stored in the aquifer and helps us determine if ***groundwater mining*** is occurring.
2. **Drains**. The SNWA model includes a set of drains in the middle of the valley to simulate groundwater evapotranspiration (ET). Changes in the discharge to drains resulting from pumping represent ***ET salvage***, or capture of water previously lost to ET. Conceptually, this number also includes capture of water discharged to springs in the valley and water used for sub-irrigation.
3. **Other Sources**. This number represents the change in net flow between Spring Valley and the adjacent valleys via ***interbasin flow***. We analyzed both the total interbasin flow and the flow to each of the adjacent valleys.
4. **Wells**. This number represents the total pumping rate for the proposed SNWA wells. This number is negative and is equal to the sum of the three other categories. In other words, the water used by the proposed wells comes from a combination of groundwater mining (storage), ET and spring capture, and changes in interbasin flow.

Predictive-Full Simulation

The flow budget results produced by ZONEBUDGET for the Predictive-Full simulation are shown in Figure 30-Figure 34. The change in pumping rate vs. time for the SNWA wells is shown in Figure 30. The wells are constructed in a staged fashion, with the first set coming online in 2029 with a pumping rate of 35,000 AFA, followed by a rate of 64,500 AFA beginning in 2039 and a rate of 91,200 AFA starting in 2044 and continuing through 2243. The net change in flow budget for each of the three source categories is shown in Figure 31. The discontinuities in the Storage category result from the staged construction of the SNWA wells. The Drain category (ET salvage) flattens out at about 50,000 AFA, with the Storage category (groundwater mining) at approximately 30,000 AFA and the Other Sources (interbasin flow) category at about 10,000 AFA. It should be noted that the Storage category does not go to zero at any point in the simulation, thus indicating groundwater mining. This is more clearly illustrated in the cumulative flow budget amounts shown in Figure 32. These numbers represent a running total of the net change in flow budget for each of the source categories. The SNWA well system is presumably designed on the concept of ET salvage. As the water table is gradually lowered by the wells, the water table drops below the ET extinction depth and the water previously lost to ET is available for capture by the wells. Once a balance is achieved, the change to ET becomes constant, and the change in storage approaches zero, indicating a sustainable condition. However, Figure 32 clearly illustrates that this is not happening in the simulation. Rather than flattening out, the Storage line continually increases in a near-linear fashion, indicating substantial long-term groundwater mining. The system never approaches a state of equilibrium or sustainability throughout the entire simulation period.

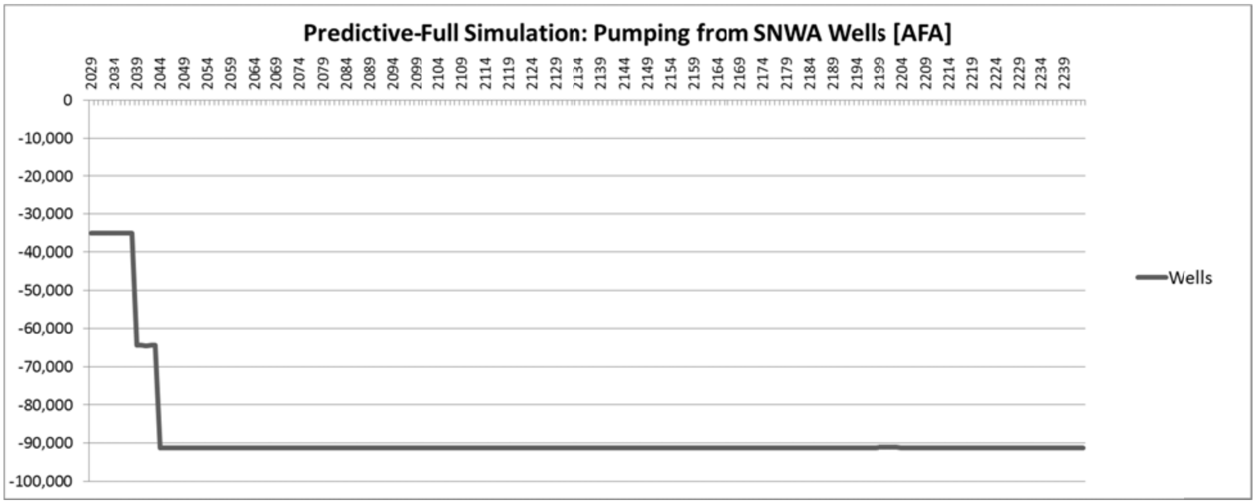

Figure 30 Pumping from SNWA Wells vs. Time for Predictive-Full Simulation.

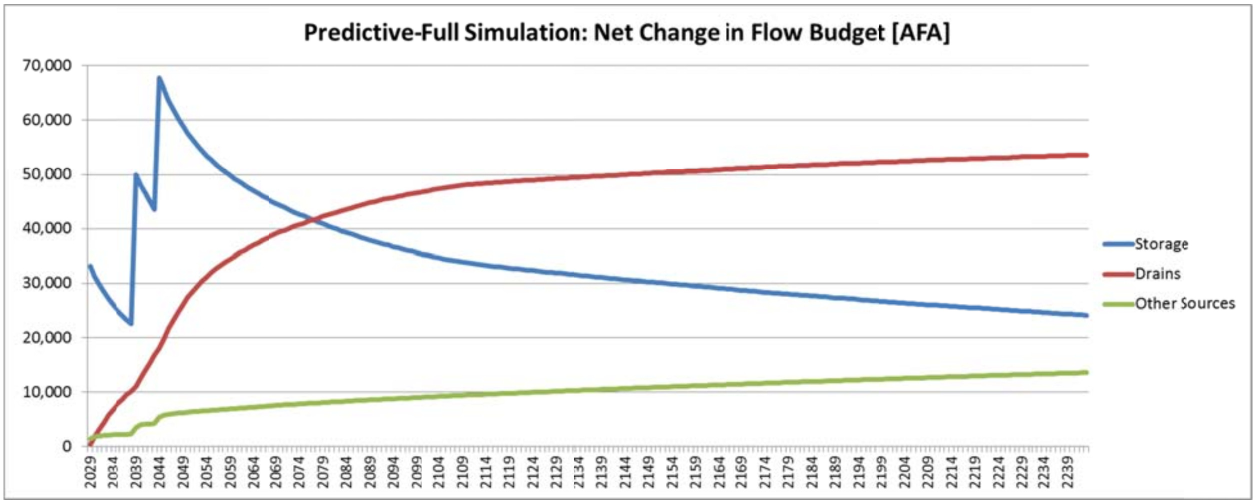

Figure 31 Net Change in Flow Budget for Source Categories for Predictive-Full Simulation.

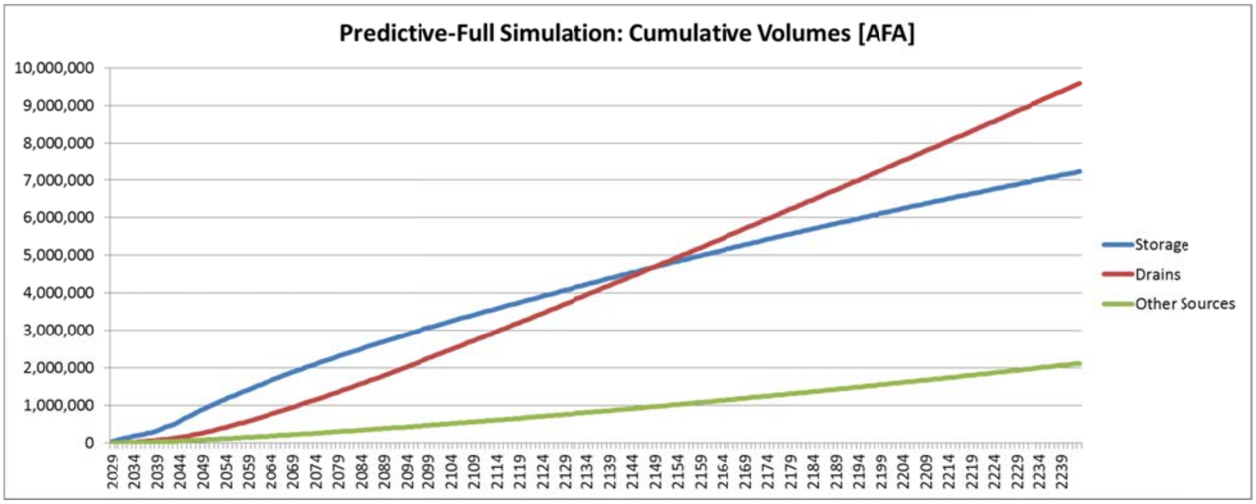

Figure 32 **Cumulative Net Change in Volume for Source Categories for Predictive-Full Simulation.**

The flow budget results can be further analyzed by viewing the source categories as a fraction of total pumping, as illustrated in Figure 33. The sum of the three sources categories equals the total pumping rate. By dividing the flow amounts by the pumping rate we can determine what percentage of pumping rate is associated with each source. In the latter stages of the simulation, net change to Drains (ET salvage) accounts for approximately 55% of the pumping, while Storage (groundwater mining) and Other Sources (interbasin flow) account for approximately 30% and 15%, respectively.

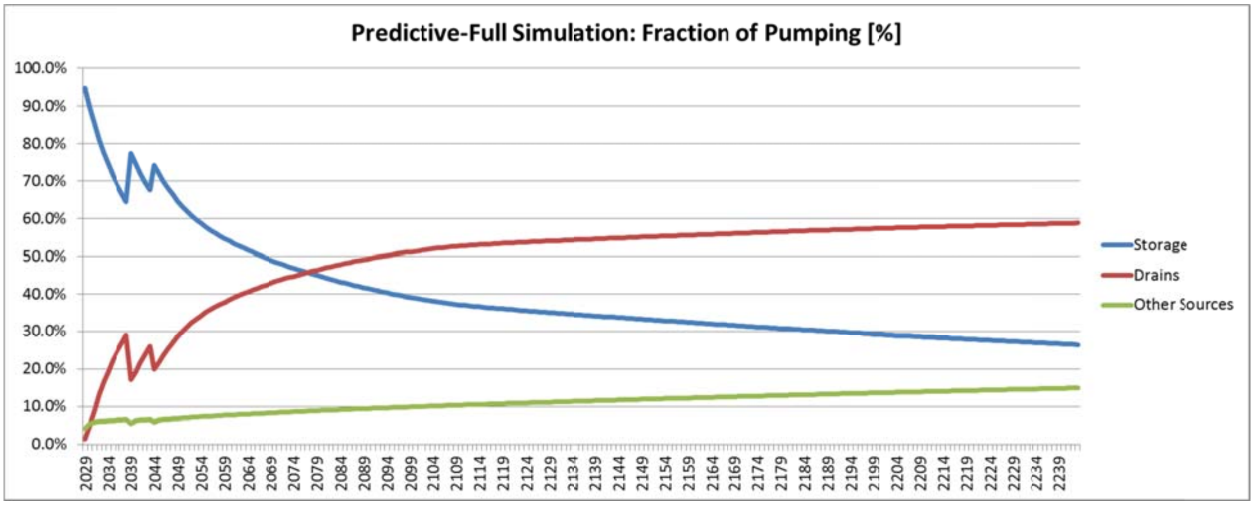

Figure 33 **Fraction of Pumping for Source Categories for Predictive-Full Simulation.**

The source of the net change interbasin flow is shown in Figure 34. Most of the net change is associated with Hamlin, Lake, and Steptoe valleys.

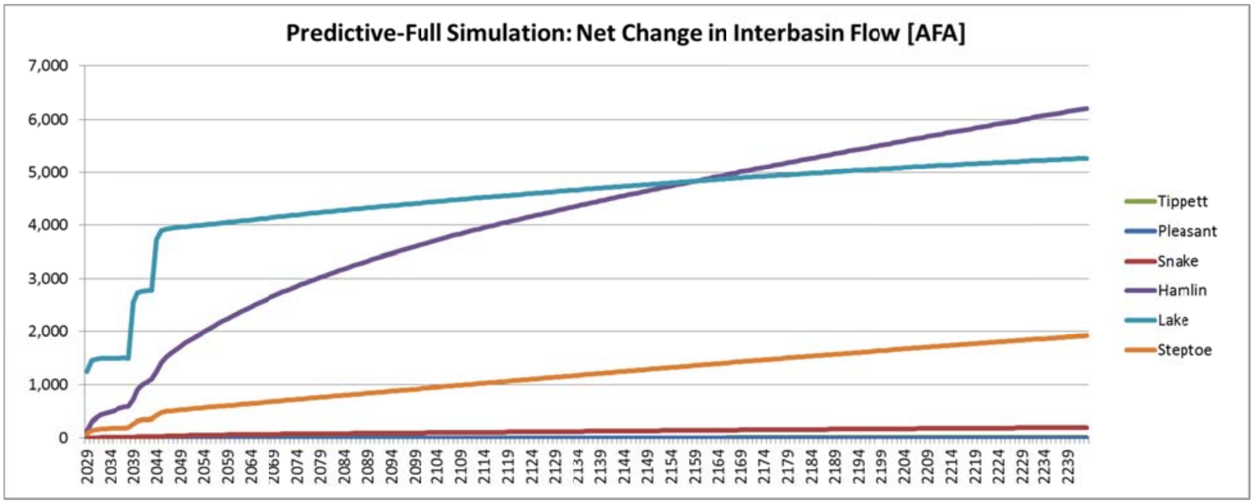

Figure 34 **Net Change in Interbasin Flow from Adjacent Valleys for Predictive-Full Simulation.**

Predictive-Minus4 Simulation

We performed a flow budget analysis using the same approach with Predictive-Minus4 simulation. The results are shown in Figure 35-Figure 39. In this case, the pumping rate starting in 2029 is 27,200 AFA, followed by a rate of 50,167 AFA beginning in 2039 and a rate of 70,941 AFA starting in 2044 and continuing through 2243. The net change and cumulative volume numbers in this case are similar to the Predictive-Full simulation. The cumulative volume numbers for storage do not reach an equilibrium condition and continue to increase in time over the entire duration of the simulation. Once again, this is indicative of groundwater mining and non-sustainable conditions.

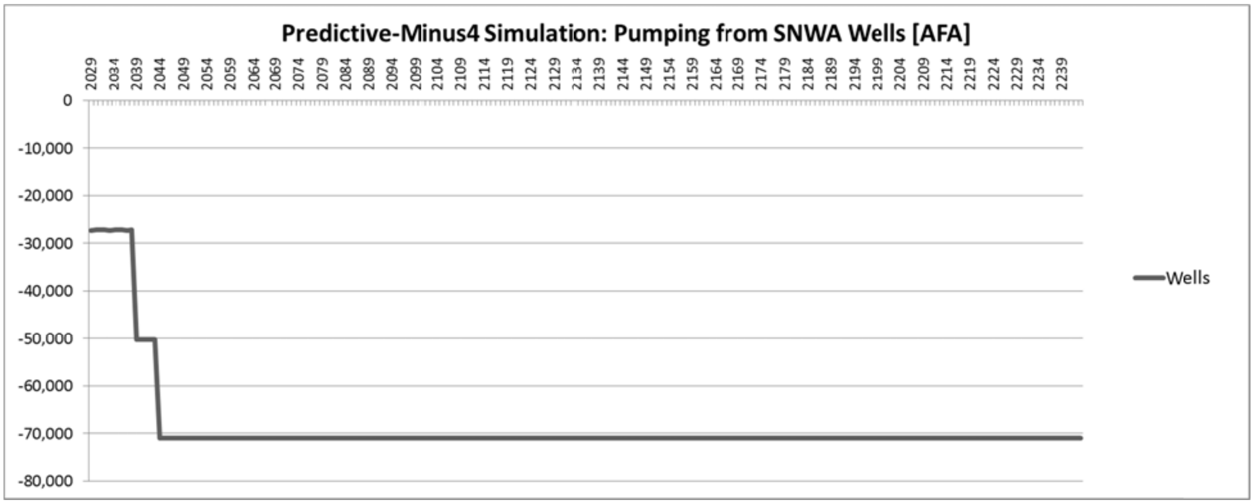

Figure 35 **Pumping from SNWA Wells vs. Time for Predictive-Minus4 Simulation.**

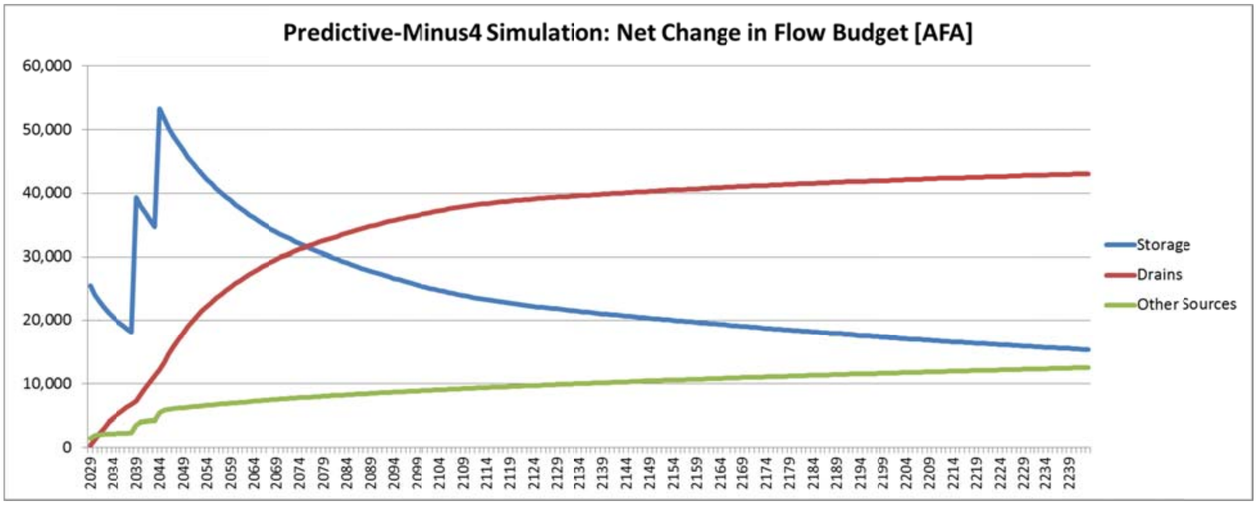

Figure 36 **Net Change in Flow Budget for Source Categories for Predictive-Minus4 Simulation.**

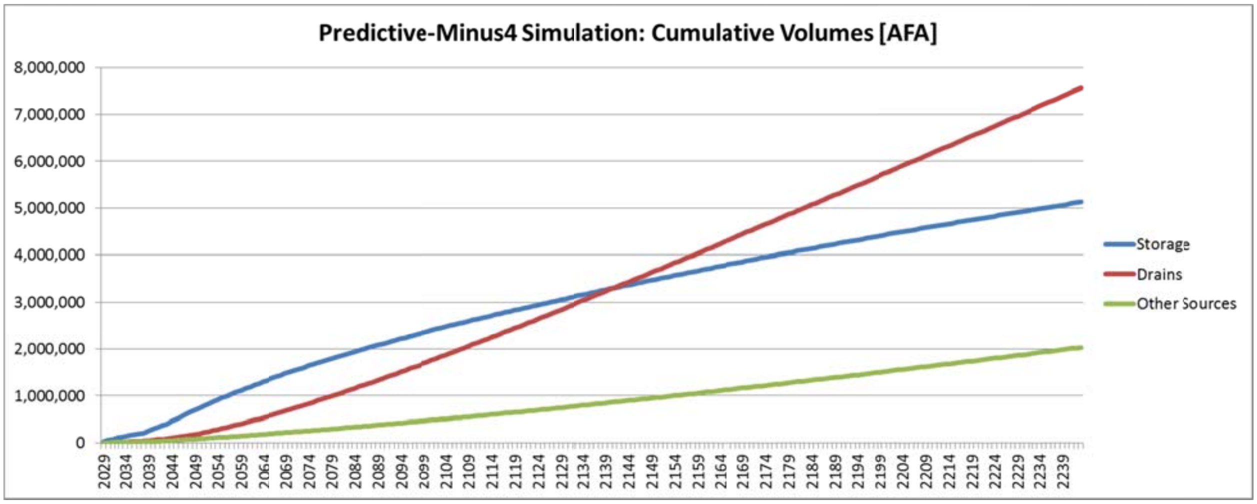

Figure 37 **Cumulative Net Change in Volume for Source Categories for Predictive-Minus4 Simulation.**

The fraction of pumping values shown in Figure 38 are also similar to the Predictive-Full case, with 55% going to drains (ET salvage), 30% to Storage (groundwater mining), and 15% to Other Sources (interbasin flow) in the middle portion of the simulation. The net change in interbasin flow numbers (Figure 39) is also similar to the Predictive-Full case.

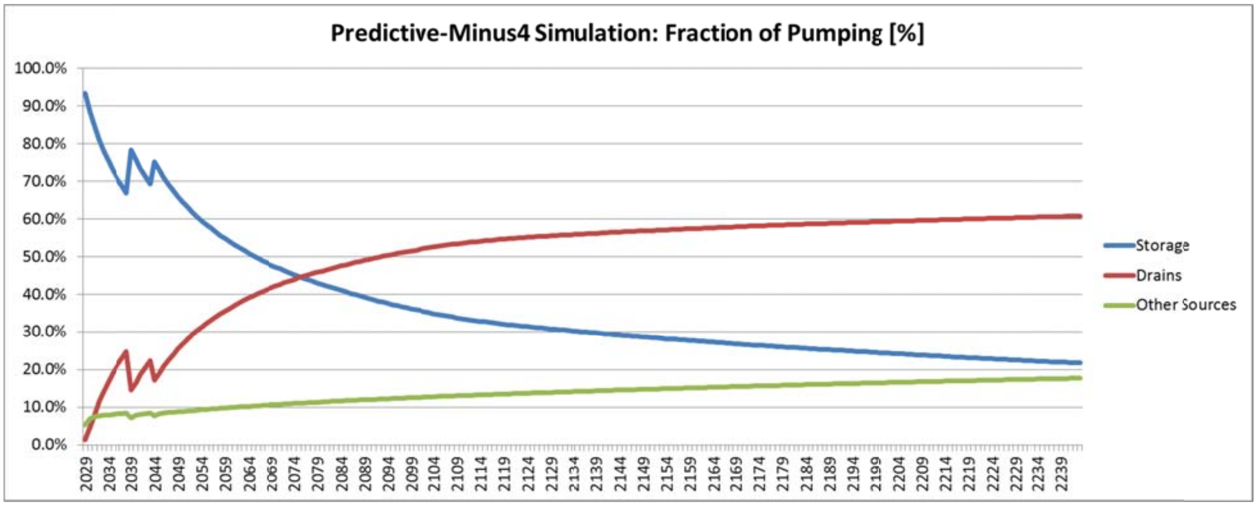

Figure 38 **Fraction of Pumping for Source Categories for Predictive-Minus4 Simulation.**

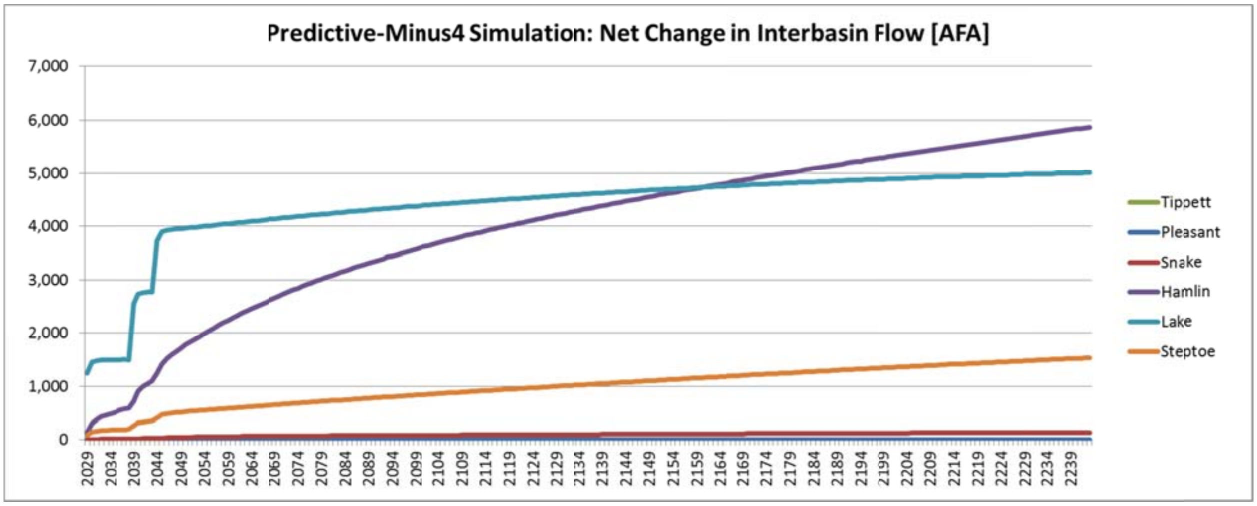

Figure 39 **Net Change in Interbasin Flow from Adjacent Valleys for Predictive-Minus4 Simulation.**

ET Salvage

The flow budget analysis illustrated that the proposed SNWA wells will not result in full ET salvage. As a result substantial amount of groundwater mining will be required to satisfy SNWA's application. The issue of incomplete ET salvage is further illuminated by examining the spatial distribution of discharge to drains over time in order to better understand the issue of incomplete ET capture.

As described in the previous section, ET salvage occurs when the water table is lowered due to the pumping of the proposed wells. The water table drops below the ET extinction depth, and water previously lost to ET can be captured for use by the wells. In order for this to work in a sustainable fashion, the water table must be lowered over a large region. The drawdown maps in Figure 9 through Figure 19 show that the aggregate cone of depression occurs over a concentrated area, resulting in extreme levels of drawdown, destruction of springs, occurrence of subsidence, and aquifer consolidation in addition to incomplete ET capture.

The incomplete ET capture issue can be illustrated through a spatial analysis of the model results. The SNWA model uses the Drain Package to simulate ET in the center of Spring Valley. The MODFLOW grid cells that were marked as drain cells are shown in Figure 40. Of the cells that are marked as Drains, only those where the water table is above the drain elevation (ground surface elevation minus ET extinction depth) actively discharge water. For some of the drain cells, the water table is below the drain elevation in the baseline simulation. The cells that are active for the year 2029 are shown in green in Figure 40. The set of active cells changes only slightly with time for the baseline simulation. It is only these active cells that are considered in the following analysis.

One of the output files produced by MODFLOW is the Cell-by-Cell Flow (CCF) file. This file includes the simulated discharge value for each of the Drain cells for each output time period. Using the discharge values for both the baseline and the predictive models, we calculated the “uncaptured ET” value for each Drain cell as follows:

$$\text{Uncaptured ET} = \frac{(a-b)}{a} \qquad \textbf{(1)}$$

where

a = discharge value from baseline model for a given time step

b = discharge value from predictive model for the same time step

A value of 1.0 means that none of the ET discharge has been captured by the wells, and a value of 0 indicates complete capture. Using this formula, we generated a series of maps showing the fraction of uncaptured ET remaining in Spring Valley at latter stages (2084, 2117, 2254) of the Predictive-Full simulation. The maps are shown in Figure 41–Figure 43. Red indicates full capture of ET, and blue indicates zero capture (full original ET remains uncaptured). The colors indicate that while ET capture eventually reaches full capacity in the south end of the valley, almost no capture occurs in the northern end of the valley. As a result of this incomplete capture, groundwater mining is induced in the center of the valley near the proposed wells to satisfy the water demand. This is illustrated clearly in Figure 44 where we superimpose the drawdown contours with the map of uncaptured ET for the Predictive-Full simulation for the year 2242.

We do not present maps for the Predictive-Minus4 and Predictive-Minus12 simulations because the Predictive-Full simulation illustrates the phenomenon in question and represents the scenario proposed by SNWA.

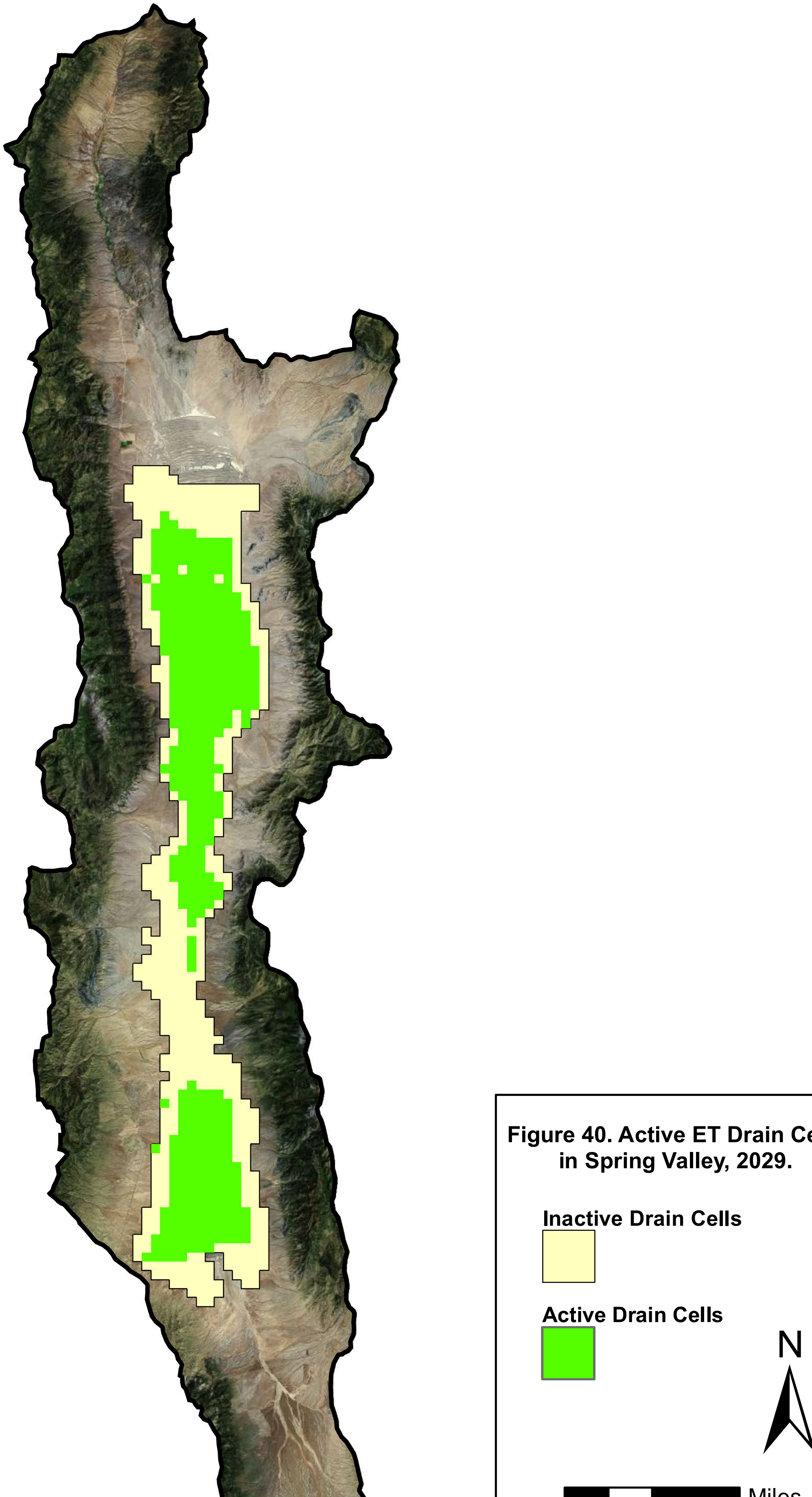

Figure 40. Active ET Drain Cells in Spring Valley, 2029.

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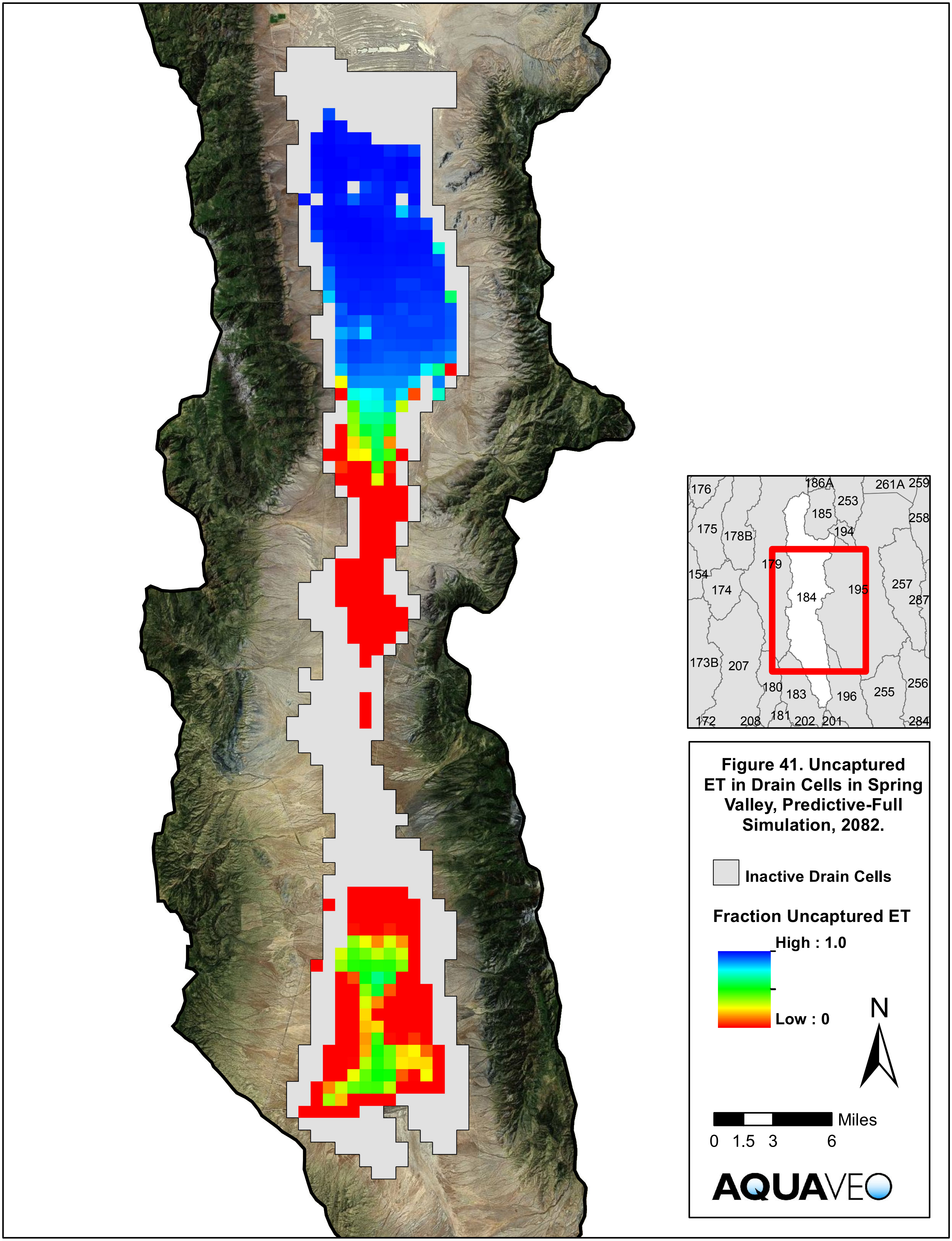


Figure 41. Uncaptured ET in Drain Cells in Spring Valley, Predictive-Full Simulation, 2082.

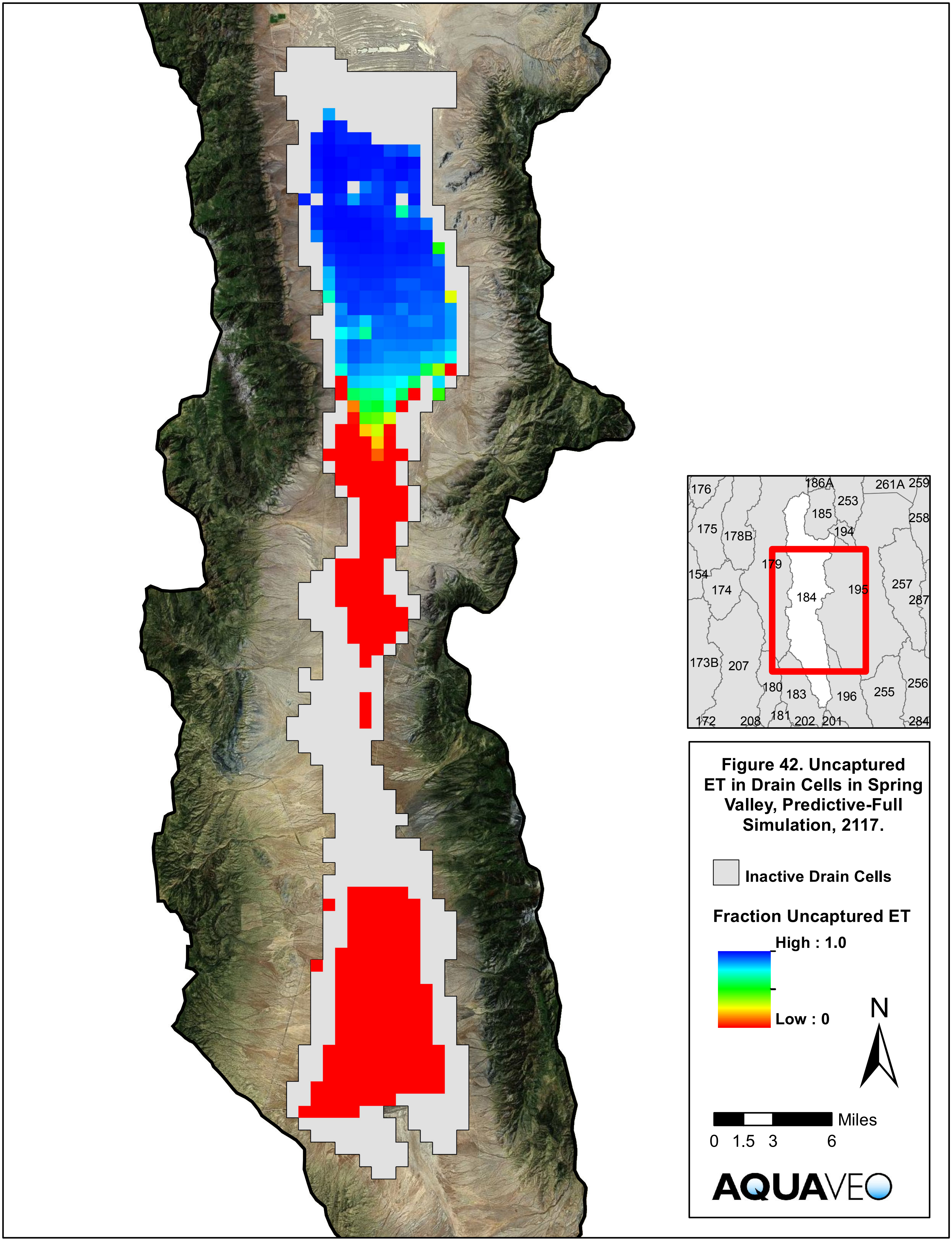


Figure 42. Uncaptured ET in Drain Cells in Spring Valley, Predictive-Full Simulation, 2117.

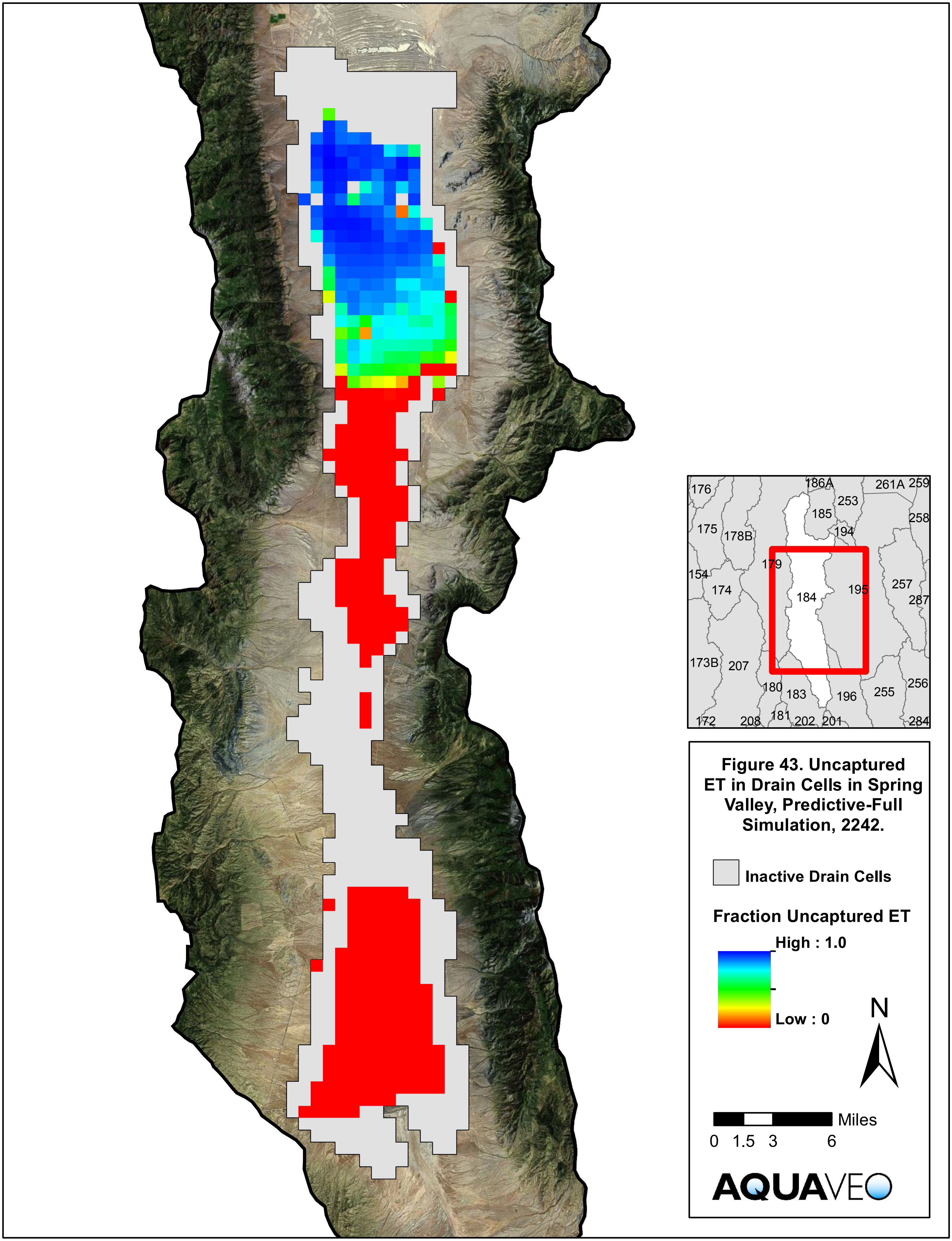


Figure 43. Uncaptured ET in Drain Cells in Spring Valley, Predictive-Full Simulation, 2242.

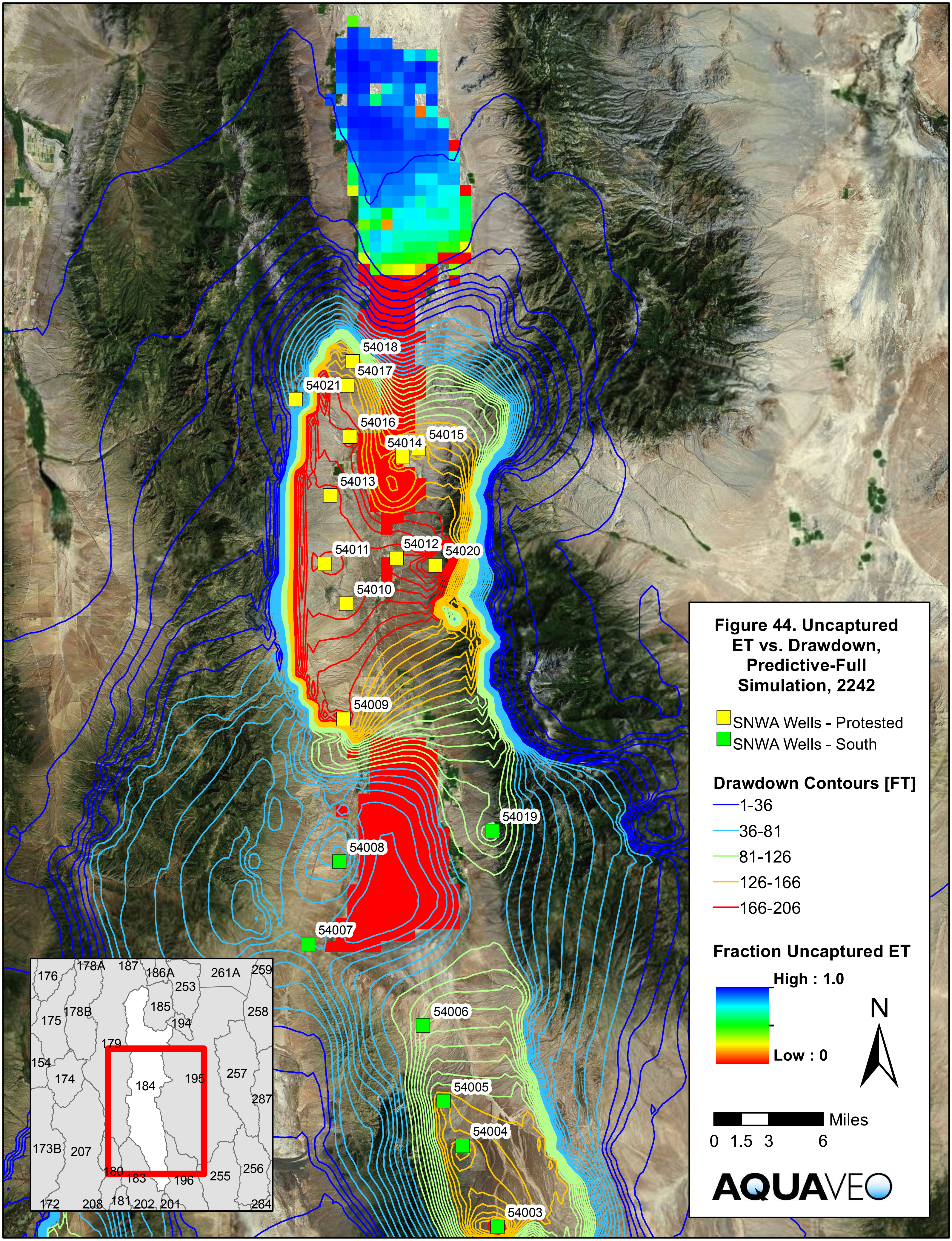


Figure 44. Uncaptured ET vs. Drawdown, Predictive-Full Simulation, 2242

Water Rights Reallocation

The flow budget analysis demonstrated that in the center and southern parts of Spring Valley, the proposed SNWA wells will reduce the water table elevation to a level that will eliminate evapotranspiration. Some of this evapotranspiration is currently used by CPB-owned ranching operations for sub-irrigated lands. Furthermore, our analysis regarding impacts to springs indicates that lowering the water table will also destroy all of the valley floor springs owned by CPB. As the sub-irrigation and spring discharge are eliminated, CPB would be forced to drill new wells to recapture water associated with the affected water rights locations or collect a portion of the water pumped the SNWA wells. This fact is acknowledged by Watrus and Drici on pages 6-7,6-9, and 6-10 of SNWA (2011b). In spite of this acknowledgement, the SNWA predictive model does NOT simulate the addition of these replacement wells (or increased pumping rates at SNWA wells) at points in time when the spring discharges are eliminated. This affects a substantial fraction of the overall water budget for Spring Valley. The omission of these replacement wells or sources causes the predictive models to underestimate the drawdown and groundwater mining caused by the proposed SNWA wells. A full accounting for the groundwater withdrawn by these water rights via replacement would result in substantially more drawdown than is predicted by the SNWA models.

Conclusions

Based on our analysis of the proposed SNWA wells in Spring Valley near CPB properties, we offer the following conclusions:

1. Northern Spring Valley contains three groundwater flow regimes: mountain block, alluvial fan, and valley floor. SNWA points of diversion are all located in alluvial fans.

2. The alluvial fan sediments are thousands of feet thick and support both confined and unconfined groundwater flow systems. The unconfined systems are recharged by surface infiltration of perennial and ephemeral stream flows as evidenced by stream gain-loss measurement and the age groundwater discharging from the distal end of the Cleve Creek alluvial fan. The confined system (i.e., within 1,000 feet of the land surface), as exemplified by the flowing artesian well in the Cleve Creek fan and spring discharges from Millick and Bastian springs, contains paleo-groundwater with a mean resident time near the distal end of the fan of thousands of years.

3. The State Engineer has determined that in most Nevada basins groundwater discharge is primarily by evapotranspiration (ET) and that the perennial yield is approximately equal to the estimated groundwater ET. Because almost all Spring Valley groundwater ET occurs in the valley floor, SNWA's application to appropriate groundwater is based on the idea that wells can be constructed so as to capture all unappropriated groundwater prior to ET loss. What this entails is either capturing the groundwater prior to entering the ET area and/or lowering the groundwater table below the root extinction depth without causing groundwater mining.

4. More than a dozen estimates of a groundwater recharge, net groundwater ET and perennial yield, or net interbasin outflow have been published since 1965. Since 2006 SNWA has presented at least three different estimates of perennial yield based on different methodologies and assumptions. This moving target is difficult to assess. The perennial yield calculation in SNWA's most recent assessment (SNWA, 2011a) is the largest perennial yield estimate to-date (i.e., 94,800 AFA). This estimate exceeds the State Engineers 2007 ruling regarding perennial yield by 14,800 AFA.

5. SNWA's appropriation application exceeds the unappropriated perennial yield of the Spring Valley basin by thousands of acre-feet. Assuming the State Engineer's 2007 perennial yield estimate of 80,000 AFA and existing groundwater rights of 14,202 AFA, SNWA's application exceeds the unappropriated perennial yield by 25,427 AFA. In other words only 72% of the requested appropriation is potentially available for perennial yield appropriation.

6. In the northern portion of the Spring Valley 12 of the SNWA 19 points of diversion are clustered about the large Cleve Creek, Bastian Creek and nearby alluvial fans, and much of the perennial yield originating north of the Cleveland Ranch will not be salvaged by SNWA wells. In the

southern portion of the valley, no points of diversion are located along much of the base of the Snake Range. Thus, assuming full project development, much of perennial yield will continue to be lost to ET. Groundwater mining would make up this uncaptured groundwater. The SNWA groundwater flow model confirms the large aerial extent of the valley floor where ET will remain uncaptured by the SNWA wells.

7. At full development SNWA's groundwater extraction plan would result in: a) drying up most springs in the northern valley including those relied upon by CPB ranching activities, b) the loss of the unusual grove of swamp cedars located below the Bastian alluvial fan, c) the loss of the sub-irrigated pasture land of the Cleveland Ranch and d) the loss of the extensive wetlands located north of Cleveland Ranch and elsewhere.

   The idea that CPB springs will dry up and phreatophytes will die is supported by SNWA's groundwater flow model. The phreatophyte root extinction depth varies by plant type but most such roots only extend ~5-20 feet below ground surface.

   The model predicts the following:

   a) Pumping all wells at the requested flow rates: water levels will decline ~70 to 185 feet beneath Murphy, Big Reservoir, Bastian Creek, Cleveland Ranch, and the unnamed springs located south of Cleveland Ranch.

   b) Pumping all wells at the requested flow rates according to the well implementation schedule will cause many of the CPB springs to dry up immediately.

   c) Pumping all but the four Cleve Creek alluvial fan wells at requested flow rates (Predictive-Minus4 Simulation): water levels will decline ~10 to 115 feet beneath Murphy, Big Reservoir, Bastian Creek, Cleveland Ranch and the unnamed springs located south of Cleveland Ranch.

   d) Pumping all but the four Cleve Creek alluvial wells at the requested flow rates according to the well implementation schedule will cause many of the CPB springs to dry up immediately.

8. Implementation of the Cleve Creek alluvial fan points of diversion (54016, 54017, 54018, and 54021) would dry up Cleveland Ranches Murphy and Big Reservoir springs, located at the distal end of the Cleve Creek fan, and the Ranches sub-irrigated land. In the State Engineer's 2007 ruling (#5726) these four wells were denied, presumably because the State Engineer recognized the impact that these wells would have on the Cleveland Ranch existing water rights and the deleterious impact the wells would have on the ranching operation.

9. Pumping the entire requested 91,224 AFA will result in extensive groundwater mining. The SNWA groundwater flow model predicts the following groundwater mining as a percentage of total groundwater extraction:

   a) Pumping all wells at the requested flow rates: 90% at project start, 50% in 2050, 30+% in 2150, and 28% in 2242.

   b) Pumping all but the four Cleve alluvial fan wells at requested flow rates (Predictive-Minus4 Simulation): 90% at project start, ~60% in 2050, ~30% in 2150, and 22% in 2242.

10. The distribution of hydraulic conductivities computed by the MODFLOW HUF Package in the SNWA model exhibits a low permeability anomaly in the middle of the alluvial fans that inconsistent with typical alluvial systems and leads to an under-prediction of drawdown at water rights locations on the fringe of the alluvial fan near the Cleveland Ranch.

11. CPB would be forced to drill new wells to capture water associated with their affected water rights. This fact is acknowledged by Watrus and Drici on pages 6-7,6-9, and 6-10 of SNWA (2011b). In spite of this acknowledgement, the SNWA predictive model does NOT simulate the addition of these replacement wells (or increased pumping rates at SNWA wells) at points in time when the spring discharges are eliminated. This affects a substantial fraction of the overall water budget for Spring Valley. The omission of these replacement wells or sources causes the predictive models to underestimate the drawdown and groundwater mining caused by the proposed SNWA wells. A full accounting for the groundwater withdrawn by these water rights via replacement would result in substantially more drawdown than is predicted by the SNWA models.

12. The extreme drawdown levels and groundwater mining causes by the SNWA wells are likely to cause land subsidence and irreversible aquifer consolidation.

13. The well field layout (i.e., points of diversion) in Spring Valley is a good design to optimize groundwater withdrawal from selected alluvial fans, but will not capture a significant portion of the groundwater ET (i.e., perennial yield). The small number of long-screened alluvial fan wells proposed by SNWA is more appropriate for groundwater mining than for a comprehensive ET salvage plan. This fact is demonstrated by the large proportion of the groundwater that the SNWA model demonstrates will be derived from groundwater mining.

References

Brothers, K., Bugo, T.S., Bernholtz, A.J., and Tracy, J.V., 1994, Hydrology and steady state ground-water model of Spring Valley, Lincoln and White Pine Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report n. 12, 69 p.,

CPB Exh-001, 2011, Water rights, land & water resources report of north Spring Valley, Nevada: unpublished report, Resource Concepts, Inc., dated July 1, 2011, 44 p.

Clancy, P.a., 1968, Water-Resources appraisal of butte Valley, Elko and White Pine Counties, Nevada: U.S. Geological Survey Water Resources-Reconnaissance Series, Rpt. 49, 58 p.

Epstein, B.J., 2004, Development and uncertainty analysis of empirical recharge prediction models for Nevada's desert basins: University of Nevada, 131 p.

Flint, A.L., Flint, L.E., Hevesi, H.A., and Blainey, J.M., 2004 Fundamental concepts of recharge in the Desert Southwest: a regional modeling perspective, *in* Hogan, J.F., Phillips, F.M., and Scanlon, B.R., eds Ground-water recharge in a desert environment: The southwestern United States, American Geophysical Union, p. 159-184.

Harrill, J.R., Gates, J.S., and Thomas, J,M., 1988, Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent States. U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C.

Harrill, J.R., and Purdic, 1998, Aquifer systems in the Great Basin region of Nevada, Utah, and adjacent states - summary report: U.S. Geological Survey, Prof. Paper 1409-A, 75 p.

Hess, J.W., and Mifflin, M.D., 1978, A feasibility study of water production form deep carbonate aquifer in Nevada: Water Resources Center, Desert Research Institute, University of Nevada System, Publication n. 41054, 87 p.

Horse, R.K., and Blake, M.C., Jr., 1970 Geologic map of White Pine County, Nevada: U.S. Geol. Survey Open-File Report 70-166.

Horse, R.K., Blake, M.C., Jr., and Smith, R.M, 1976, Geology and mineral resources of White Pine County, Nevada: Nevada Bureau of Mines and Geology, Bull. 85, 10 5 p.

Lopes, T.J., and Evetts, D.M., 2004, Ground-water pumpage and artificial recharge estimates for calendar year 2000 and average annual natural recharge and interbasin flow by hydrographic area, Nevada: U.S. Geological Survey, Scientific Investigations Report 2004-5239, 81 p.

Nicols, W.D., 2000, Regional ground-water evapotranspiration and ground-water budges, Great Basin, Nevada: U.S. Geological Survey, Prof. Paper 1628.

Mayo, A.L., 2010, Ambient well-bore mixing, aquifer cross contamination, pumping stress, and water quality form long-screened wells: What is sampled and what is not?: Hydrogeology Journal. v. 18, p. 823-937.

Nevada Division of Water Resources, 2011, Spring Valley Hydrographic Basin 10-184 NRS 533.364 inventory: Nevada State Engineer, 6 p. plus appendices.

Nevada State Engineer, 2007, Ruling #5726, Nevada State Engineer, April 16, 2007

Reheis, M., 1999, Extent of Pleistocene lakes in the western Great Basin: U.S. Geol. Survey Misc. Field Studies Map MF-2323.

Rush, F.E., and Kazmi, S.A.T., 1965, Water resources appraisal of Spring Valley in White Pine and Lincoln Counties, Nevada Department of Conservation and Natural. Resources, Reconnaissance Series Report, 22, 36 p.

Pavelko, M.T., 2007, Spring database for the Basin and Range carbonate-rock aquifer system, White Pine county, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey, Data series 272, 10 p.

Prudic, D.E., Harrill, J.R., and Burbey, T.J., 1993, Conceptual Evolution of regional ground-water flow in the carbonate rock province of the Great Basin, Nevada, Utah, and adjacent states; U.S. Geological Survey, Open-file Report 93-170, 102 p.

Southern Nevada Water Authority, 2009a, Conceptual model of groundwater flow for the central carbonate-rock province - Clark, Lincoln, and White Pine Counties groundwater development project: Southern Nevada Water Authority, Las Vegas, Nevada, 416 p.

Southern Nevada Water Authority, 2009b, Transient numerical model of the groundwater flow for the Central Carbonate-Rock Province - Clark, Lincoln, and White Pine Counties groundwater development project: Southern Nevada Water Authority, Las Vegas, Nevada, 394 p.

Southern Nevada Water Authority, 2011a, Hydrology and water resources of Spring, Cave, Dry Lake and Delmar valleys, Nevada and vicinity: Southern Nevada Water Authority, Las Vegas, Nevada, 313 p.

Southern Nevada Water Authority, 2011b, Conflicts analysis related to Southern Nevada Water Authority groundwater applications in Spring, Cave, Dry Lake, and Delamar valleys, Nevada and vicinity: Southern Nevada Water Authority, Las Vegas, Nevada, 151 p.

water.usgs.gov/nrp/gwsoftware/zonebud3/zonebudget3.html, 2011, access August 24, 2011.

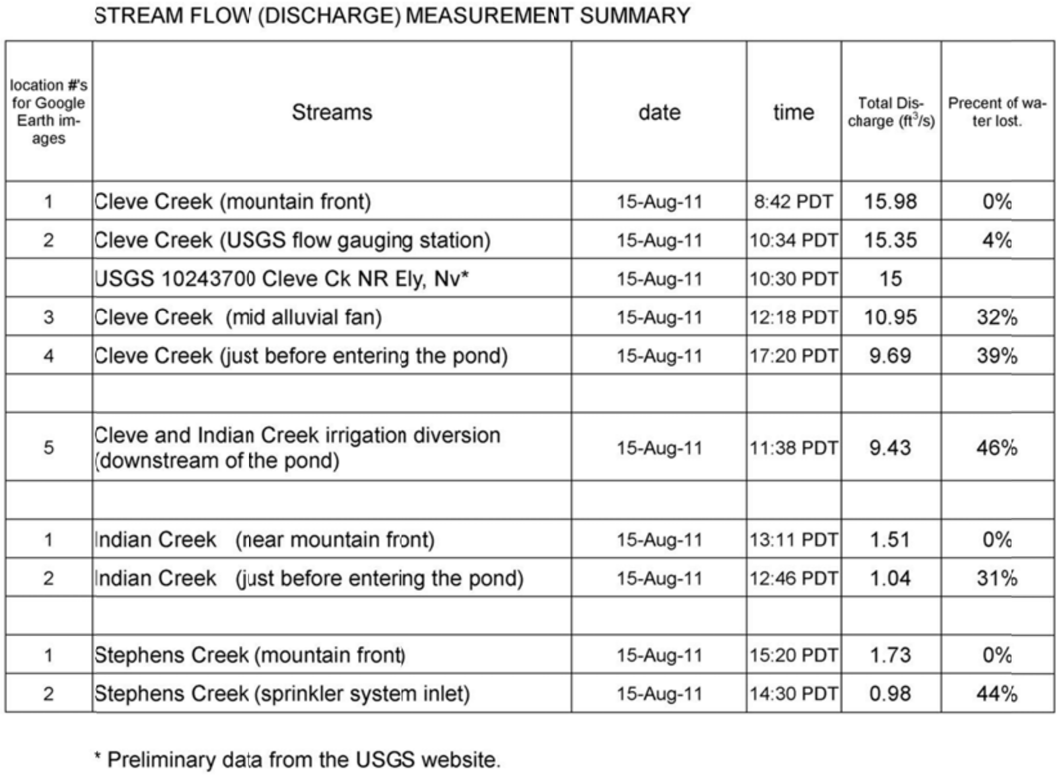
waterdata.usgs.gov, 2011, accessed August 15, 2011.

seamless.usgs.gov, 2011, access August 24, 2011.

Watson, P., Sinclair, P., and Waggoner, R., 1976, Quantitative evaluation of a method for estimating recharge to the desert basins of Nevada: Journal of Hydrology, v. 31, p. 335-357.

Welch, A.H., and Bright, D.J. eds., 2008, Water resources of the basin and range carbonate-rock aquifer systems, White Pine County, Nevada, and adjacent area in Nevada and Utah – Draft Report: U.S. Geological Survey, Scientific Investigations Report 2007-5261, 112 p.

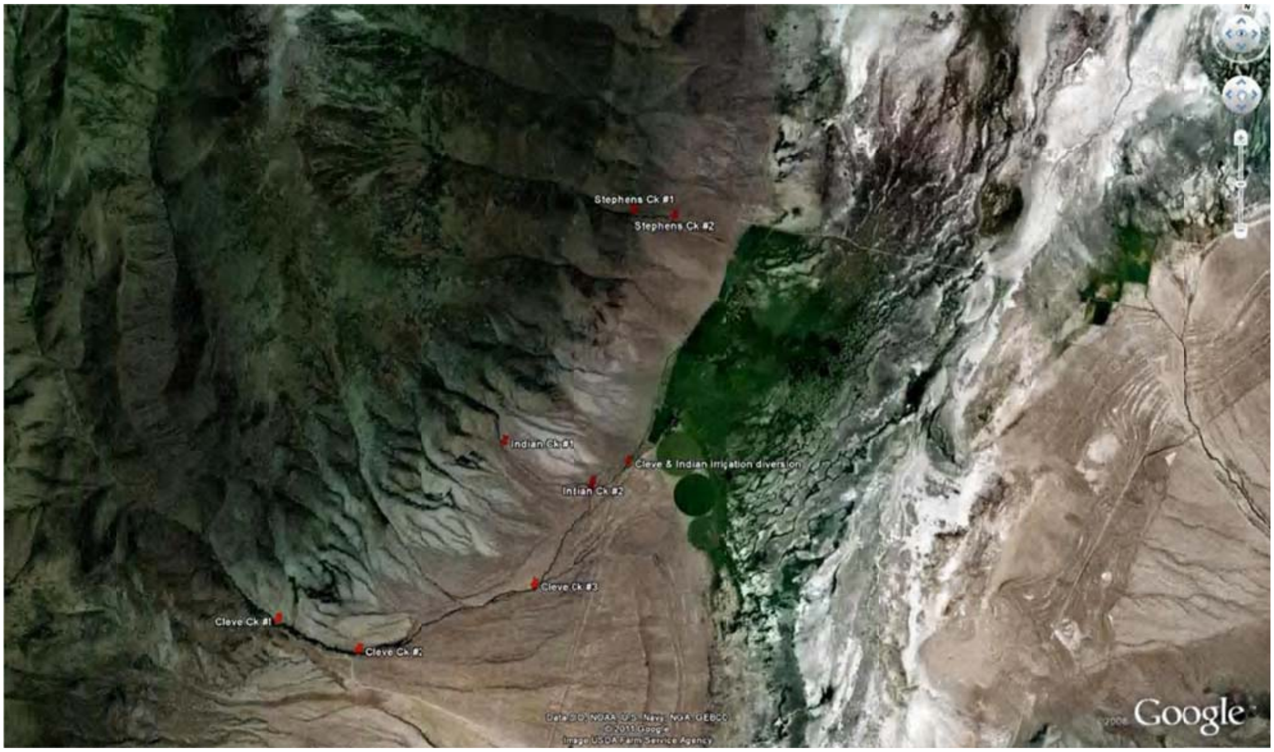
Appendix A – Gain/Loss Measurements



STREAM FLOW (DISCHARGE) MEASUREMENT SUMMARY

location #'s for Google Earth images	Streams	date	time	Total Discharge (ft^3/s)	Precent of water lost.
1	Cleve Creek (mountain front)	15-Aug-11	8:42 PDT	15.98	0%
2	Cleve Creek (USGS flow gauging station)	15-Aug-11	10:34 PDT	15.35	4%
	USGS 10243700 Cleve Ck NR Ely, Nv*	15-Aug-11	10:30 PDT	15	
3	Cleve Creek (mid alluvial fan)	15-Aug-11	12:18 PDT	10.95	32%
4	Cleve Creek (just before entering the pond)	15-Aug-11	17:20 PDT	9.69	39%
5	Cleve and Indian Creek irrigation diversion (downstream of the pond)	15-Aug-11	11:38 PDT	9.43	46%
1	Indian Creek (near mountain front)	15-Aug-11	13:11 PDT	1.51	0%
2	Indian Creek (just before entering the pond)	15-Aug-11	12:46 PDT	1.04	31%
1	Stephens Creek (mountain front)	15-Aug-11	15:20 PDT	1.73	0%
2	Stephens Creek (sprinkler system inlet)	15-Aug-11	14:30 PDT	0.98	44%

* Preliminary data from the USGS website.




Cleve & Ind
Indian Ck #2
Cleve Ck #4
Cleve Ck #3
Cleve Ck #1
Cleve Ck #2
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image USDA Farm Service Agency
Google


Indian Ck #1
Cleve & Indian Irrigation
Indian Ck #2
Cleve Ck #4
© 2011 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image USDA Farm Service Agency
Google


Stephens Ck #1
Stephens Ck #2
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image USDA Farm Service Agency
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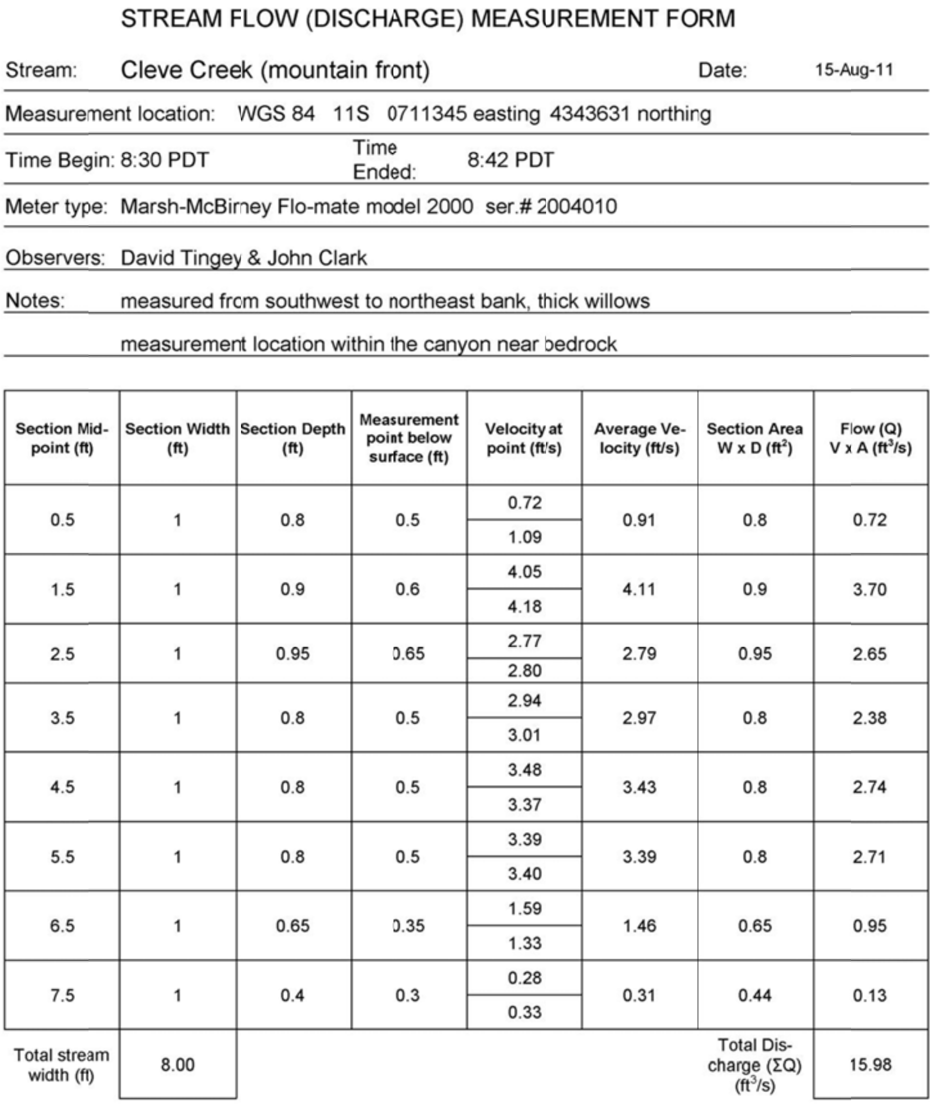


STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Cleve Creek (mountain front) Date: 15-Aug-11

Measurement location: WGS 84 11S 0711345 easting 4343631 northing

Time Begin: 8:30 PDT Time Ended: 8:42 PDT

Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

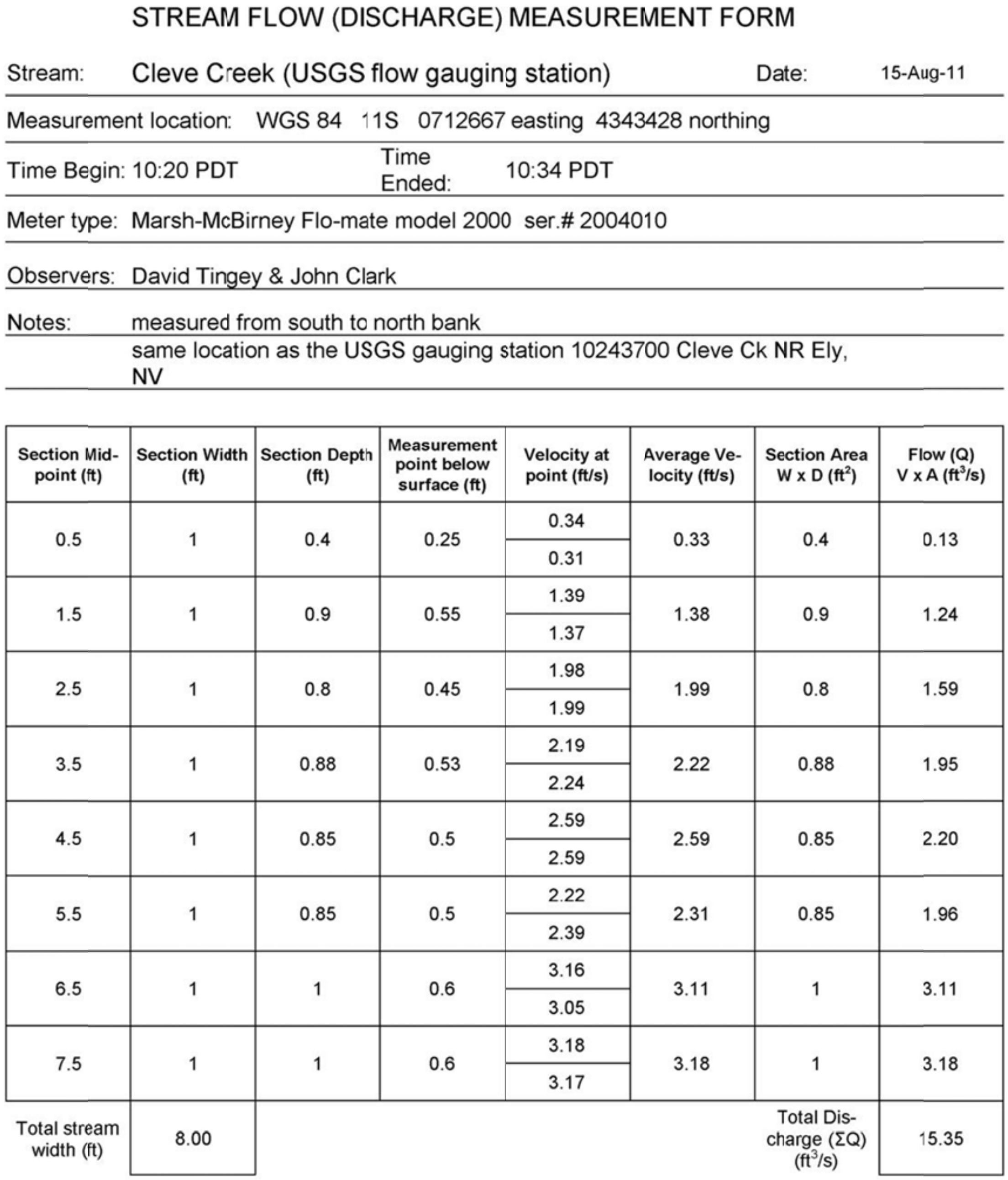
Observers: David Tingey & John Clark

Notes: measured from southwest to northeast bank, thick willows

measurement location within the canyon near bedrock

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1	0.8	0.5	0.72 1.09	0.91	0.8	0.72
1.5	1	0.9	0.6	4.05 4.18	4.11	0.9	3.70
2.5	1	0.95	0.65	2.77 2.80	2.79	0.95	2.65
3.5	1	0.8	0.5	2.94 3.01	2.97	0.8	2.38
4.5	1	0.8	0.5	3.48 3.37	3.43	0.8	2.74
5.5	1	0.8	0.5	3.39 3.40	3.39	0.8	2.71
6.5	1	0.65	0.35	1.59 1.33	1.46	0.65	0.95
7.5	1	0.4	0.3	0.28 0.33	0.31	0.44	0.13
Total stream width (ft)	8.00					Total Discharge (ΣQ) (ft^3/s)	15.98

Stream	date	time	Total Discharge (ft^3/s)
Cleve Creek (mountain front)	15-Aug-11	8:42 PDT	15.98



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Cleve Creek (USGS flow gauging station) Date: 15-Aug-11

Measurement location: WGS 84 11S 0712667 easting 4343428 northing

Time Begin: 10:20 PDT Time Ended: 10:34 PDT

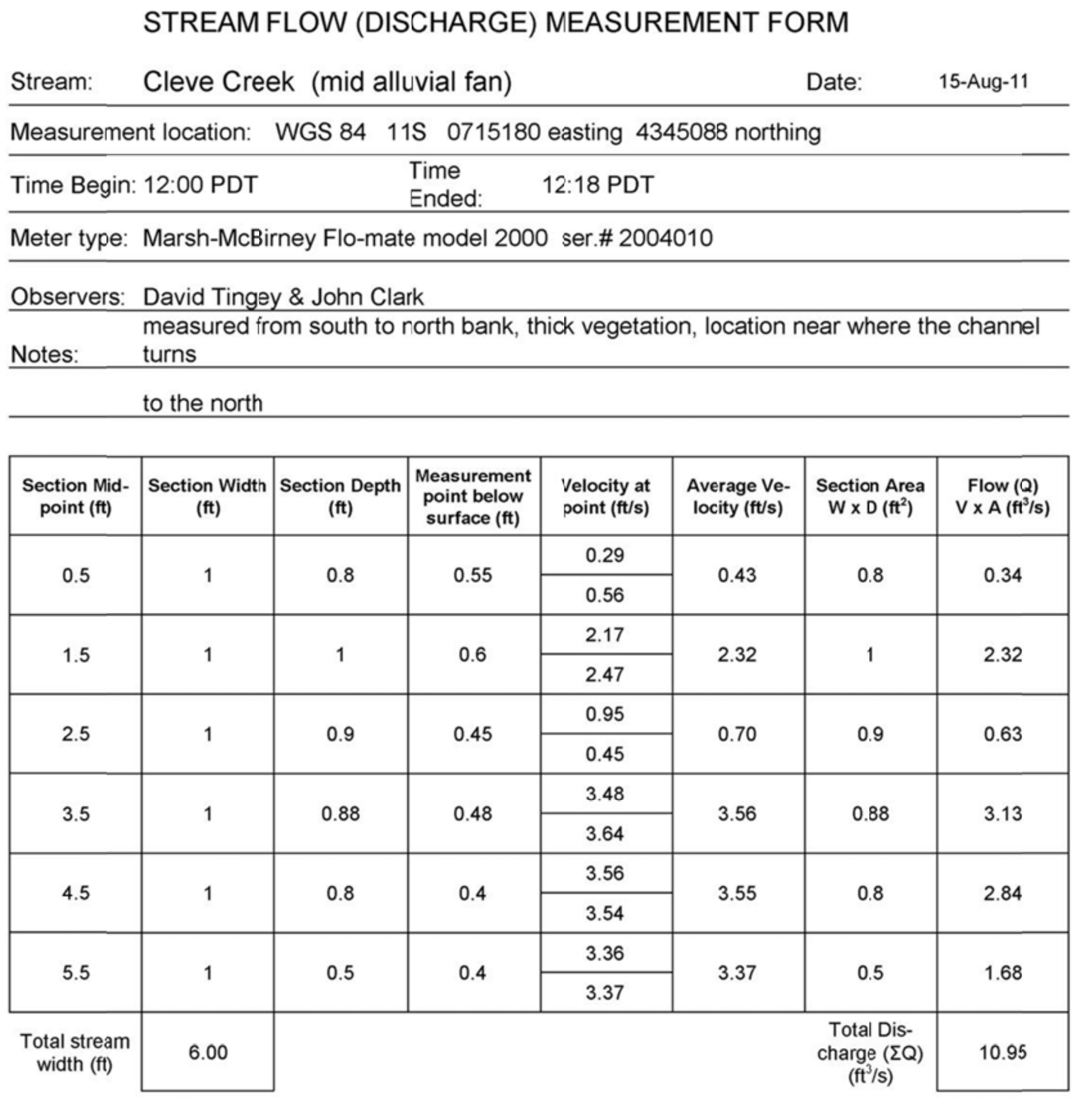
Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

Observers: David Tingey & John Clark

Notes: measured from south to north bank
same location as the USGS gauging station 10243700 Cleve Ck NR Ely, NV

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1	0.4	0.25	0.34 0.31	0.33	0.4	0.13
1.5	1	0.9	0.55	1.39 1.37	1.38	0.9	1.24
2.5	1	0.8	0.45	1.98 1.99	1.99	0.8	1.59
3.5	1	0.88	0.53	2.19 2.24	2.22	0.88	1.95
4.5	1	0.85	0.5	2.59 2.59	2.59	0.85	2.20
5.5	1	0.85	0.5	2.22 2.39	2.31	0.85	1.96
6.5	1	1	0.6	3.16 3.05	3.11	1	3.11
7.5	1	1	0.6	3.18 3.17	3.18	1	3.18
Total stream width (ft)	8.00					Total Discharge (ΣQ) (ft^3/s)	15.35

Stream	date	time	Total Discharge (ft^3/s)
Cleve Creek (USGS flow gauging station)	15-Aug-11	10:34 PDT	15.35



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Cleve Creek (mid alluvial fan) Date: 15-Aug-11

Measurement location: WGS 84 11S 0715180 easting 4345088 northing

Time Begin: 12:00 PDT Time Ended: 12:18 PDT

Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

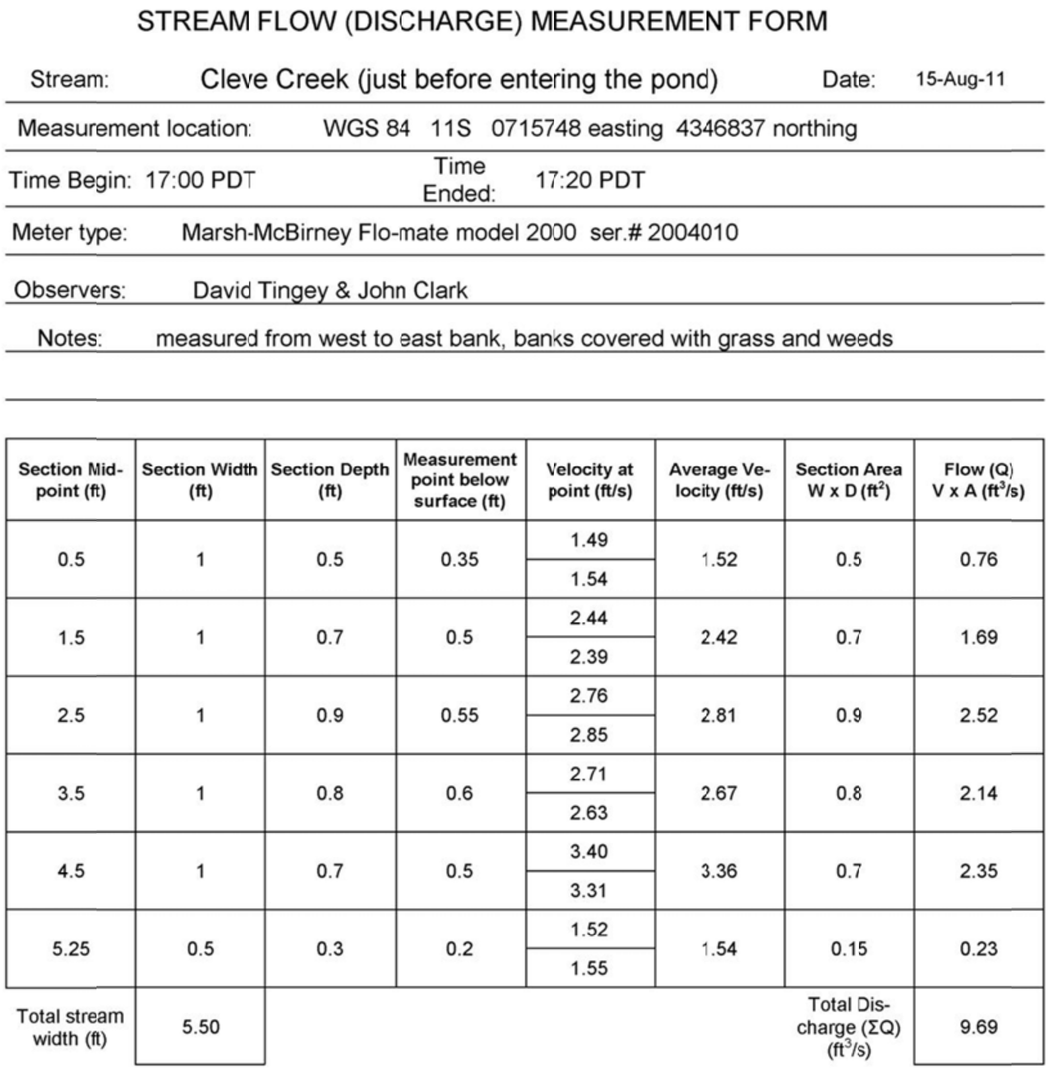
Observers: David Tingey & John Clark

Notes: measured from south to north bank, thick vegetation, location near where the channel turns

to the north

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1	0.8	0.55	0.29 0.56	0.43	0.8	0.34
1.5	1	1	0.6	2.17 2.47	2.32	1	2.32
2.5	1	0.9	0.45	0.95 0.45	0.70	0.9	0.63
3.5	1	0.88	0.48	3.48 3.64	3.56	0.88	3.13
4.5	1	0.8	0.4	3.56 3.54	3.55	0.8	2.84
5.5	1	0.5	0.4	3.36 3.37	3.37	0.5	1.68
Total stream width (ft)	6.00					Total Discharge (ΣQ) (ft^3/s)	10.95

Stream	date	time	Total Discharge (ft^3/s)
Cleve Creek (mid alluvial fan)	15-Aug-11	12:18 PDT	10.95



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Cleve Creek (just before entering the pond) Date: 15-Aug-11

Measurement location: WGS 84 11S 0715748 easting 4346837 northing

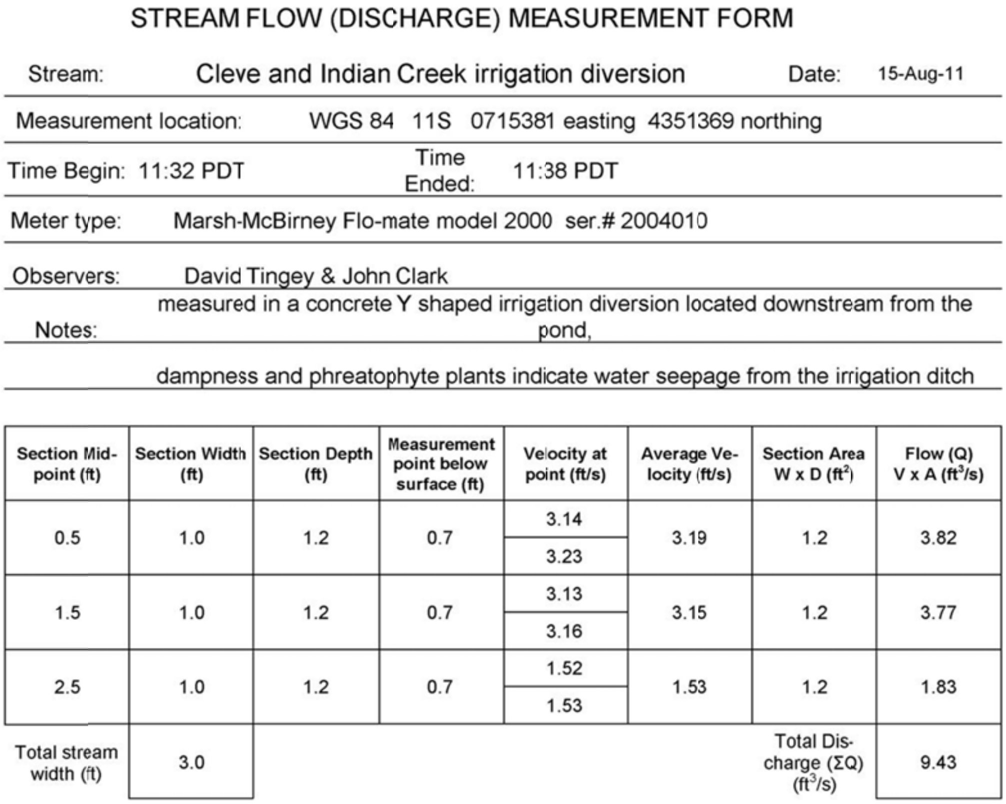
Time Begin: 17:00 PDT Time Ended: 17:20 PDT

Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

Observers: David Tingey & John Clark

Notes: measured from west to east bank, banks covered with grass and weeds

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1	0.5	0.35	1.49 1.54	1.52	0.5	0.76
1.5	1	0.7	0.5	2.44 2.39	2.42	0.7	1.69
2.5	1	0.9	0.55	2.76 2.85	2.81	0.9	2.52
3.5	1	0.8	0.6	2.71 2.63	2.67	0.8	2.14
4.5	1	0.7	0.5	3.40 3.31	3.36	0.7	2.35
5.25	0.5	0.3	0.2	1.52 1.55	1.54	0.15	0.23
Total stream width (ft)	5.50					Total Discharge (ΣQ) (ft^3/s)	9.69



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Cleve and Indian Creek irrigation diversion Date: 15-Aug-11

Measurement location: WGS 84 11S 0715381 easting 4351369 northing

Time Begin: 11:32 PDT Time Ended: 11:38 PDT

Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

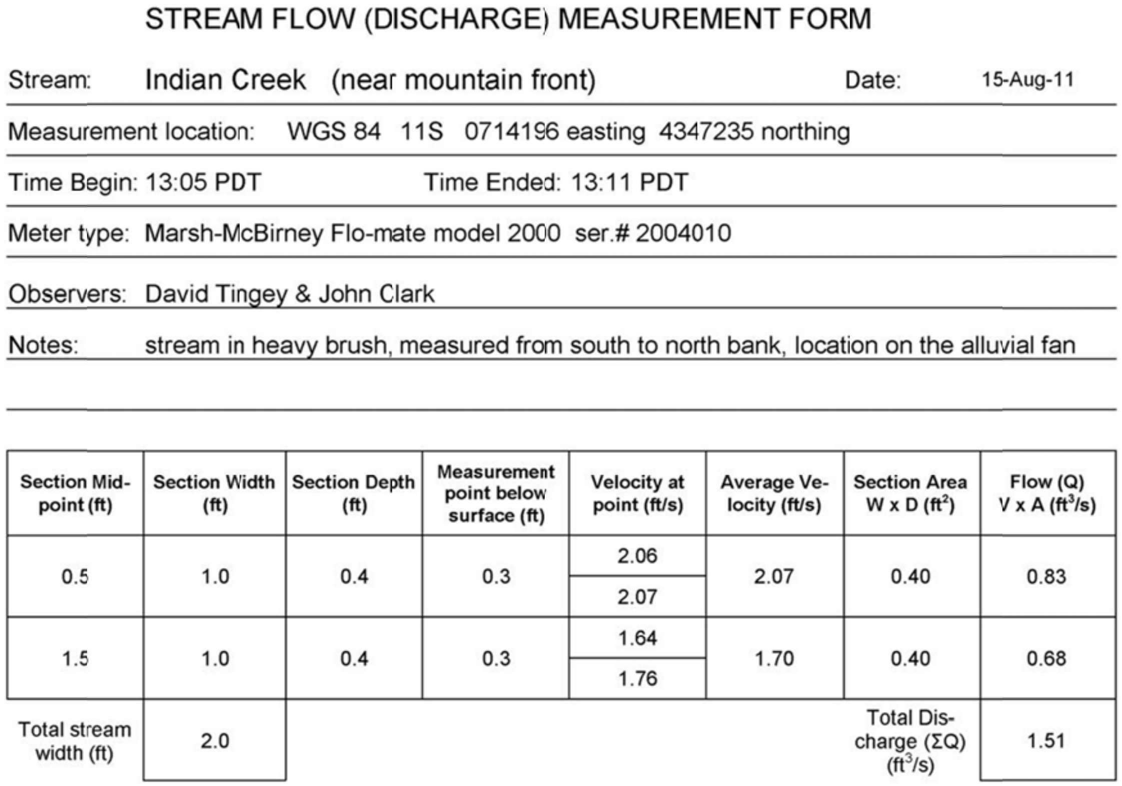
Observers: David Tingey & John Clark

Notes: measured in a concrete Y shaped irrigation diversion located downstream from the pond,

dampness and phreatophyte plants indicate water seepage from the irrigation ditch

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1.0	1.2	0.7	3.14	3.19	1.2	3.82
				3.23			
1.5	1.0	1.2	0.7	3.13	3.15	1.2	3.77
				3.16			
2.5	1.0	1.2	0.7	1.52	1.53	1.2	1.83
				1.53			
Total stream width (ft)	3.0					Total Discharge (ΣQ) (ft^3/s)	9.43

Streams	date	time	Total Discharge (ft^3/s)
Cleve and Indian Creek irrigation diversion (downstream of the pond)	15-Aug-11	11:38 PDT	9.43



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Indian Creek (near mountain front) Date: 15-Aug-11

Measurement location: WGS 84 11S 0714196 easting 4347235 northing

Time Begin: 13:05 PDT Time Ended: 13:11 PDT

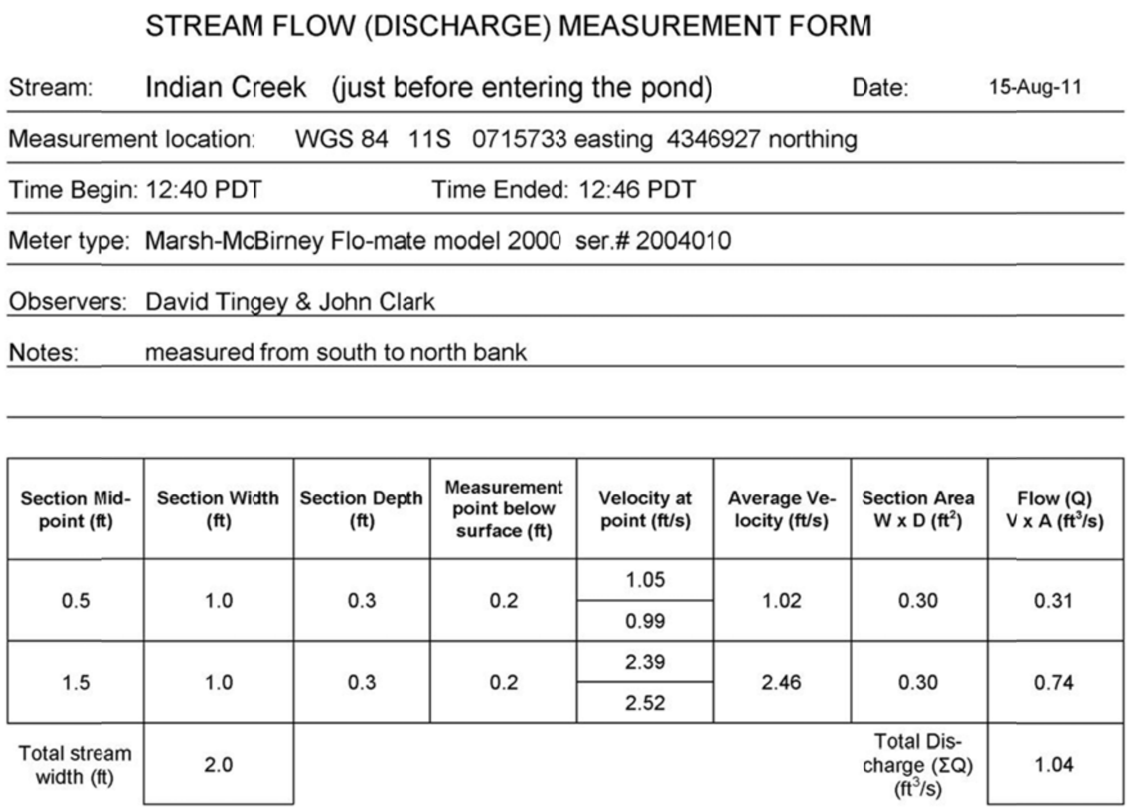
Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

Observers: David Tingey & John Clark

Notes: stream in heavy brush, measured from south to north bank, location on the alluvial fan

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1.0	0.4	0.3	2.06 2.07	2.07	0.40	0.83
1.5	1.0	0.4	0.3	1.64 1.76	1.70	0.40	0.68
Total stream width (ft)	2.0					Total Discharge (ΣQ) (ft^3/s)	1.51

Stream	date	time	Total Discharge (ft^3/s)
Indian Creek (near mountain front)	15-Aug-11	13:11 PDT	1.51



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Indian Creek (just before entering the pond) Date: 15-Aug-11

Measurement location: WGS 84 11S 0715733 easting 4346927 northing

Time Begin: 12:40 PDT Time Ended: 12:46 PDT

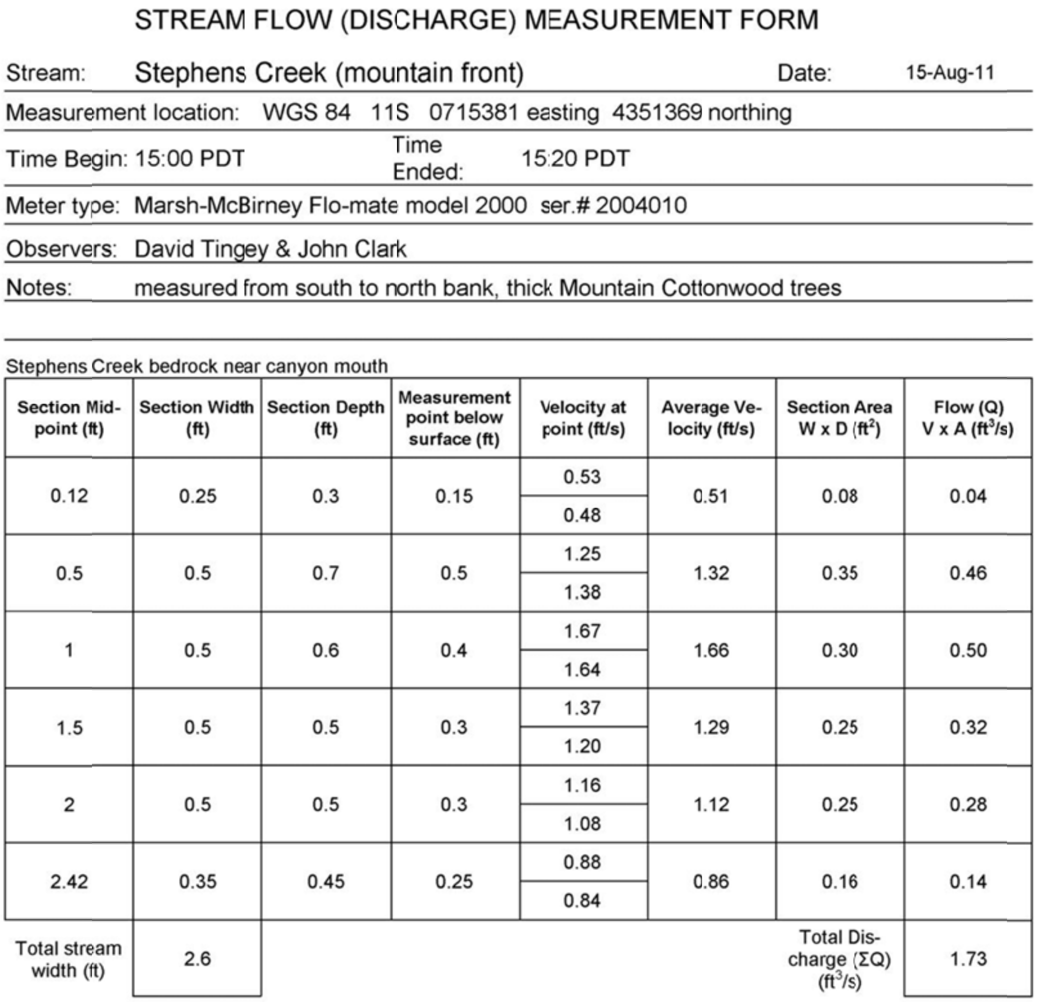
Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

Observers: David Tingey & John Clark

Notes: measured from south to north bank

Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.5	1.0	0.3	0.2	1.05 0.99	1.02	0.30	0.31
1.5	1.0	0.3	0.2	2.39 2.52	2.46	0.30	0.74
Total stream width (ft)	2.0					Total Discharge (ΣQ) (ft^3/s)	1.04

Stream	date	time	Total Dis-charge (ft^3/s)
Indian Creek (just before entering the pond)	15-Aug-11	12:46 PDT	1.04



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Stephens Creek (mountain front) Date: 15-Aug-11

Measurement location: WGS 84 11S 0715381 easting 4351369 northing

Time Begin: 15:00 PDT Time Ended: 15:20 PDT

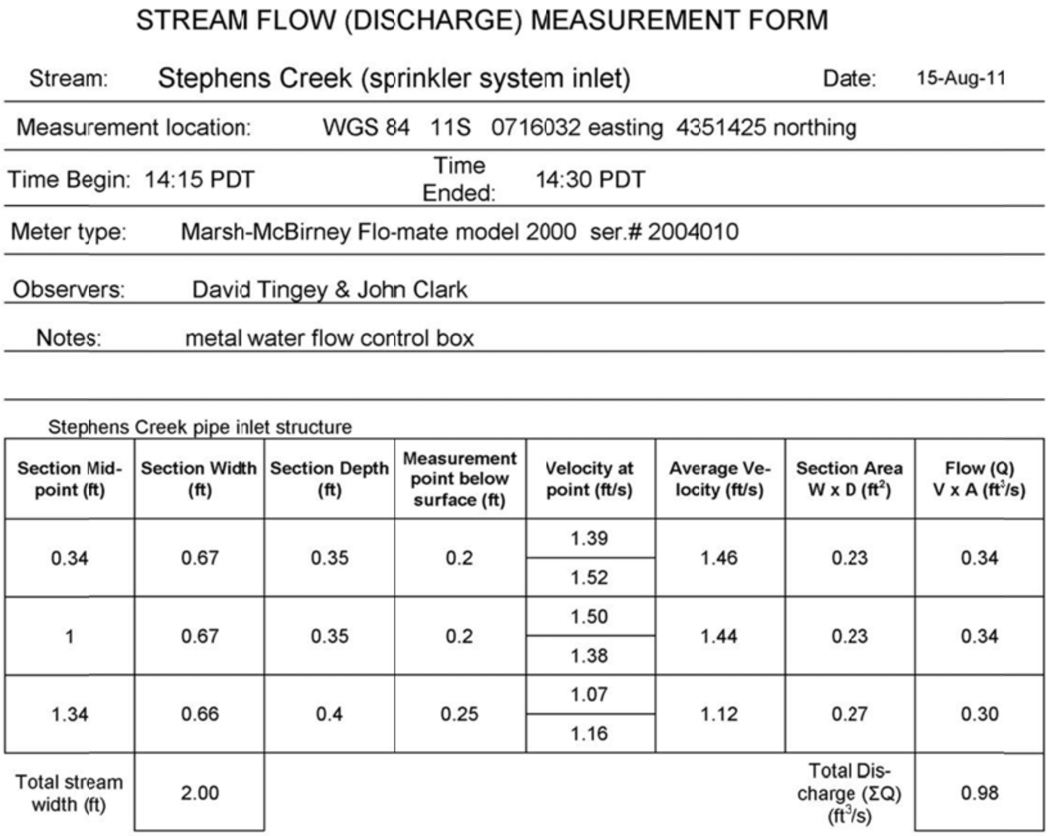
Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

Observers: David Tingey & John Clark

Notes: measured from south to north bank, thick Mountain Cottonwood trees

Stephens Creek bedrock near canyon mouth

Section Mid-point (ft)	**Section Width (ft)**	**Section Depth (ft)**	**Measurement point below surface (ft)**	**Velocity at point (ft/s)**	**Average Velocity (ft/s)**	**Section Area W x D (ft^2)**	**Flow (Q) V x A (ft^3/s)**
0.12	0.25	0.3	0.15	0.53	0.51	0.08	0.04
				0.48			
0.5	0.5	0.7	0.5	1.25	1.32	0.35	0.46
				1.38			
1	0.5	0.6	0.4	1.67	1.66	0.30	0.50
				1.64			
1.5	0.5	0.5	0.3	1.37	1.29	0.25	0.32
				1.20			
2	0.5	0.5	0.3	1.16	1.12	0.25	0.28
				1.08			
2.42	0.35	0.45	0.25	0.88	0.86	0.16	0.14
				0.84			
Total stream width (ft)	2.6					Total Discharge (ΣQ) (ft^3/s)	1.73



STREAM FLOW (DISCHARGE) MEASUREMENT FORM

Stream: Stephens Creek (sprinkler system inlet) Date: 15-Aug-11

Measurement location: WGS 84 11S 0716032 easting 4351425 northing

Time Begin: 14:15 PDT Time Ended: 14:30 PDT

Meter type: Marsh-McBirney Flo-mate model 2000 ser.# 2004010

Observers: David Tingey & John Clark

Notes: metal water flow control box

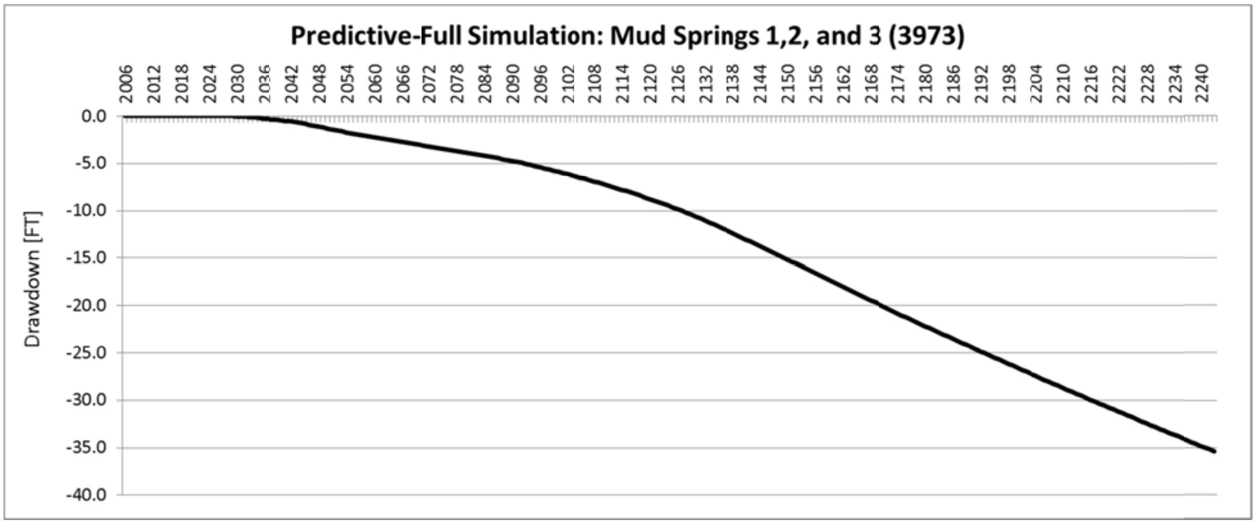
Stephens Creek pipe inlet structure

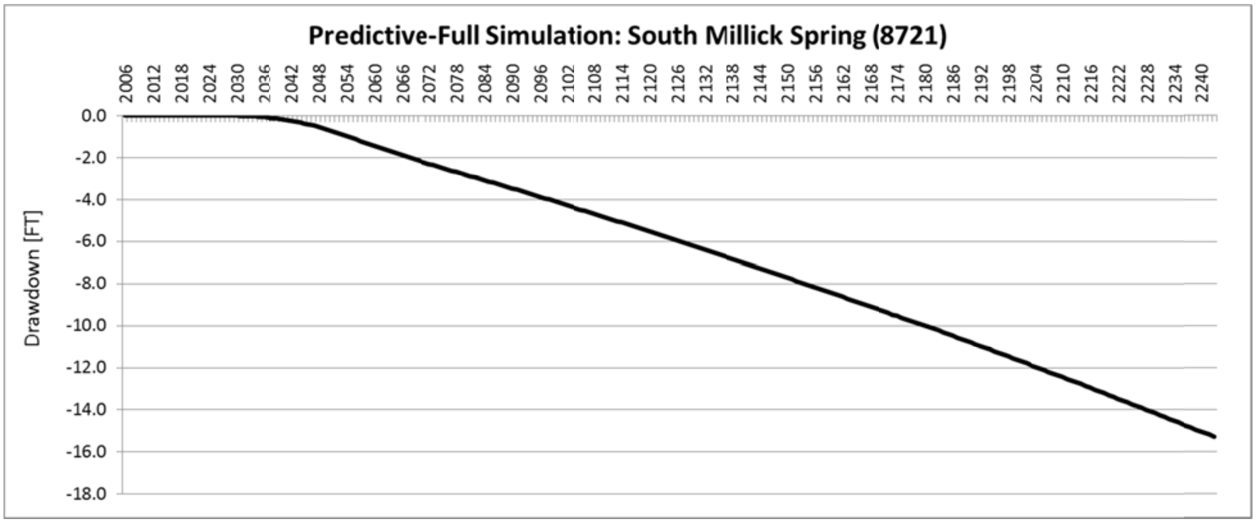
Section Mid-point (ft)	Section Width (ft)	Section Depth (ft)	Measurement point below surface (ft)	Velocity at point (ft/s)	Average Velocity (ft/s)	Section Area W x D (ft^2)	Flow (Q) V x A (ft^3/s)
0.34	0.67	0.35	0.2	1.39	1.46	0.23	0.34
				1.52			
1	0.67	0.35	0.2	1.50	1.44	0.23	0.34
				1.38			
1.34	0.66	0.4	0.25	1.07	1.12	0.27	0.30
				1.16			
Total stream width (ft)	2.00					Total Discharge (ΣQ) (ft^3/s)	0.98

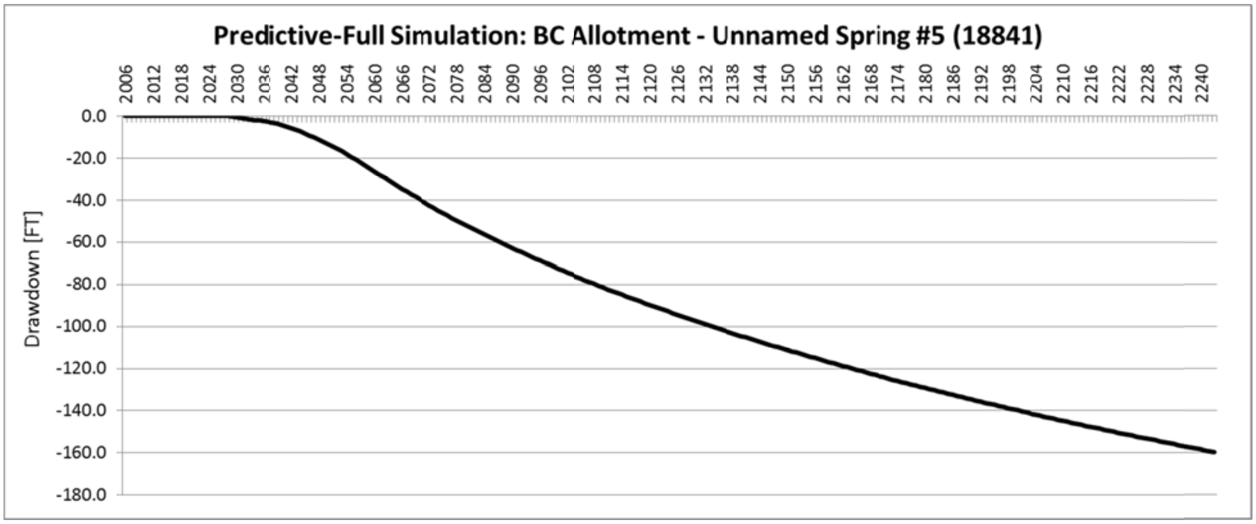
Appendix B – Drawdown Charts

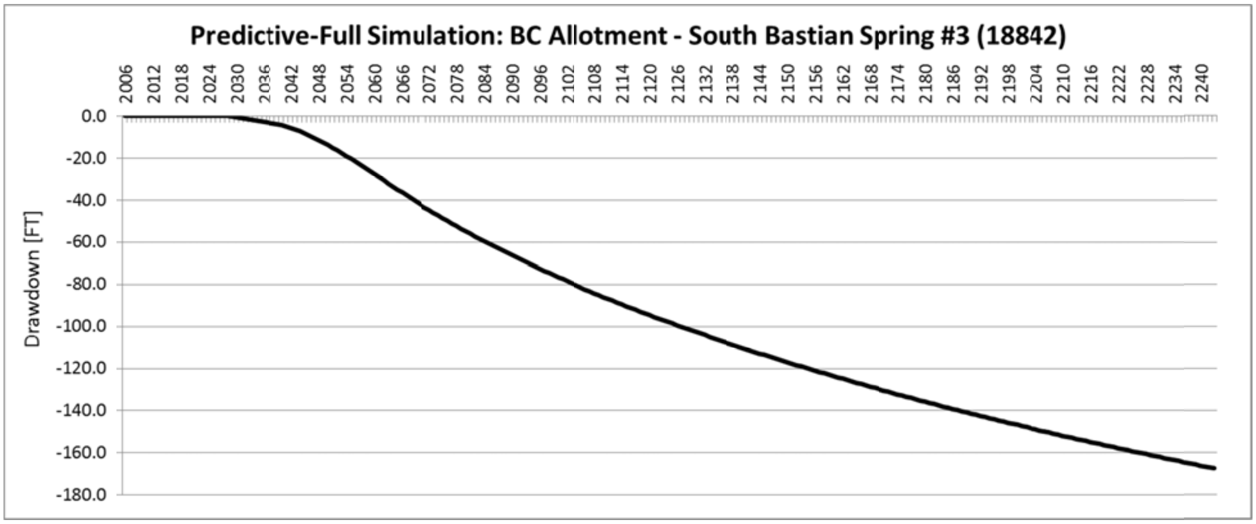
The following charts illustrate drawdown vs. time at each of the CPB-owned water rights locations associated with valley floor springs or wells. Two sets of charts are shown, one set for the Predictive-Full simulation and one for the Predictive-Minus4 simulation.

Predictive-Full Simulation






Predictive-Full Simulation: BC Allotment - Unnamed Spring #5 (18841)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
2120
2126
2132
2138
2144
2150
2156
2162
2168
2174
2180
2186
2192
2198
2204
2210
2216
2222
2228
2234
2240


Predictive-Full Simulation: BC Allotment - South Bastian Spring #3 (18842)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
2120
2126
2132
2138
2144
2150
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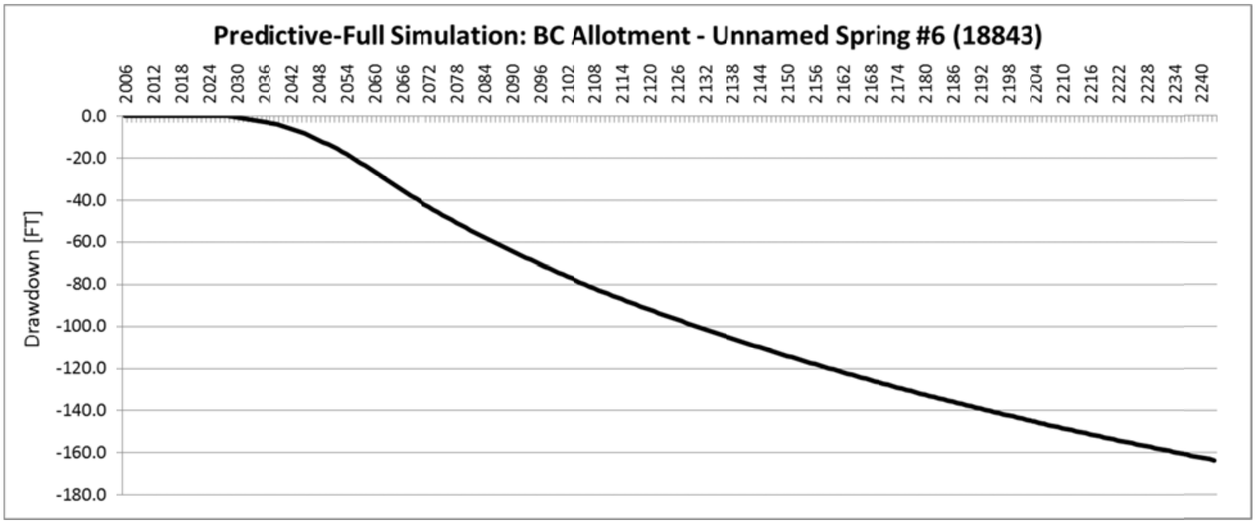
2216
2222
2228
2234
2240


Predictive-Full Simulation: BC Allotment - Unnamed Spring #6 (18843)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
-180.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
2120
2126
2132
2138
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2198
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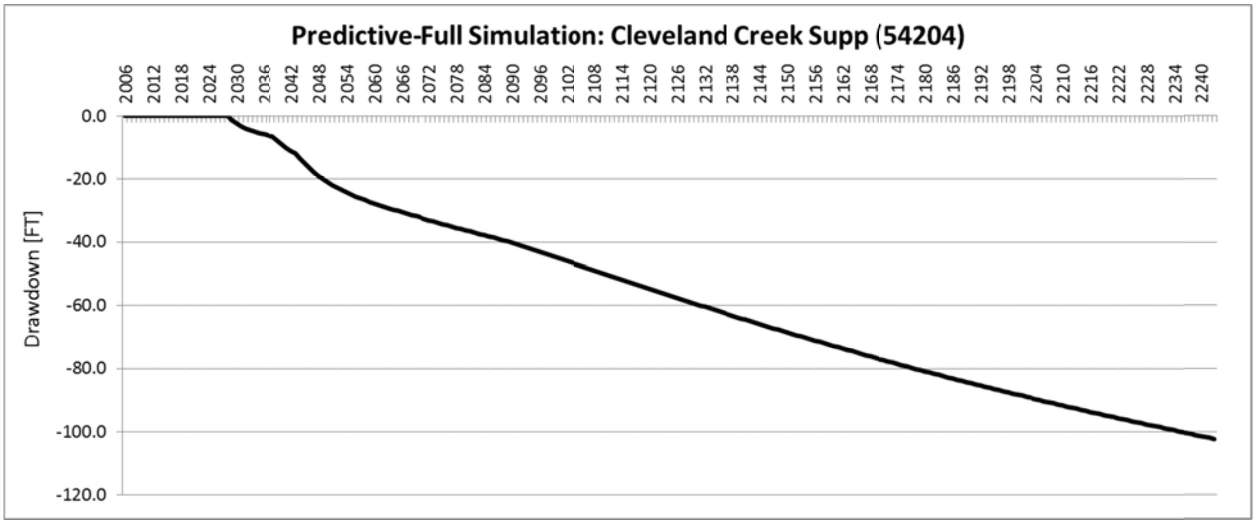
2222
2228
2234
2240



Predictive-Full Simulation: Cleveland Creek Supp (54204)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
2120
2126
2132
2138
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2228
2234
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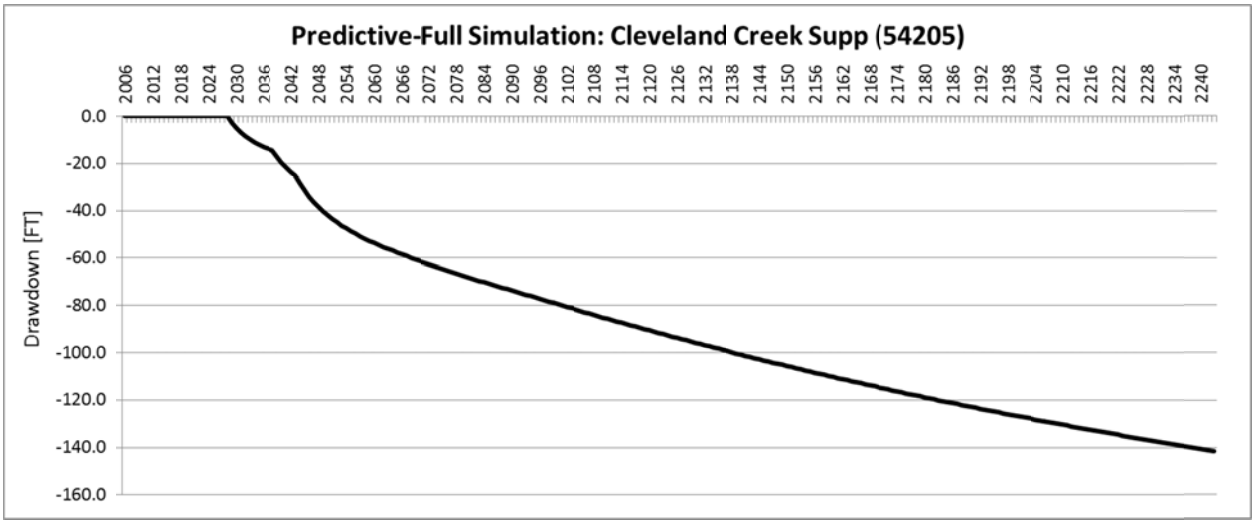

Predictive-Full Simulation: Cleveland Creek Supp (54205)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
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2138
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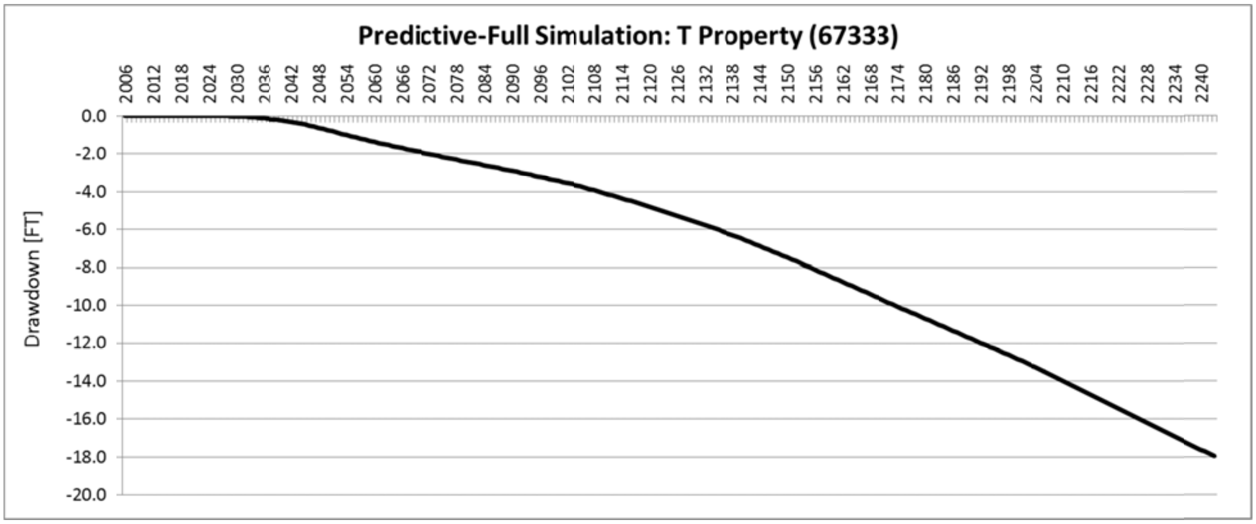

Predictive-Full Simulation: T Property (67333)
Drawdown [FT]
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
2120
2126
2132
2138
2144
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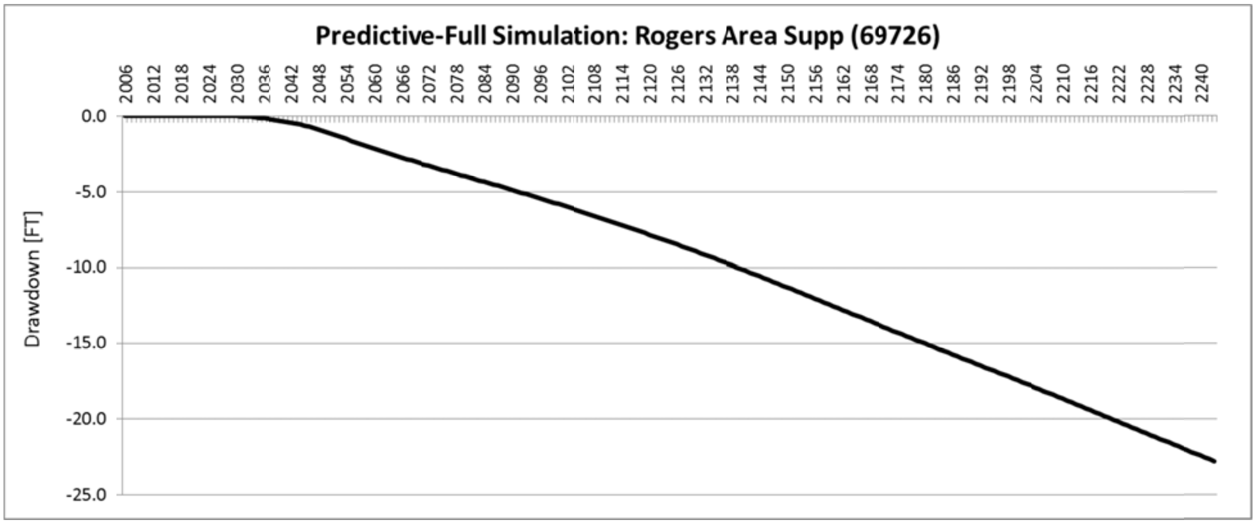
Predictive-Full Simulation: Rogers Area Supp (69726)
Drawdown [FT]
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
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2228
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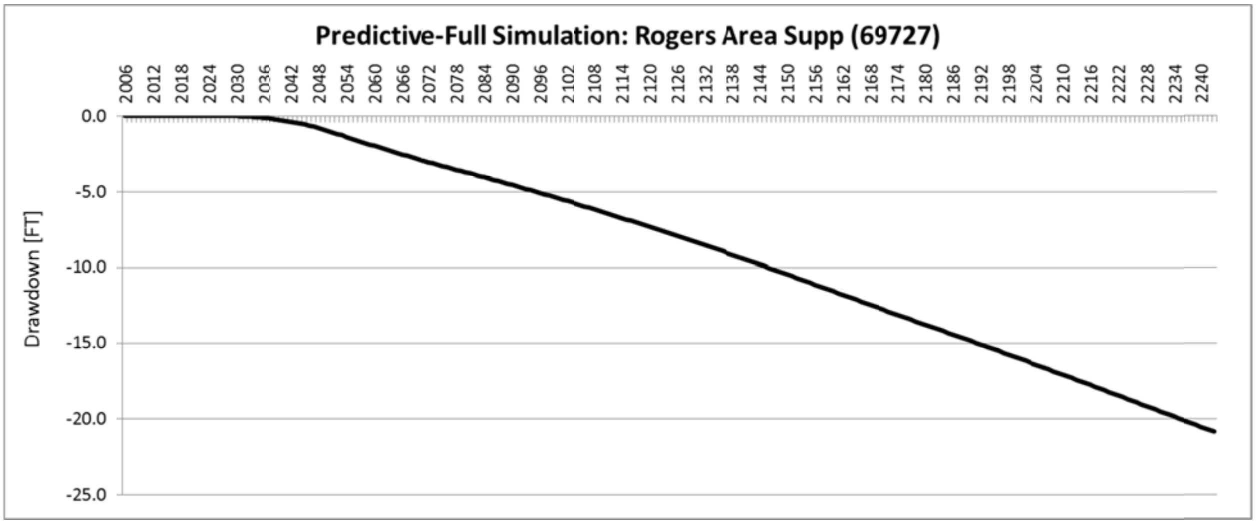
Predictive-Full Simulation: Rogers Area Supp (69727)
Drawdown [FT]
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
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2090
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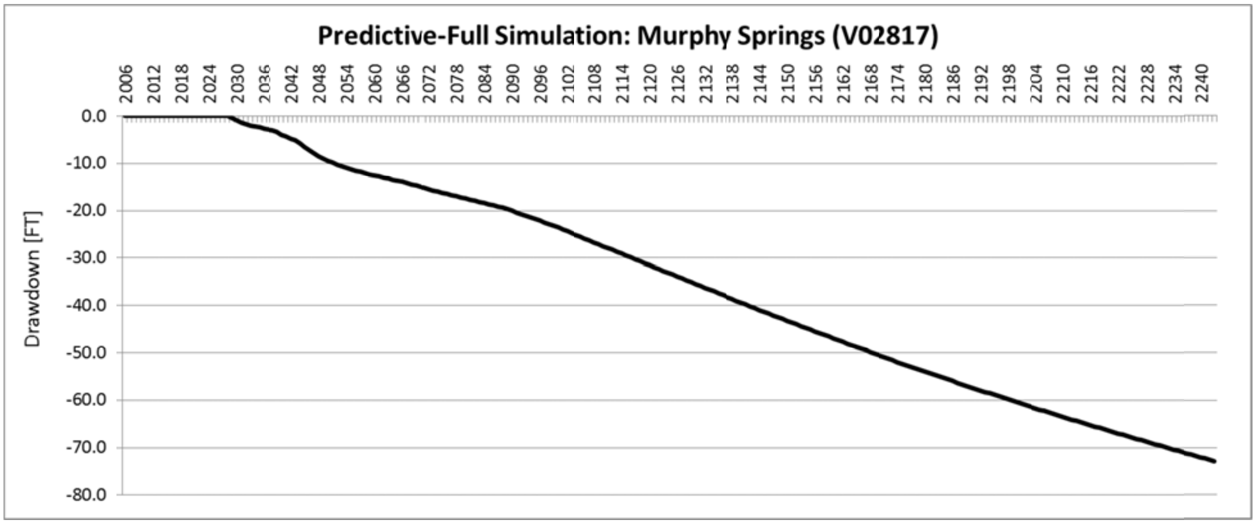
Predictive-Full Simulation: Murphy Springs (V02817)
Drawdown [FT]
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
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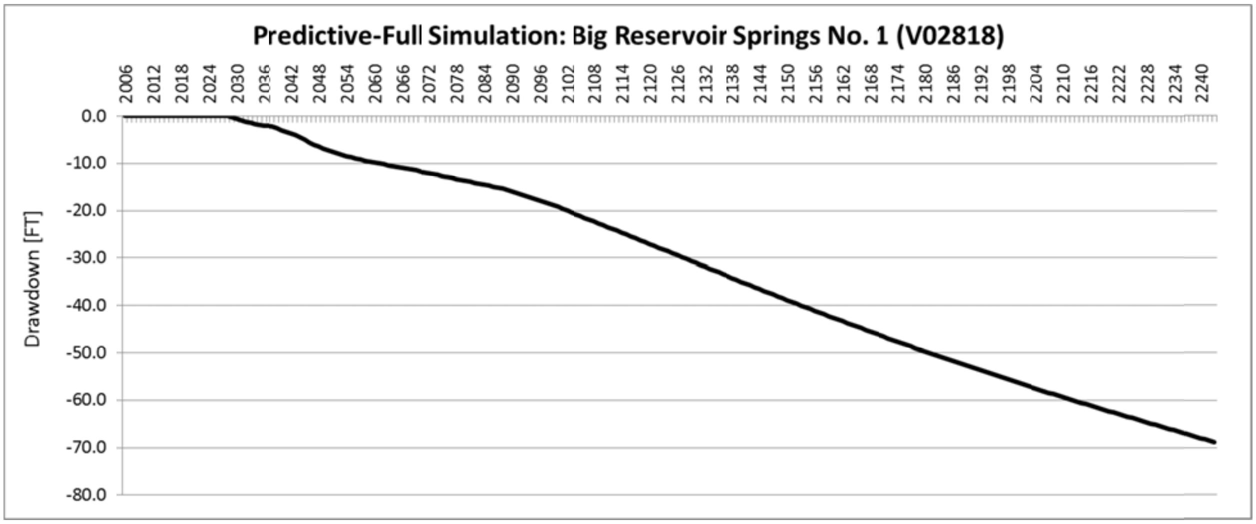
Predictive-Full Simulation: Big Reservoir Springs No. 1 (V02818)
Drawdown [FT]
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
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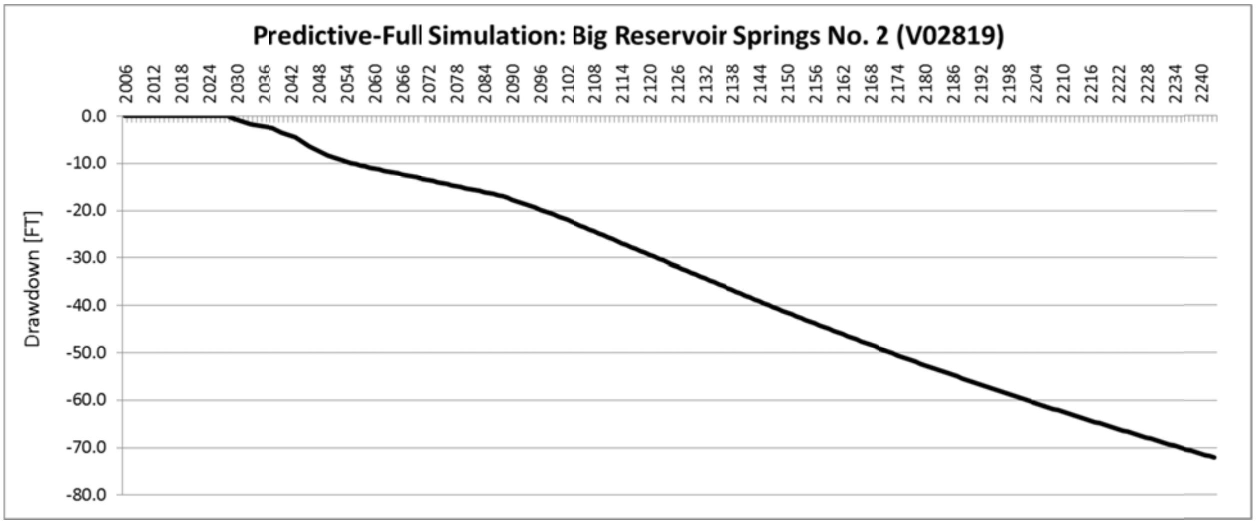
Predictive-Full Simulation: Big Reservoir Springs No. 2 (V02819)
Drawdown [FT]
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-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
2006
2012
2018
2024
2030
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2042
2048
2054
2060
2066
2072
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2234
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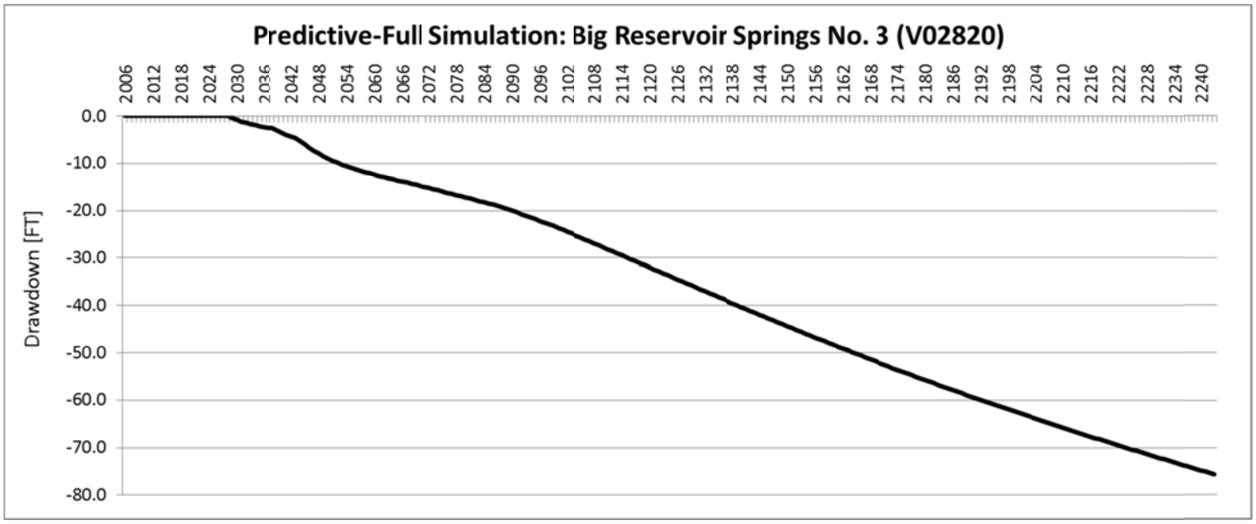
Predictive-Full Simulation: Big Reservoir Springs No. 3 (V02820)
Drawdown [FT]
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
2006
2012
2018
2024
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2036
2042
2048
2054
2060
2066
2072
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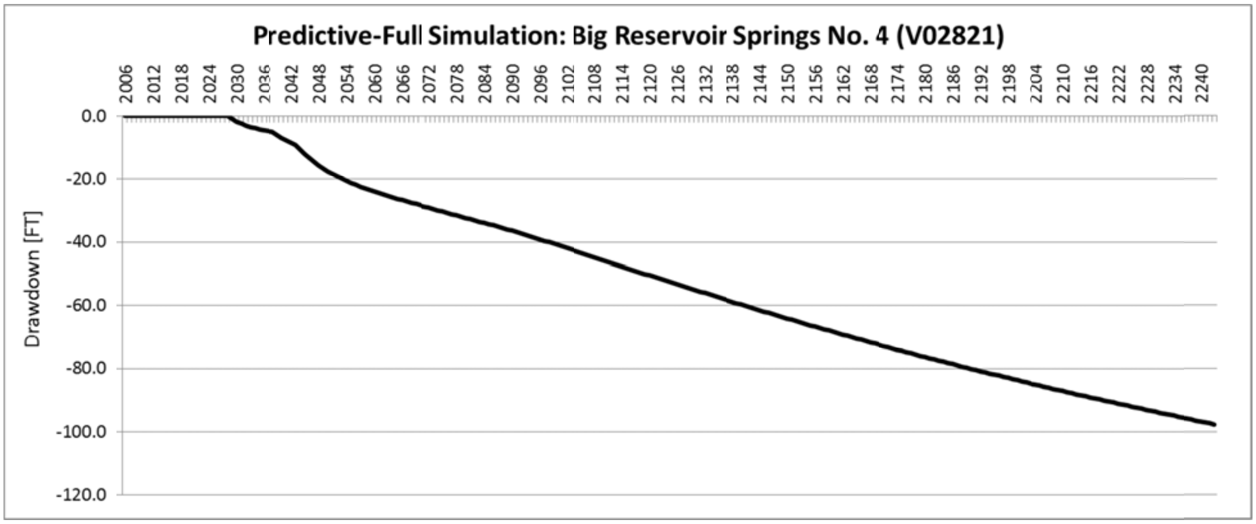
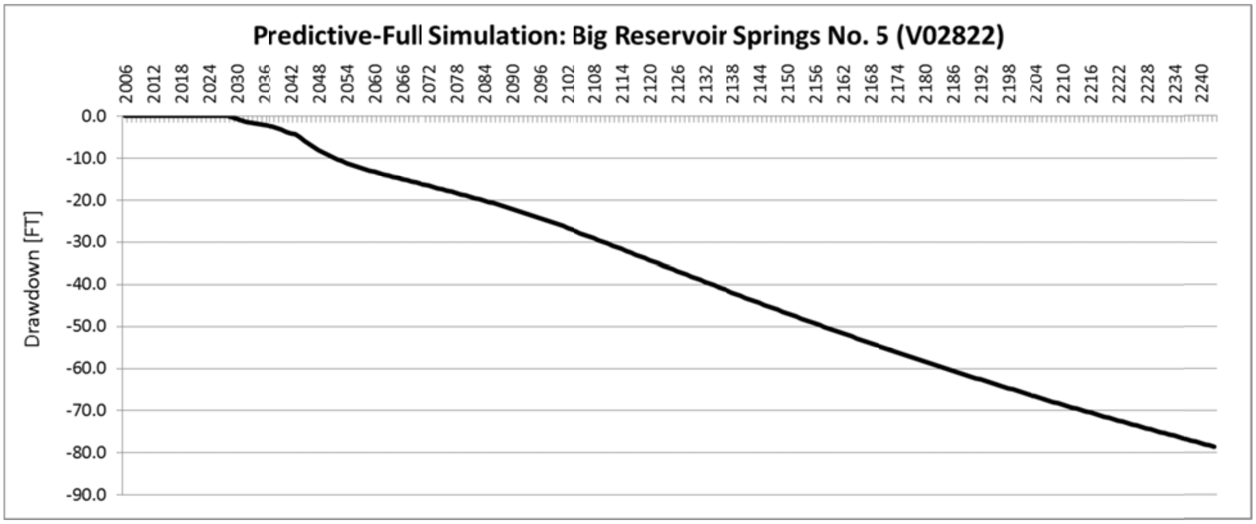
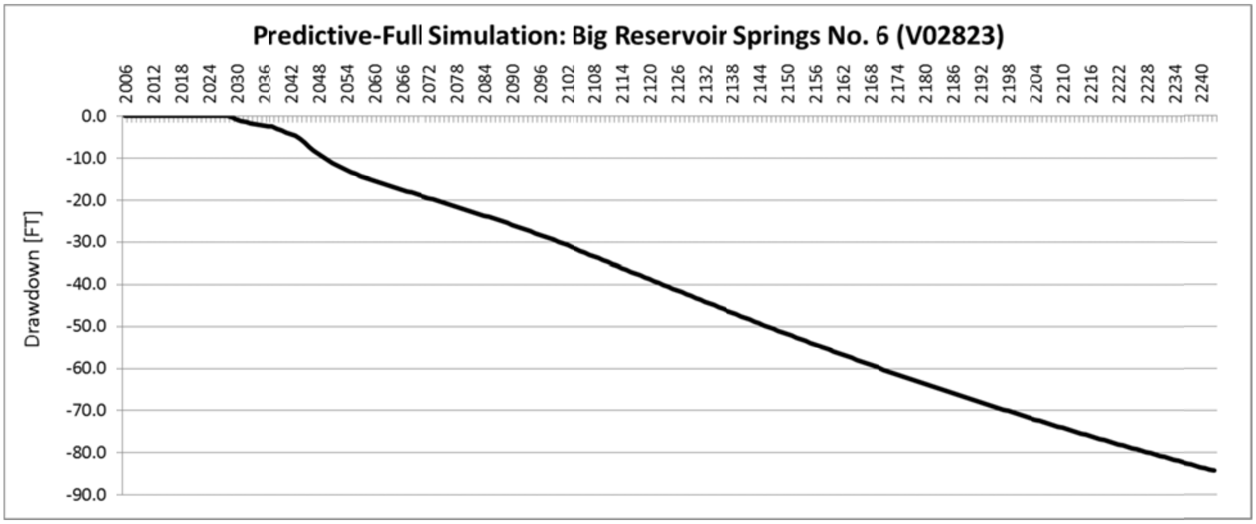
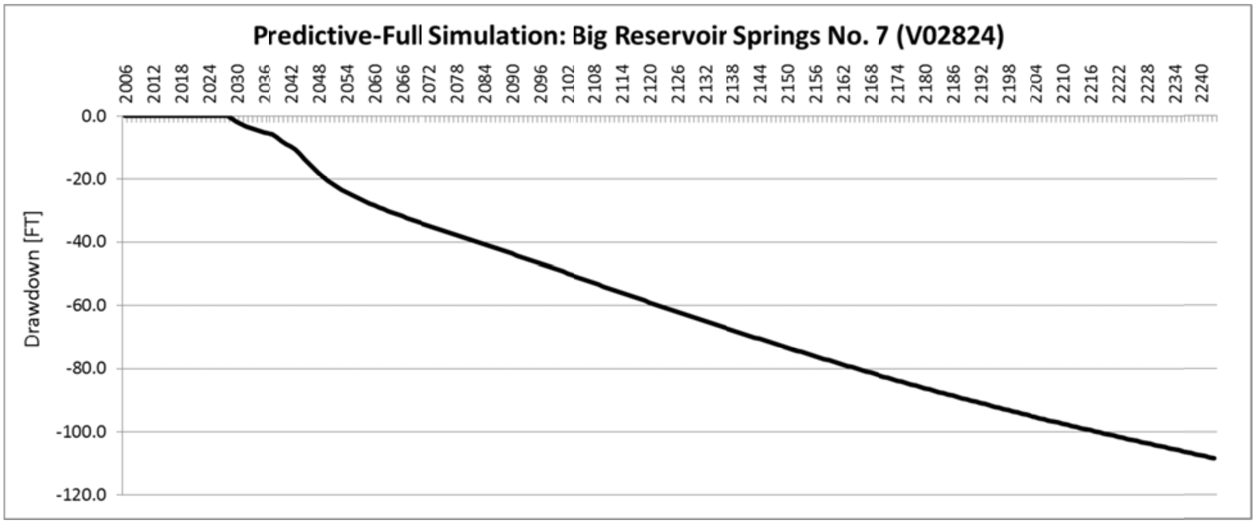

Predictive-Full Simulation: Big Reservoir Springs No. 4 (V02821)


Predictive-Full Simulation: Big Reservoir Springs No. 5 (V02822)


Predictive-Full Simulation: Big Reservoir Springs No. 6 (V02823)


Predictive-Full Simulation: Big Reservoir Springs No. 7 (V02824)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
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2066
2072
2078
2084
2090
2096
2102
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2132
2138
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2180
2186
2192
2198
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2210
2216
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2228
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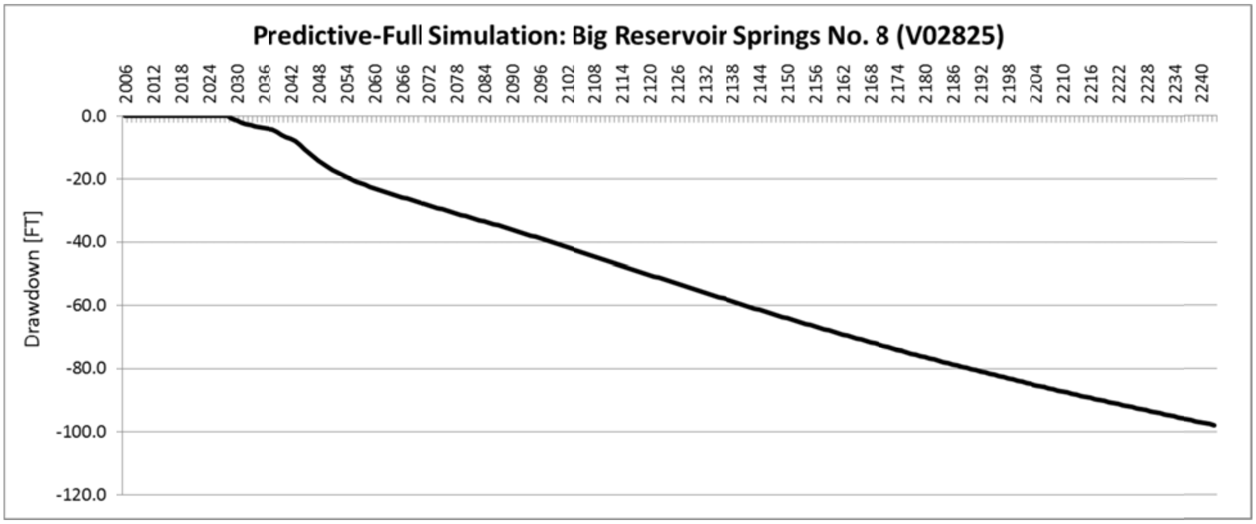
Predictive-Full Simulation: Big Reservoir Springs No. 8 (V02825)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
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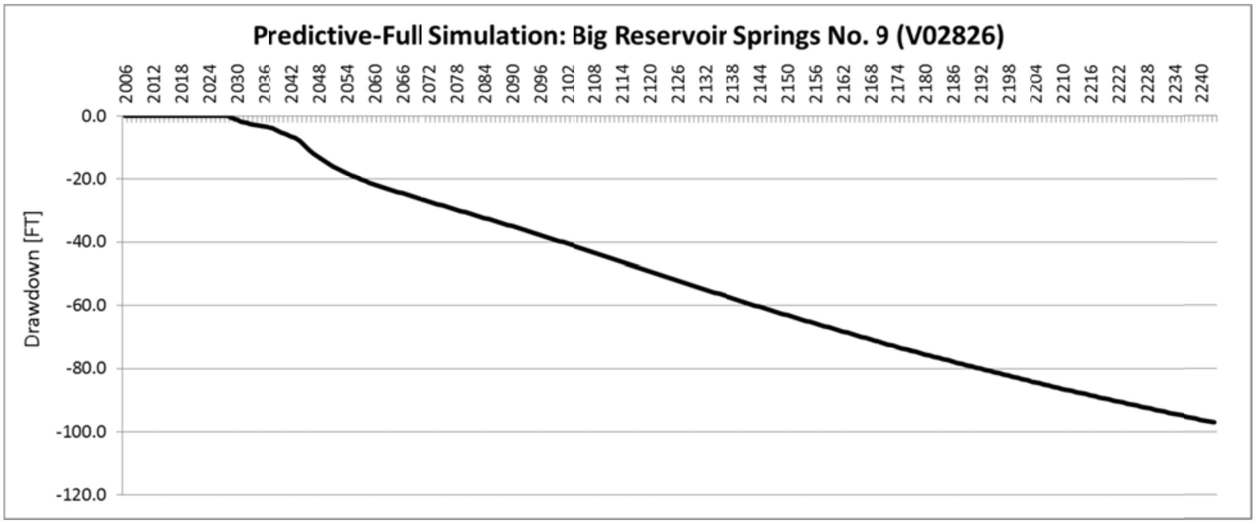
2222
2228
2234
2240


Predictive-Full Simulation: Big Reservoir Springs No. 9 (V02826)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
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2084
2090
2096
2102
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2126
2132
2138
2144
2150
2156
2162
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2174
2180
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2198
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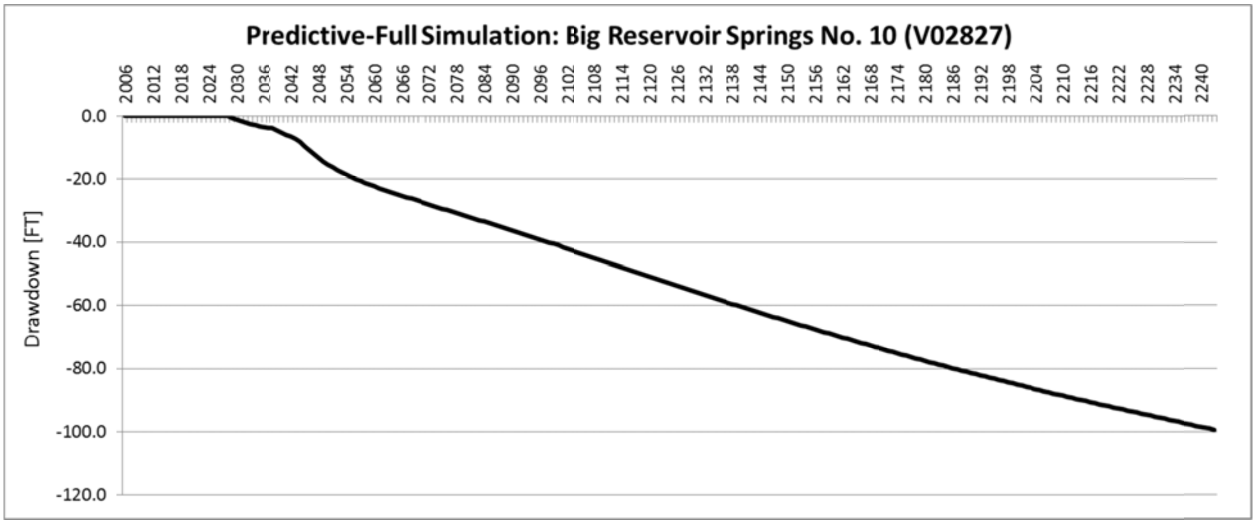
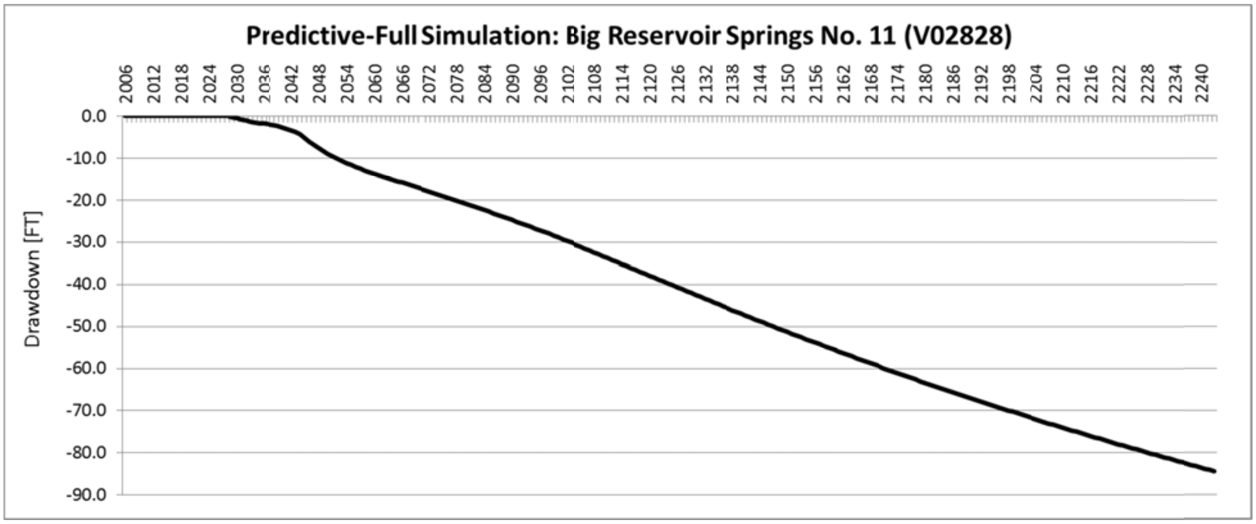
2210
2216
2222
2228
2234
2240


Predictive-Full Simulation: Big Reservoir Springs No. 10 (V02827)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
2114
2120
2126
2132
2138
2144
2150
2156
2162
2168
2174
2180
2186
2192
2198
2204
2210
2216
2222
2228
2234
2240


Predictive-Full Simulation: Big Reservoir Springs No. 11 (V02828)
Drawdown [FT]
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
2006
2012
2018
2024
2030
2036
2042
2048
2054
2060
2066
2072
2078
2084
2090
2096
2102
2108
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2120
2126
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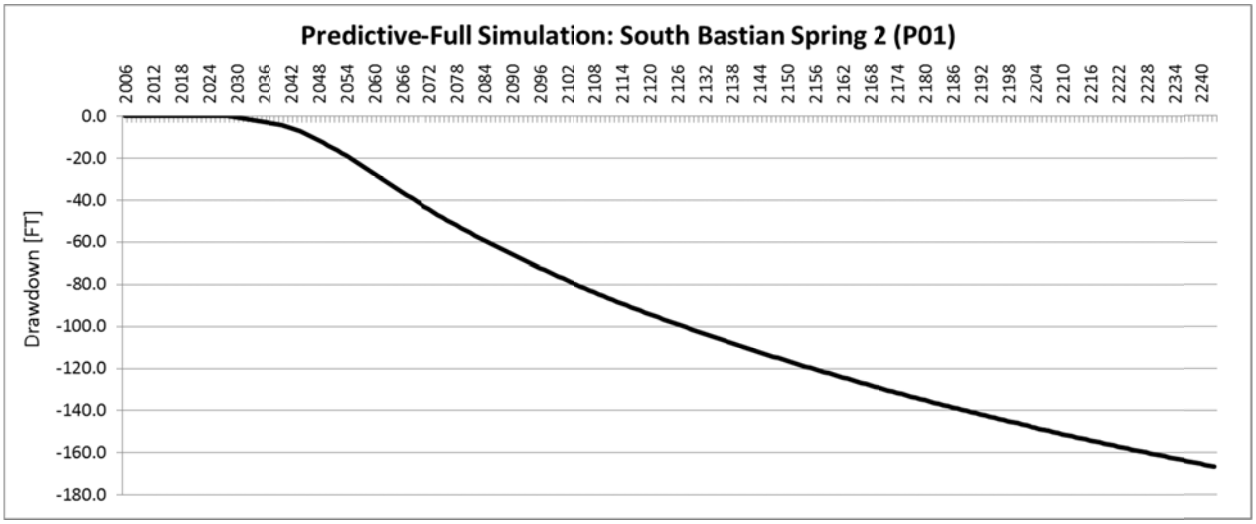
Predictive-Full Simulation: South Bastian Spring 2 (P01)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
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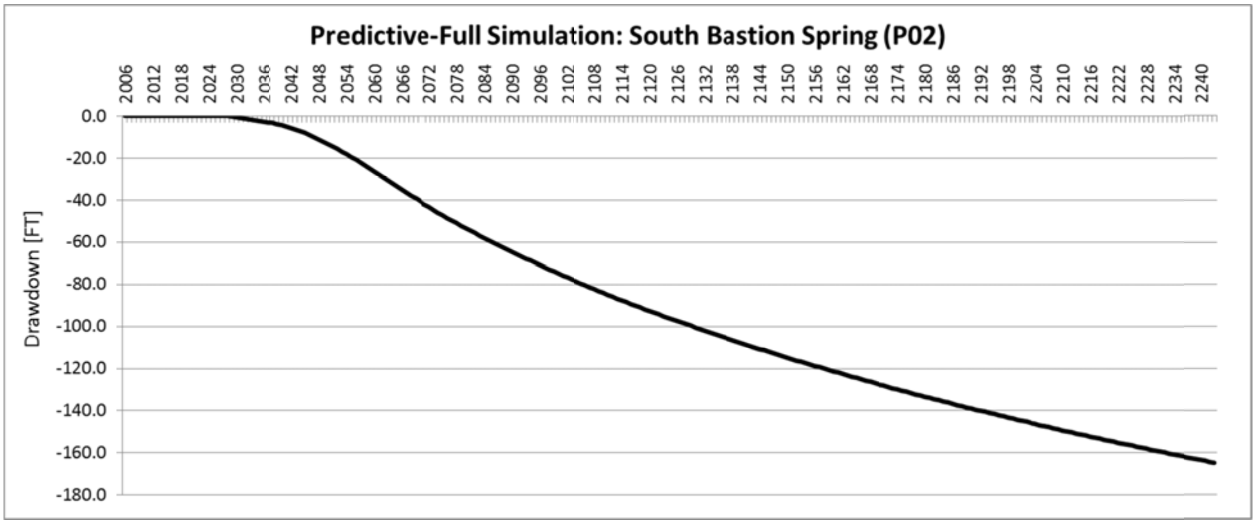
Predictive-Full Simulation: South Bastion Spring (P02)
Drawdown [FT]
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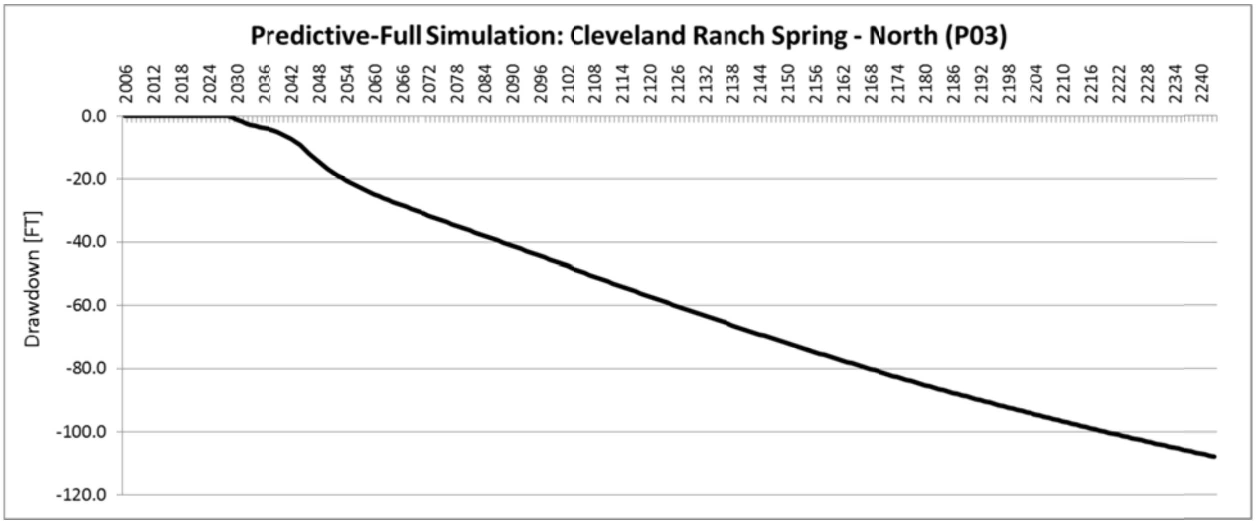
Predictive-Full Simulation: Cleveland Ranch Spring - North (P03)
Drawdown [FT]
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2012
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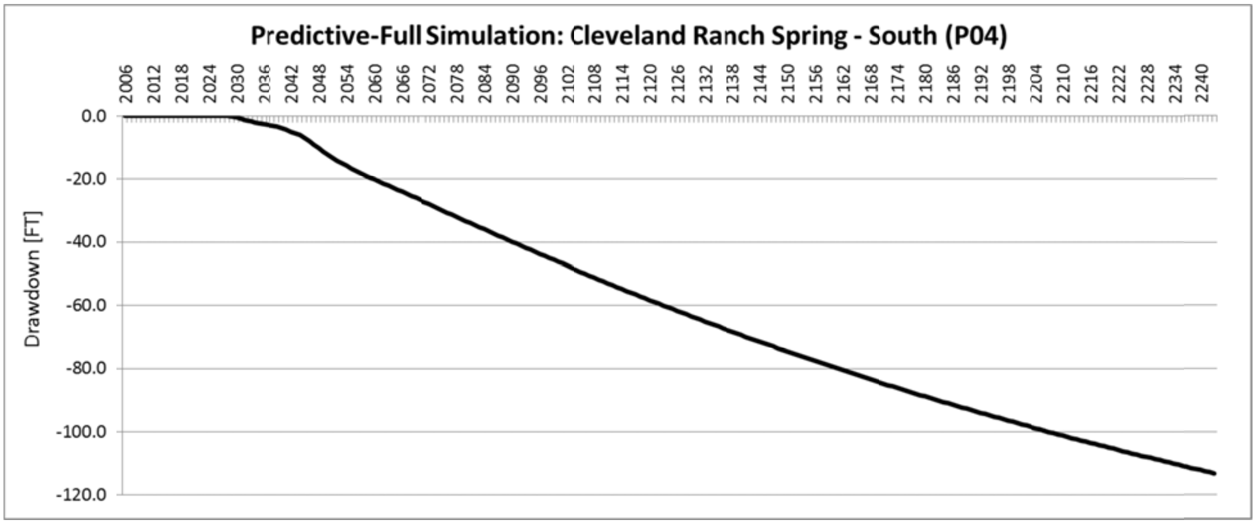
Predictive-Full Simulation: Cleveland Ranch Spring - South (P04)
Drawdown [FT]
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-100.0
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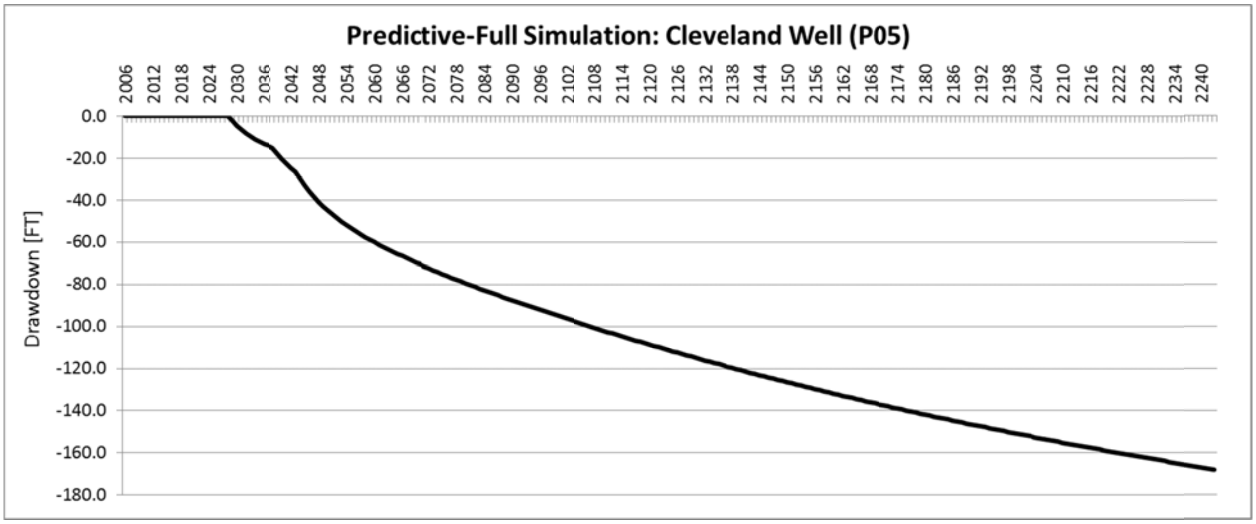
Predictive-Full Simulation: Cleveland Well (P05)
Drawdown [FT]
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-80.0
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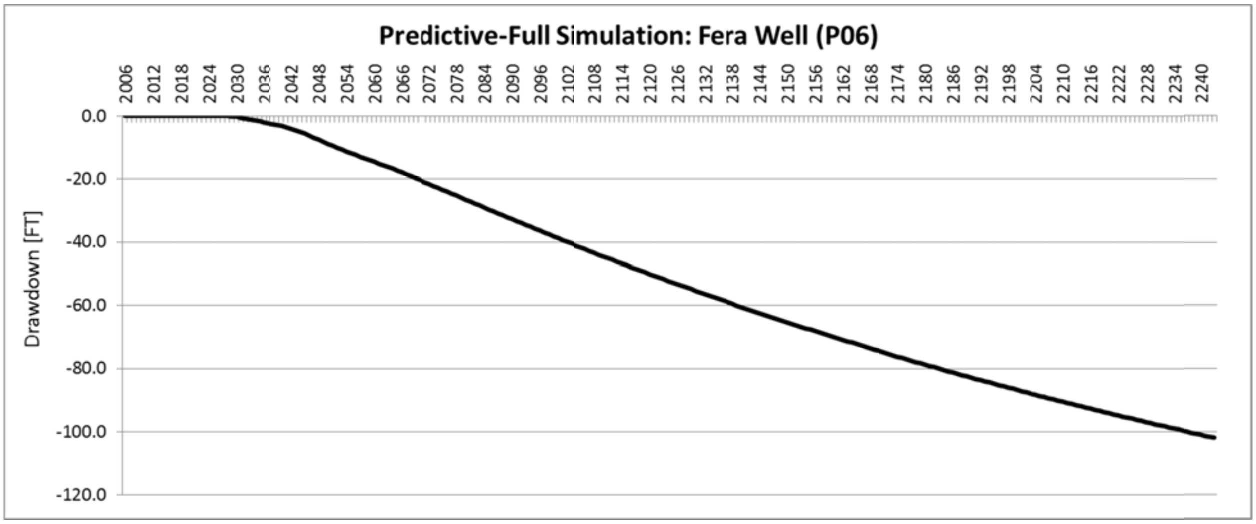
Predictive-Full Simulation: Fera Well (P06)
Drawdown [FT]
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-40.0
-60.0
-80.0
-100.0
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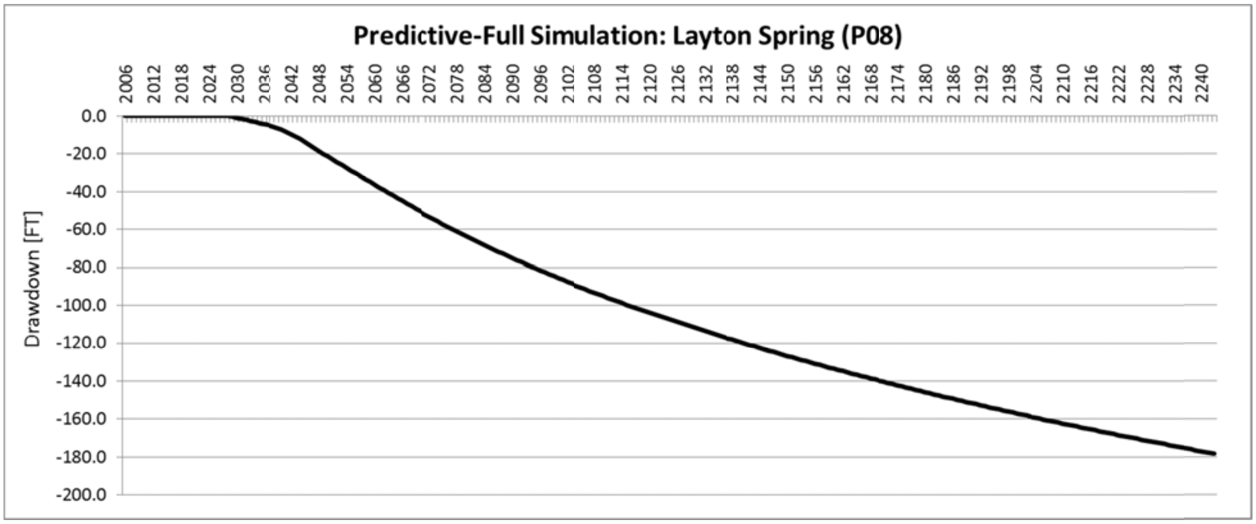
Predictive-Full Simulation: Layton Spring (P08)
Drawdown [FT]
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-80.0
-100.0
-120.0
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2012
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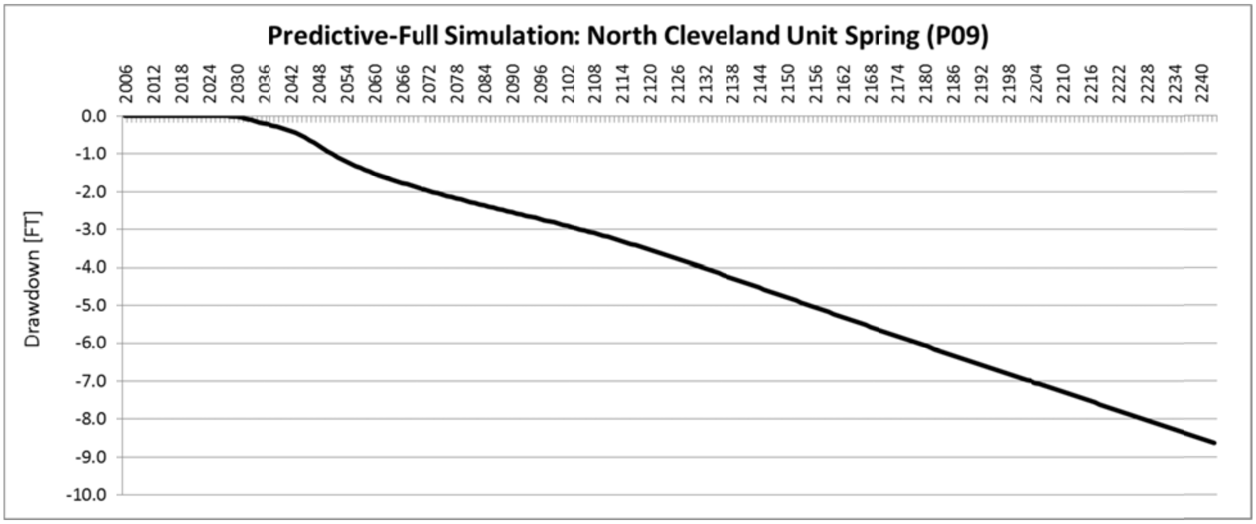
Predictive-Full Simulation: North Cleveland Unit Spring (P09)
Drawdown [FT]
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-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
2006
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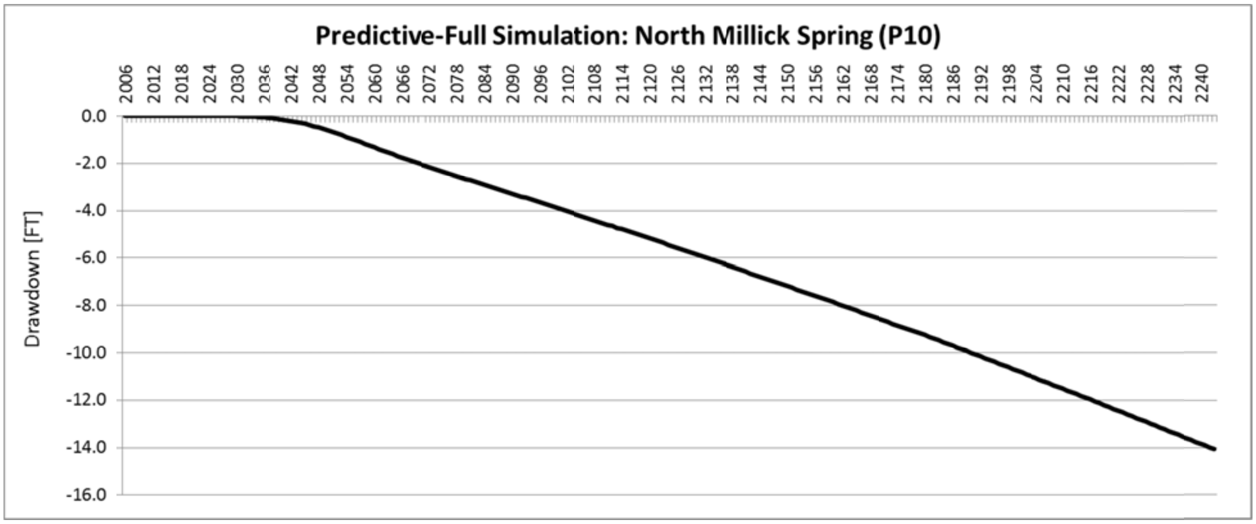
Predictive-Full Simulation: North Millick Spring (P10)
Drawdown [FT]
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-4.0
-6.0
-8.0
-10.0
-12.0
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2012
2018
2024
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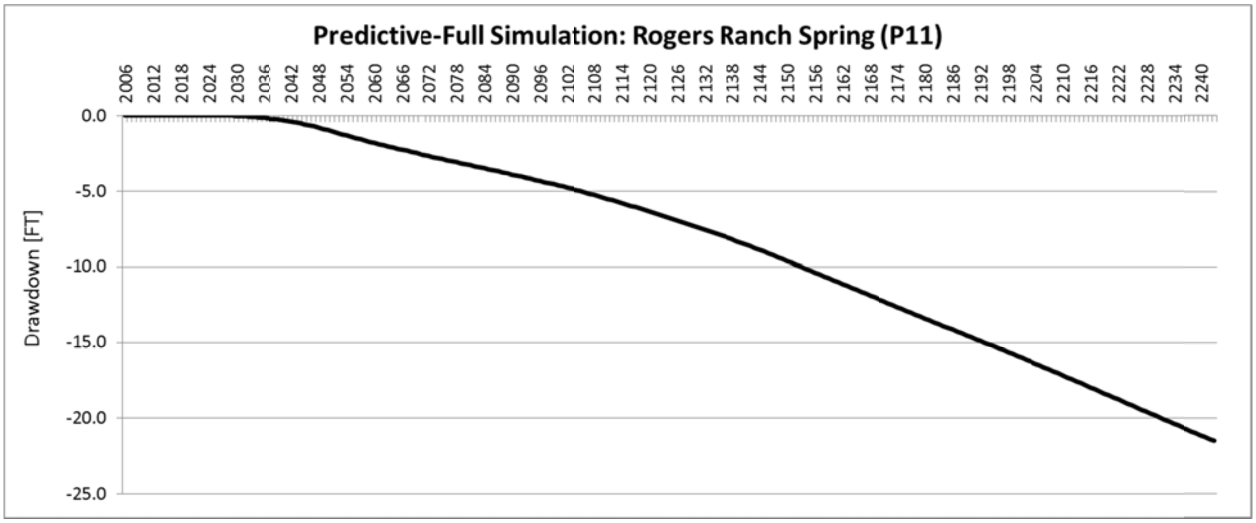
Predictive-Full Simulation: Rogers Ranch Spring (P11)
Drawdown [FT]
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-5.0
-10.0
-15.0
-20.0
-25.0
2006
2012
2018
2024
2030
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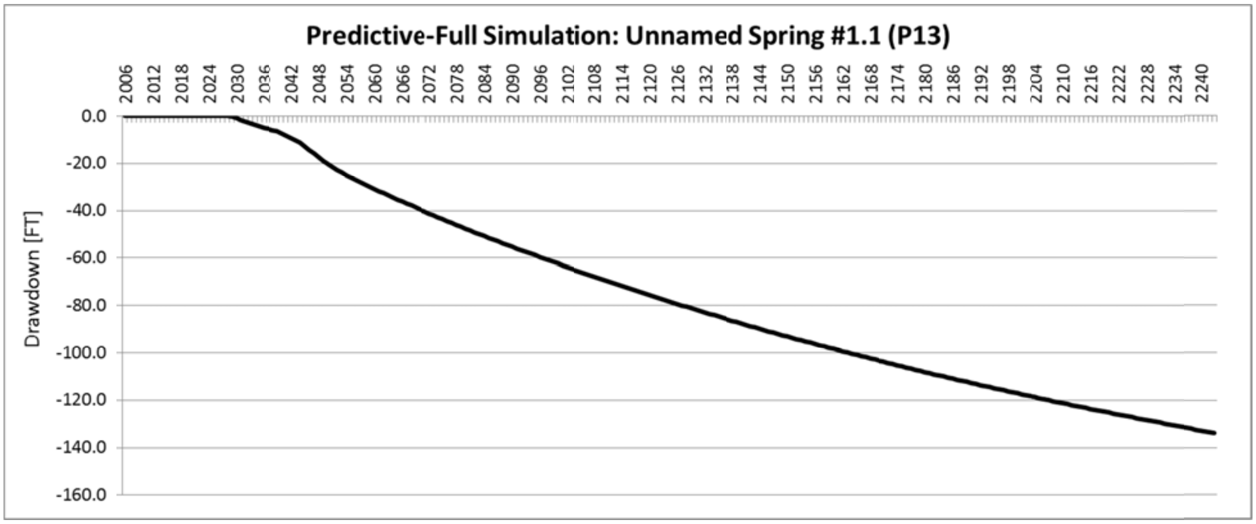
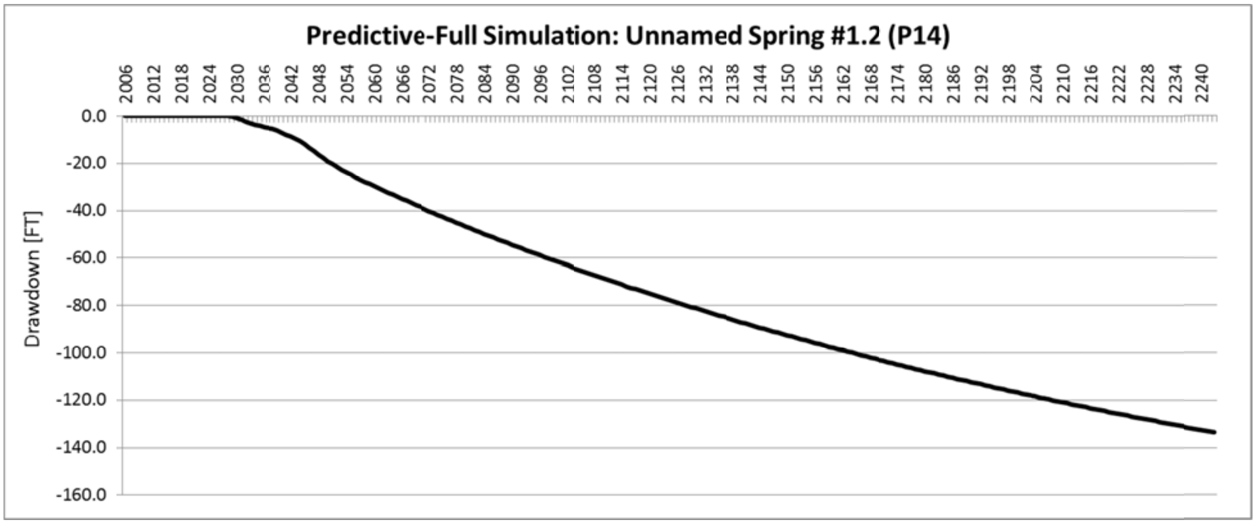

Predictive-Full Simulation: Unnamed Spring #1.1 (P13)
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
Drawdown [FT]


Predictive-Full Simulation: Unnamed Spring #1.2 (P14)
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240
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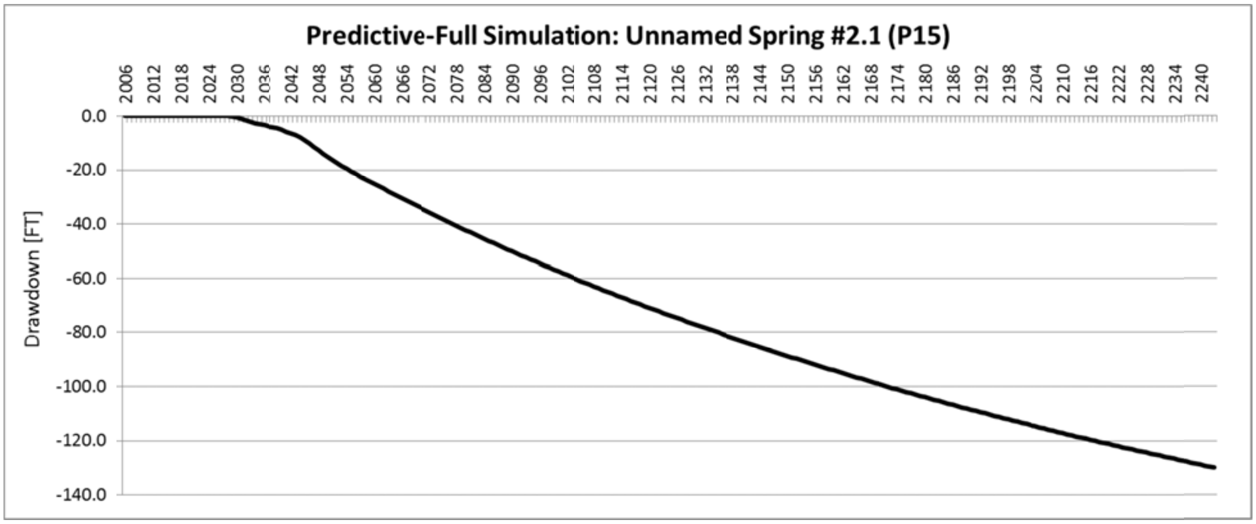
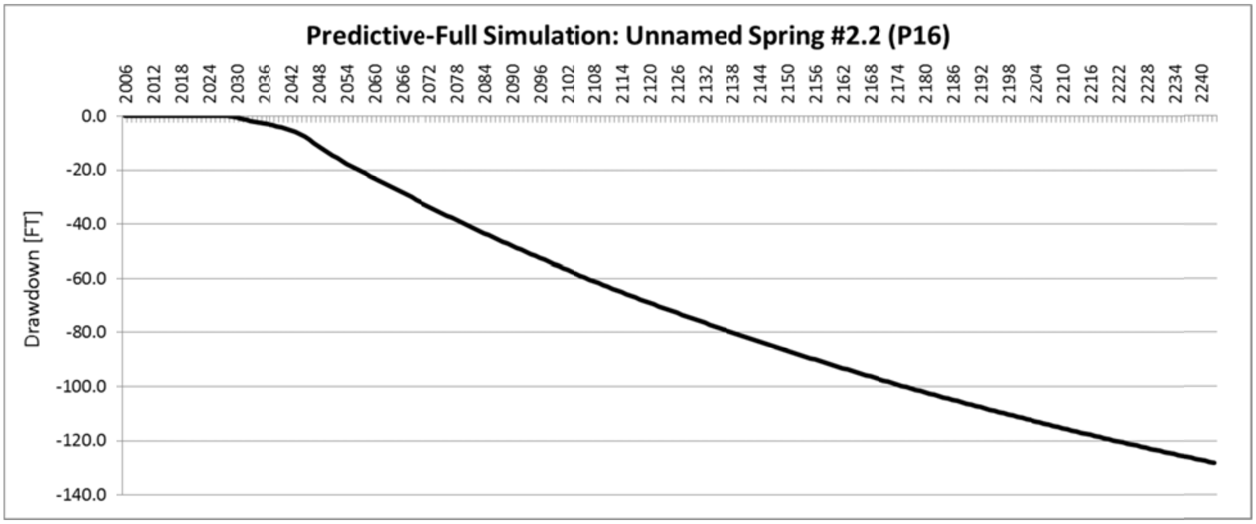
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
Drawdown [FT]


Predictive-Full Simulation: Unnamed Spring #2.1 (P15)
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
Drawdown [FT]


Predictive-Full Simulation: Unnamed Spring #2.2 (P16)
Drawdown [FT]
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-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
2006
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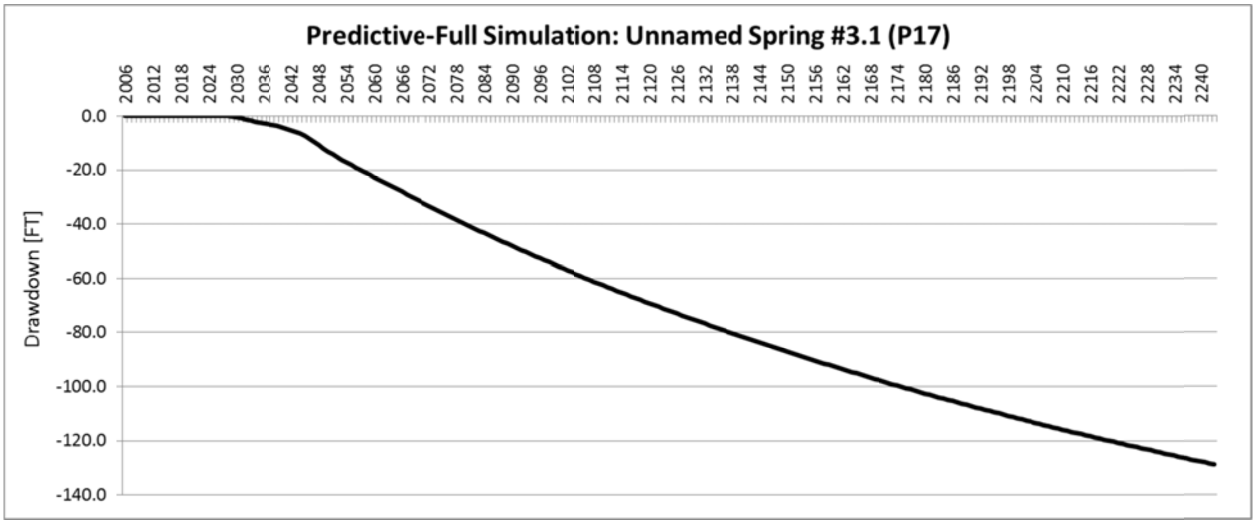
Predictive-Full Simulation: Unnamed Spring #3.1 (P17)
Drawdown [FT]
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-100.0
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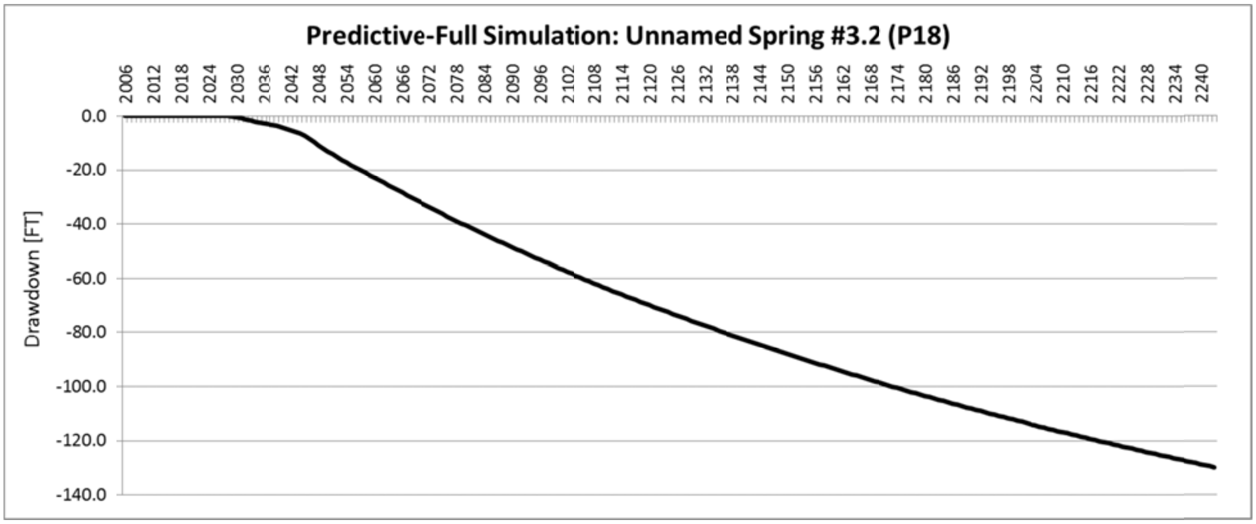
Predictive-Full Simulation: Unnamed Spring #3.2 (P18)
Drawdown [FT]
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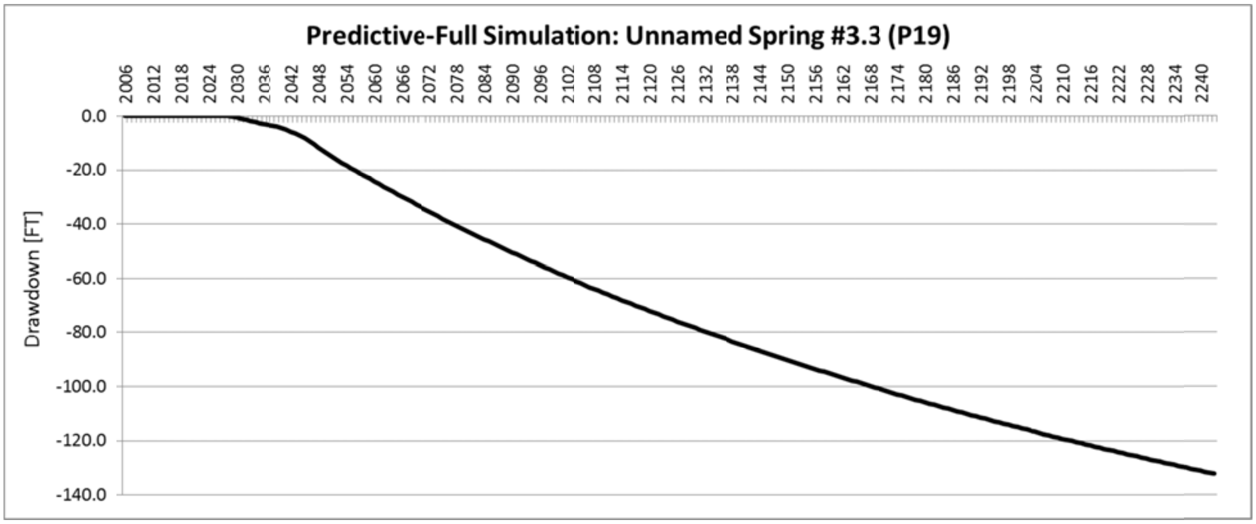
Predictive-Full Simulation: Unnamed Spring #3.3 (P19)
Drawdown [FT]
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-100.0
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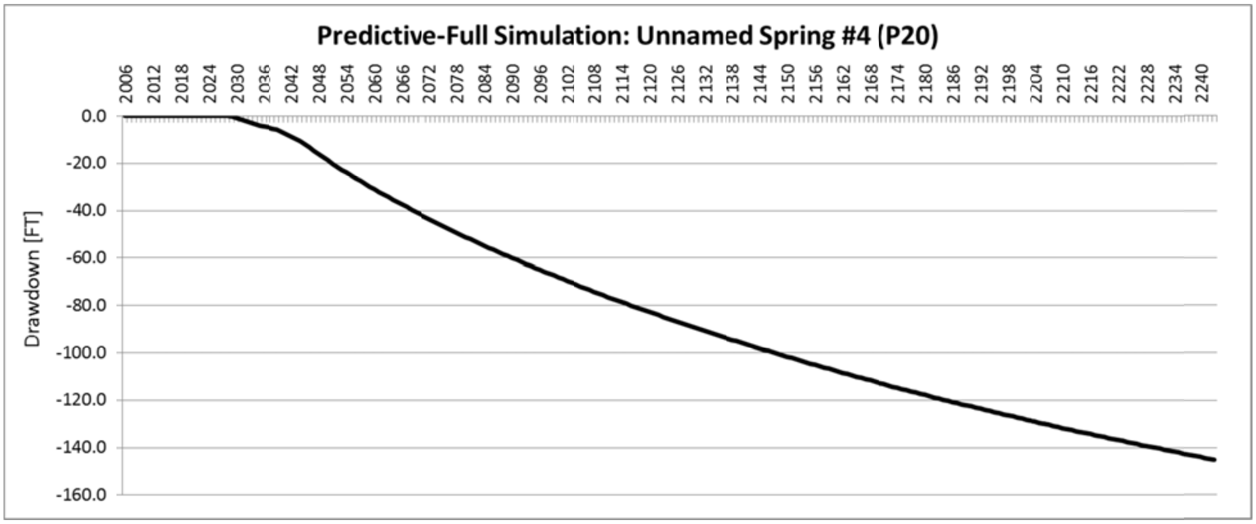
Predictive-Full Simulation: Unnamed Spring #4 (P20)
Drawdown [FT]
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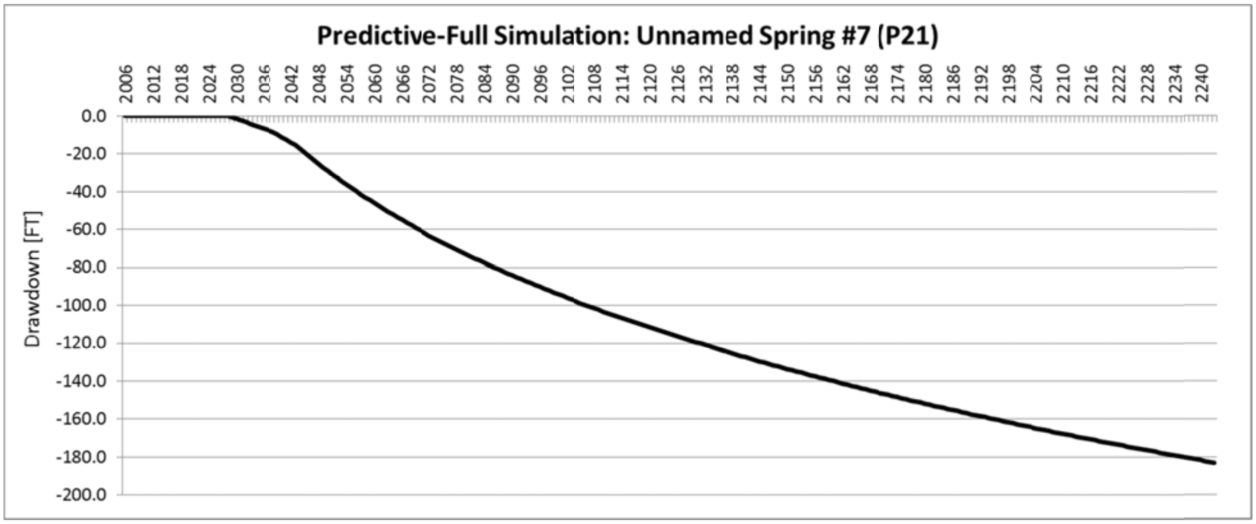
Predictive-Full Simulation: Unnamed Spring #7 (P21)
Drawdown [FT]
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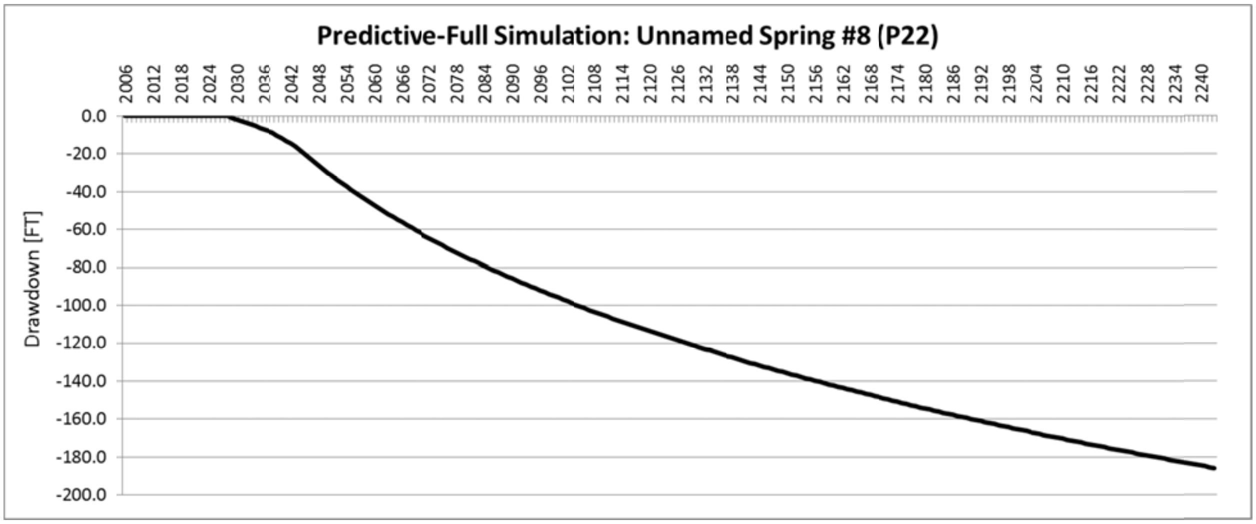
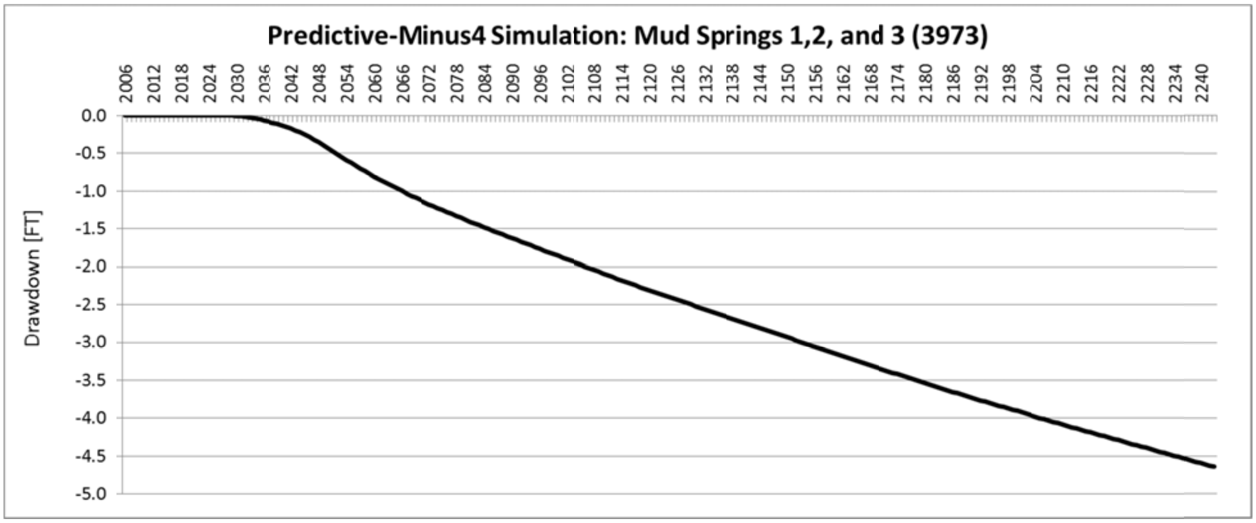
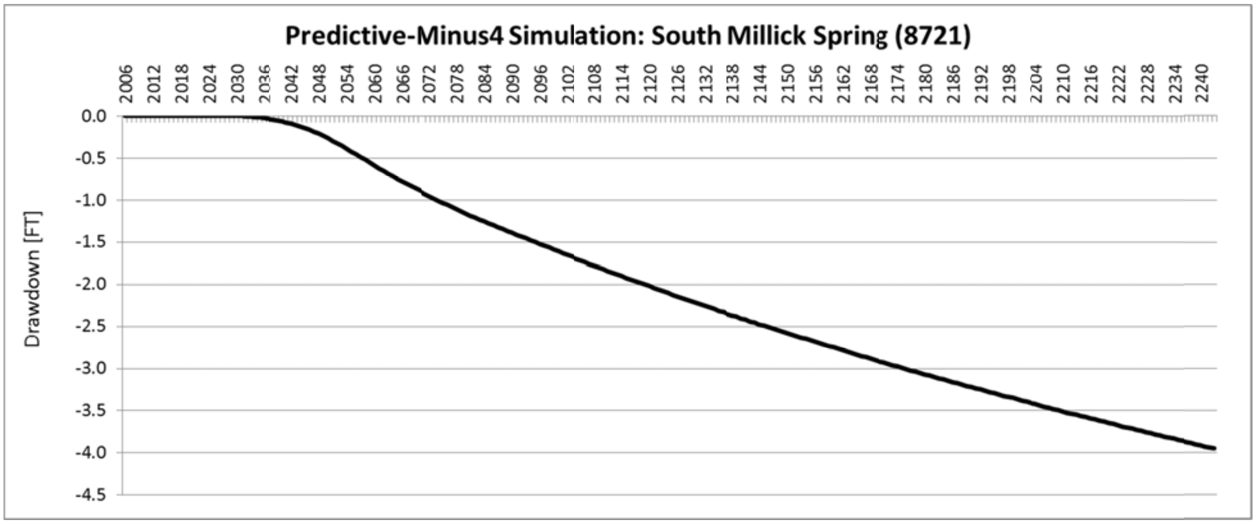
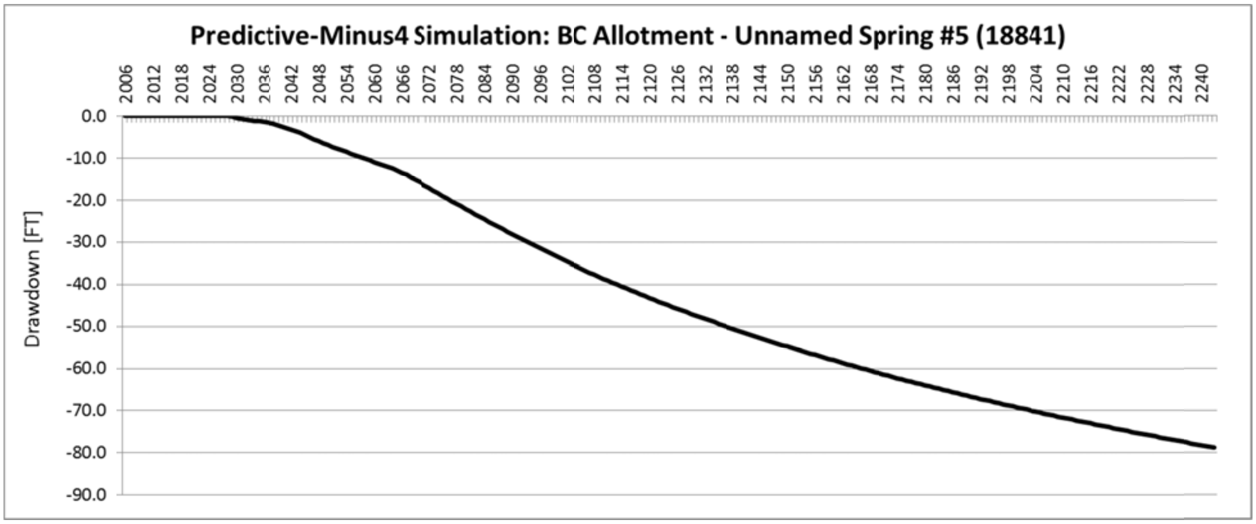
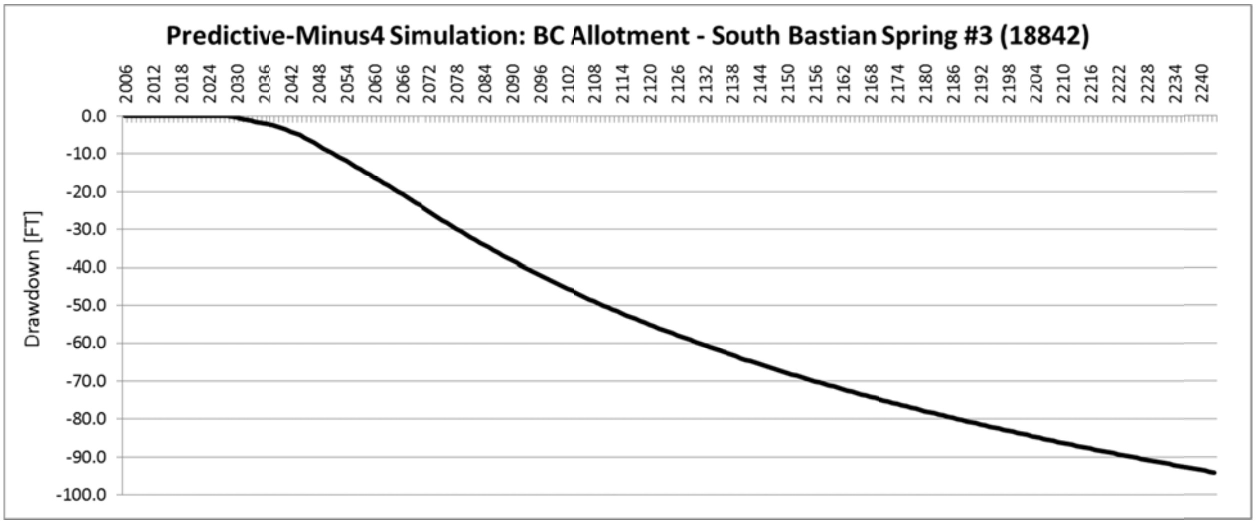


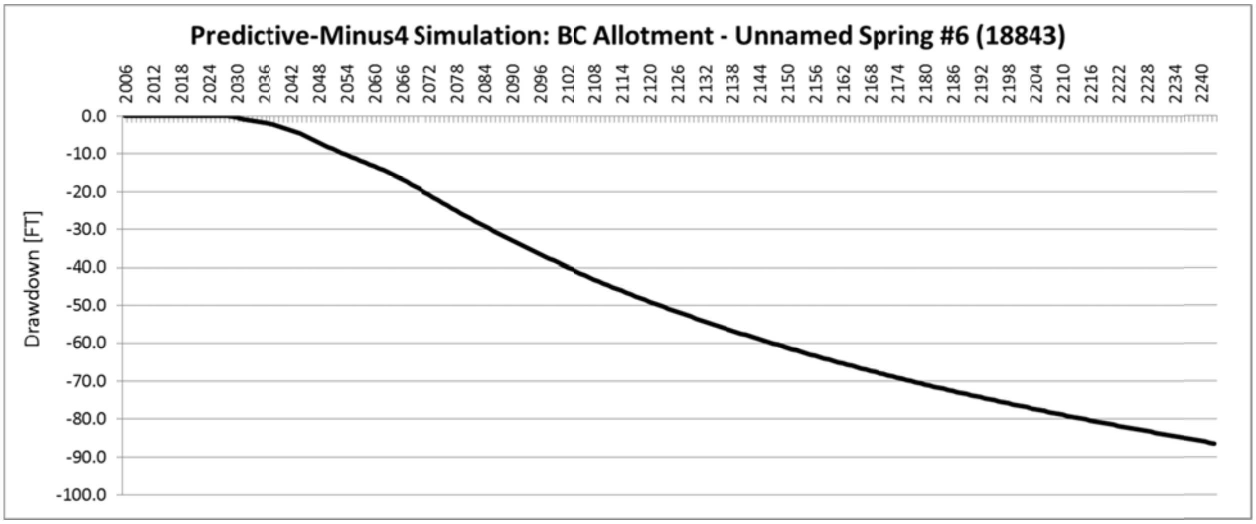
Predictive-Minus4 Simulation




Predictive-Minus4 Simulation: South Millick Spring (8721)


Predictive-Minus4 Simulation: BC Allotment - Unnamed Spring #5 (18841)


Predictive-Minus4 Simulation: BC Allotment - South Bastian Spring #3 (18842)


Predictive-Minus4 Simulation: BC Allotment - Unnamed Spring #6 (18843)
Drawdown [FT]
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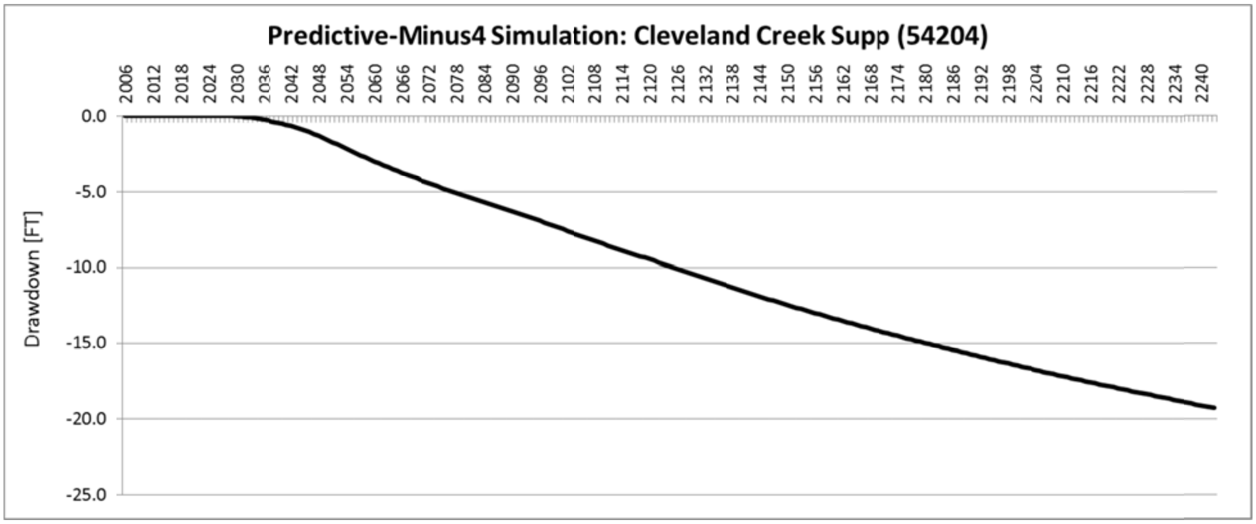
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240


Predictive-Minus4 Simulation: Cleveland Creek Supp (54204)
Drawdown [FT]
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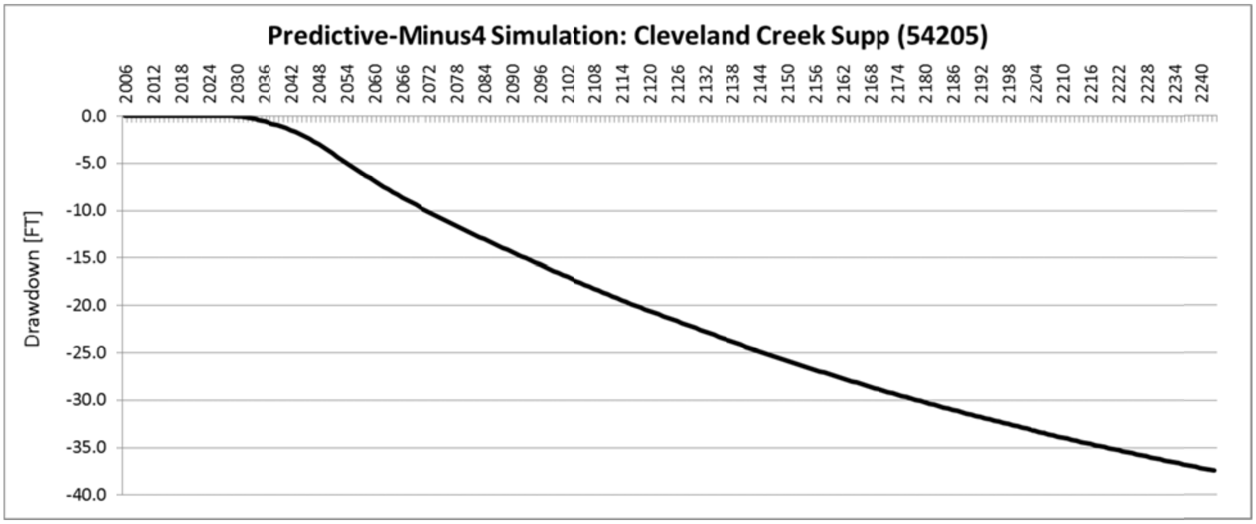
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240


Predictive-Minus4 Simulation: Cleveland Creek Supp (54205)
Drawdown [FT]
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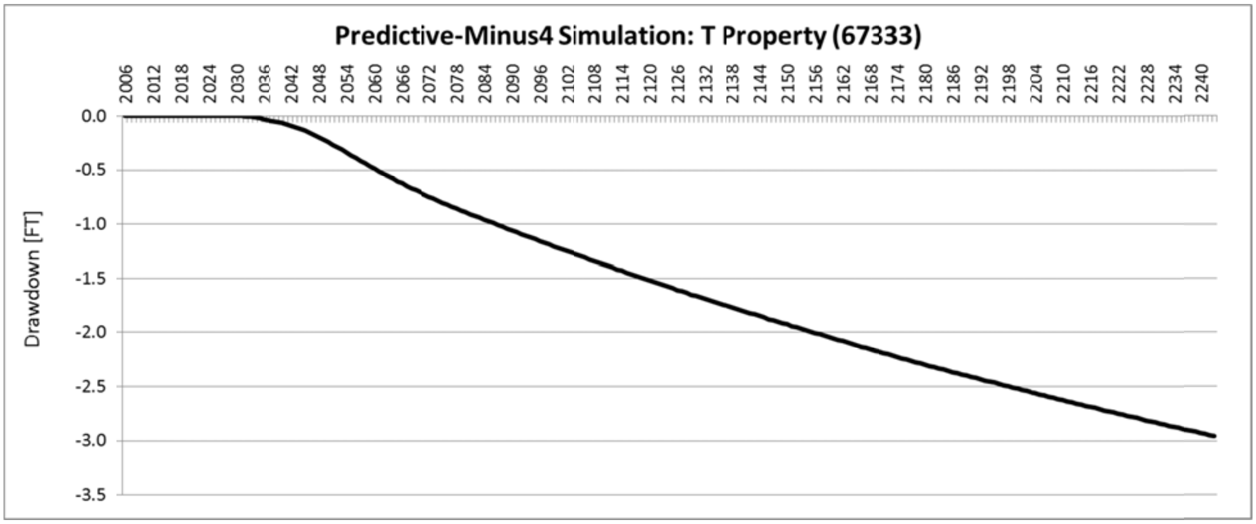
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240


Predictive-Minus4 Simulation: T Property (67333)
Drawdown [FT]
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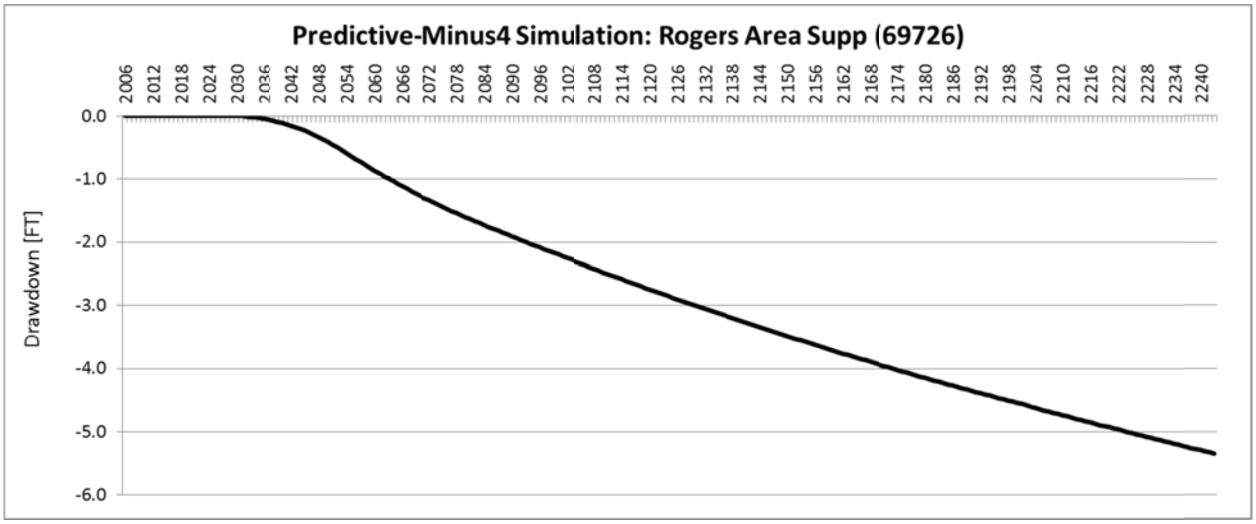
Predictive-Minus4 Simulation: Rogers Area Supp (69726)
Drawdown [FT]
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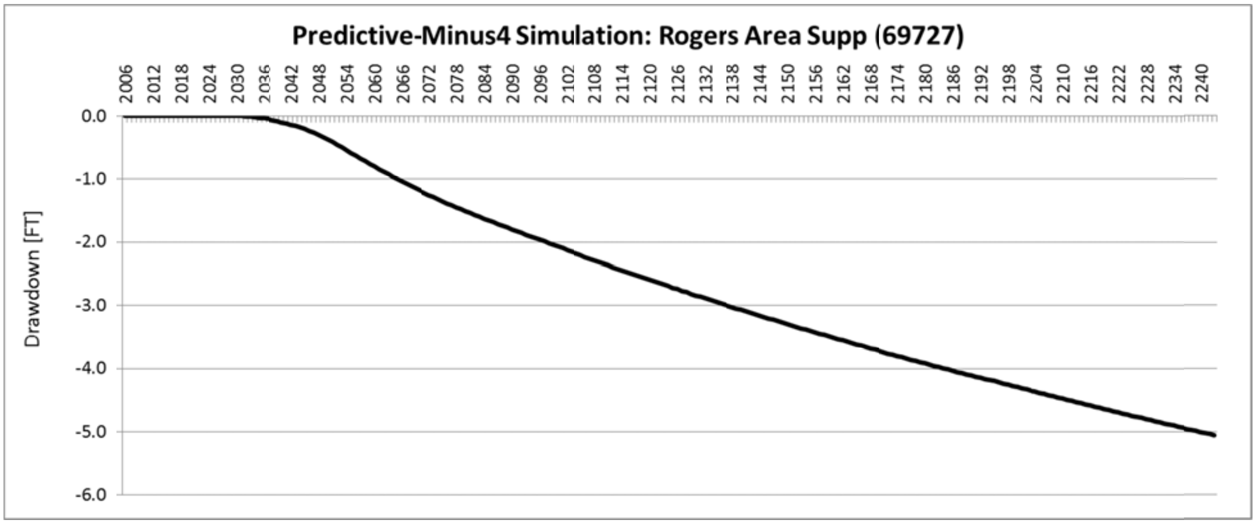
Predictive-Minus4 Simulation: Rogers Area Supp (69727)
Drawdown [FT]
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-4.0
-5.0
-6.0
2006
2012
2018
2024
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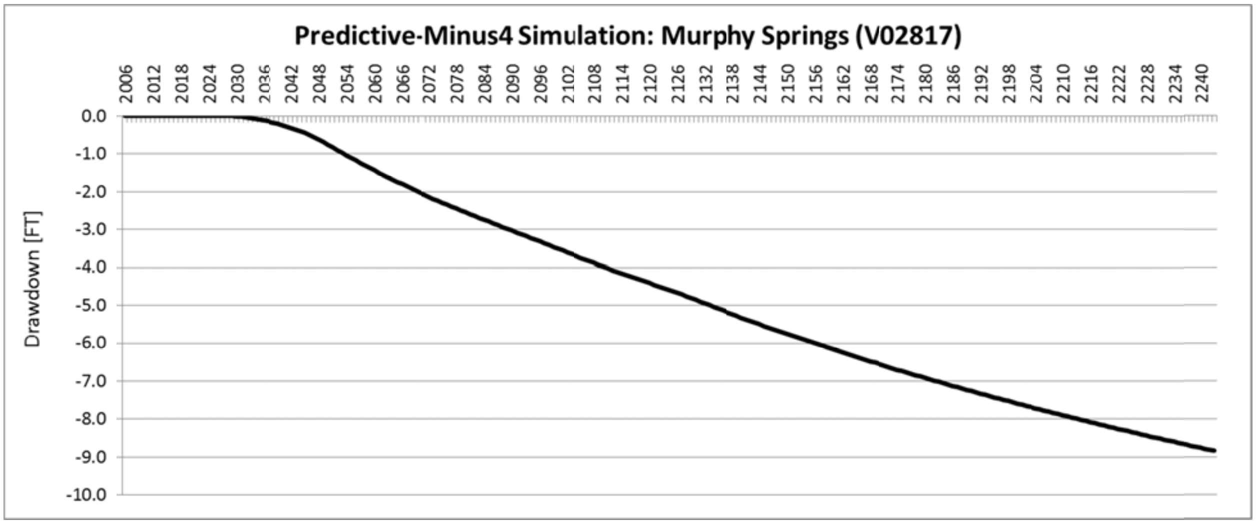
Predictive-Minus4 Simulation: Murphy Springs (V02817)
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2012
2018
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2216
2222
2228
2234
2240
0.0
-1.0
-2.0
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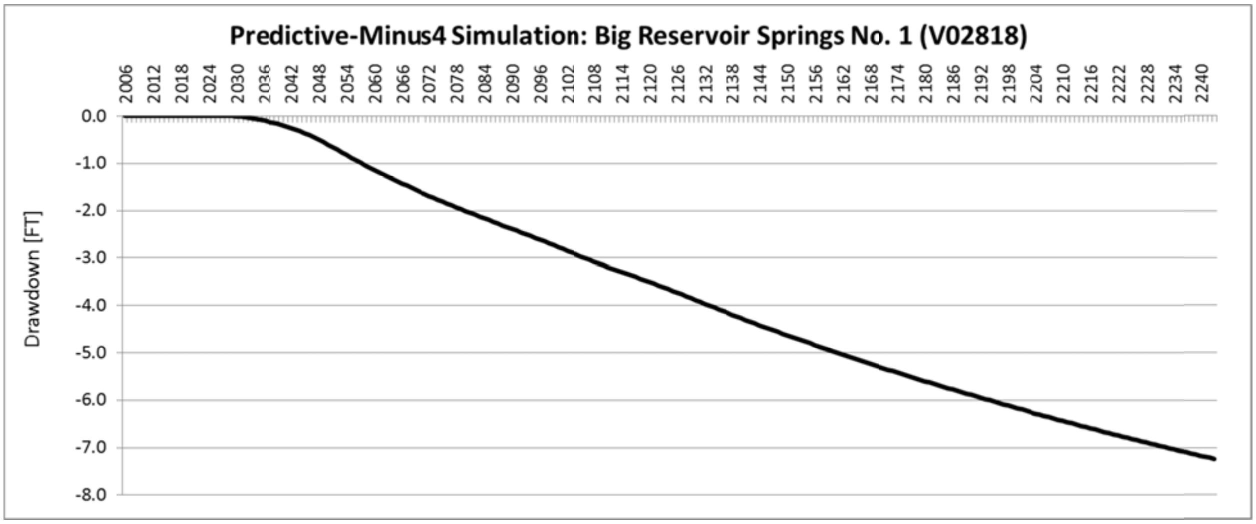
-9.0
-10.0
Drawdown [FT]


Predictive-Minus4 Simulation: Big Reservoir Springs No. 1 (V02818)
2006
2012
2018
2024
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2036
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2078
2084
2090
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2204
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2222
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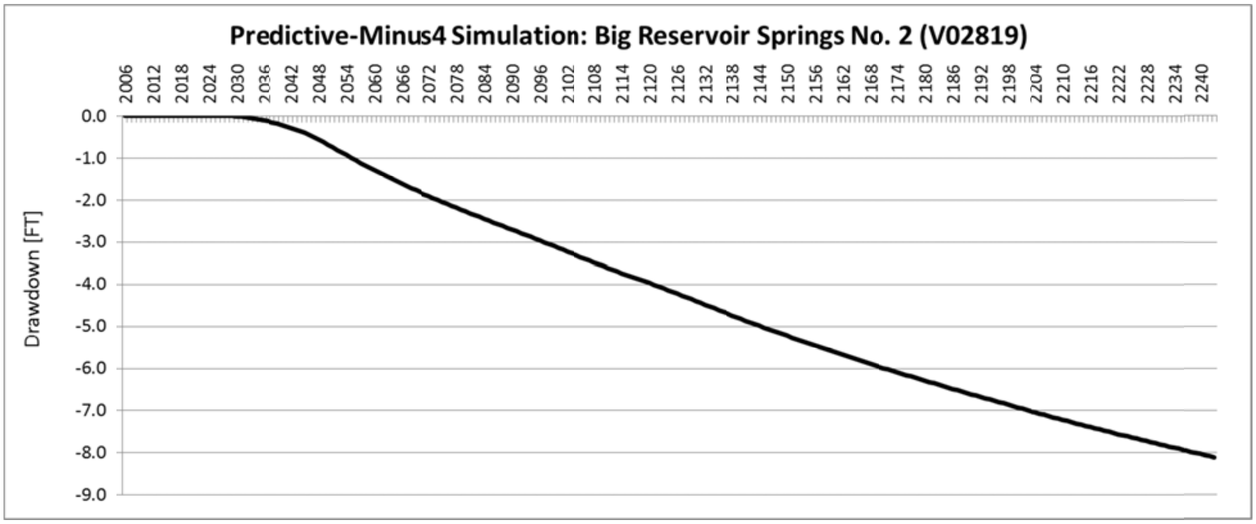
Drawdown [FT]


Predictive-Minus4 Simulation: Big Reservoir Springs No. 2 (V02819)
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2012
2018
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2084
2090
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2222
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0.0
-1.0
-2.0
-3.0
-4.0
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-6.0
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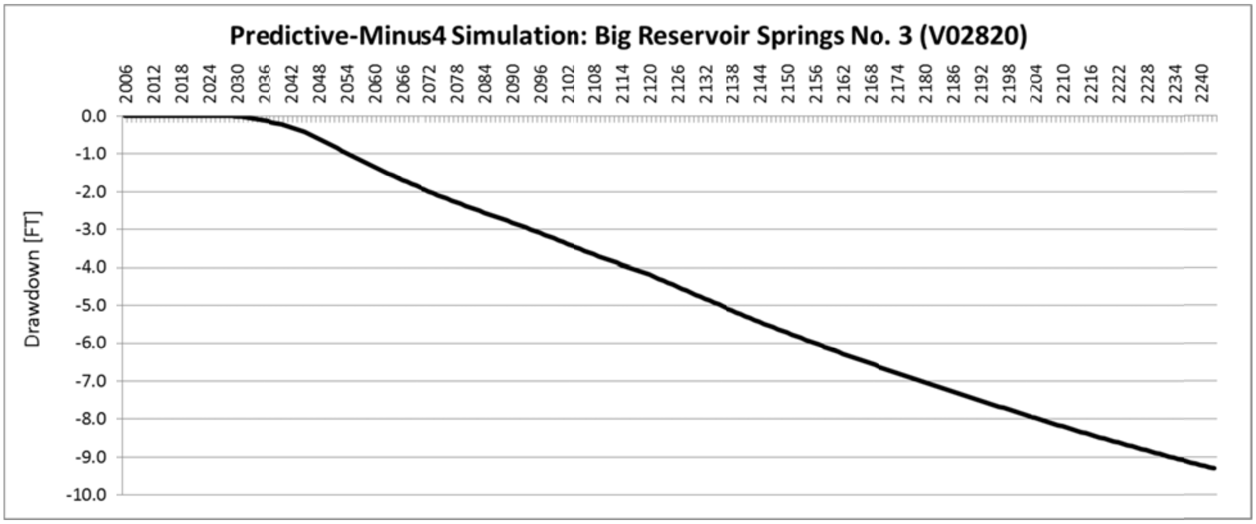
-8.0
-9.0
Drawdown [FT]


Predictive-Minus4 Simulation: Big Reservoir Springs No. 3 (V02820)
Drawdown [FT]
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2006
2012
2018
2024
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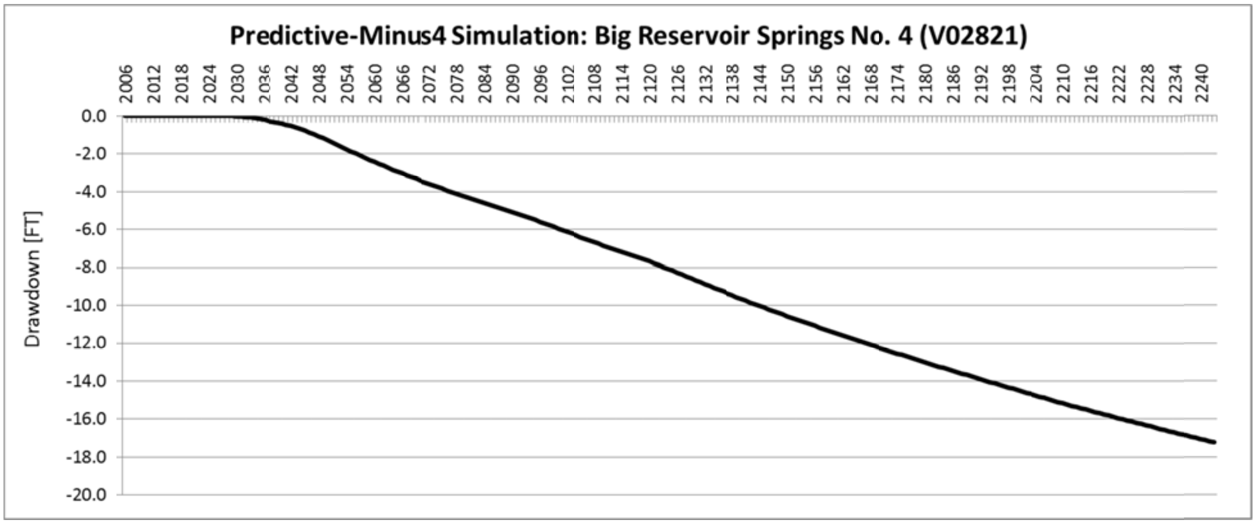
Predictive-Minus4 Simulation: Big Reservoir Springs No. 4 (V02821)
Drawdown [FT]
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-18.0
-20.0
2006
2012
2018
2024
2030
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2048
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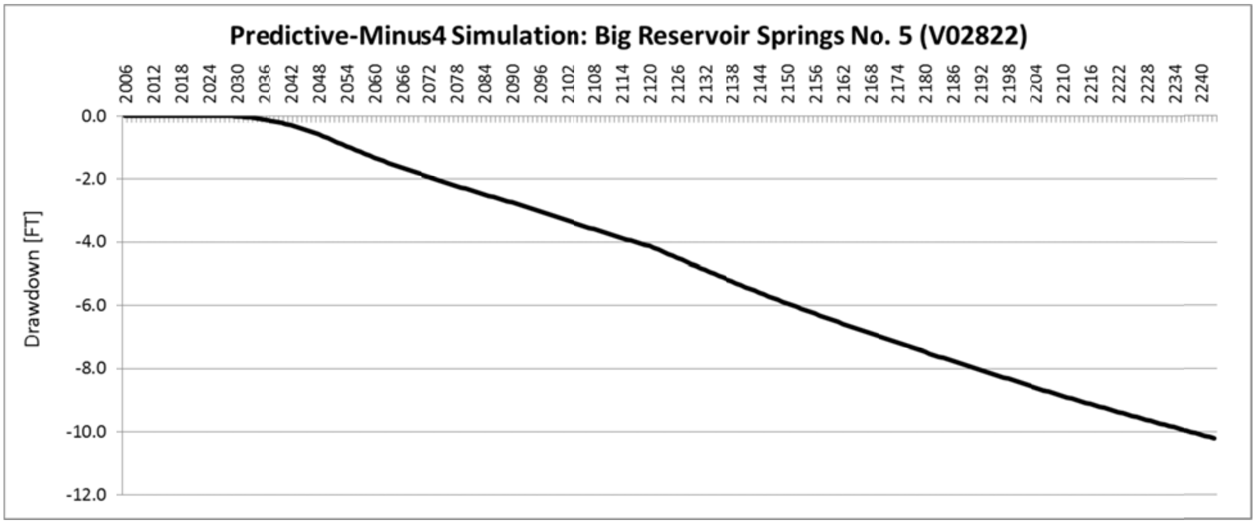
Predictive-Minus4 Simulation: Big Reservoir Springs No. 5 (V02822)
Drawdown [FT]
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-8.0
-10.0
-12.0
2006
2012
2018
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2030
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2054
2060
2066
2072
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2084
2090
2096
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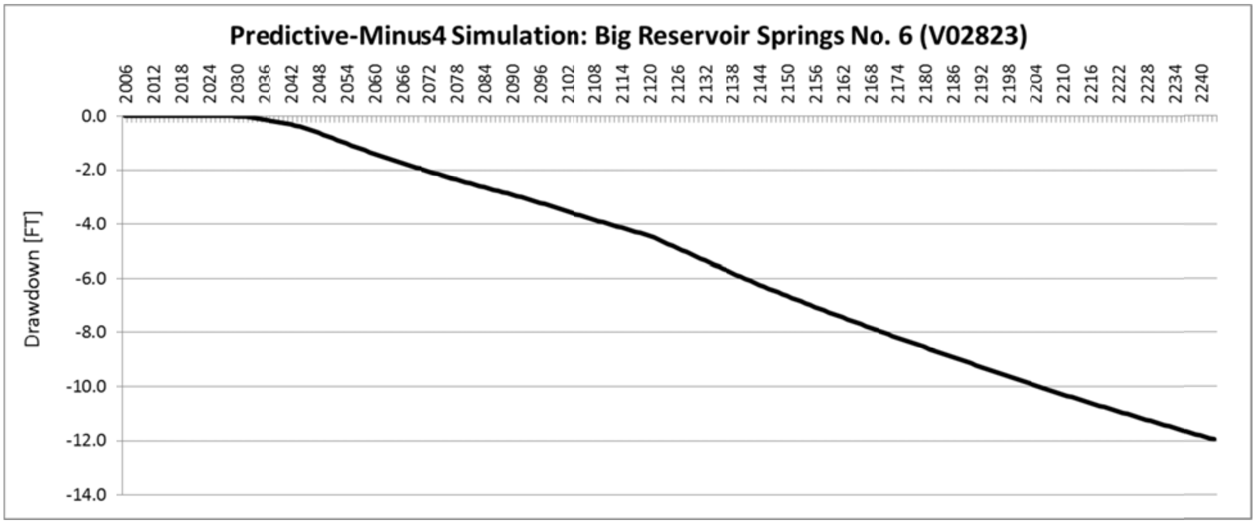
Predictive-Minus4 Simulation: Big Reservoir Springs No. 6 (V02823)
Drawdown [FT]
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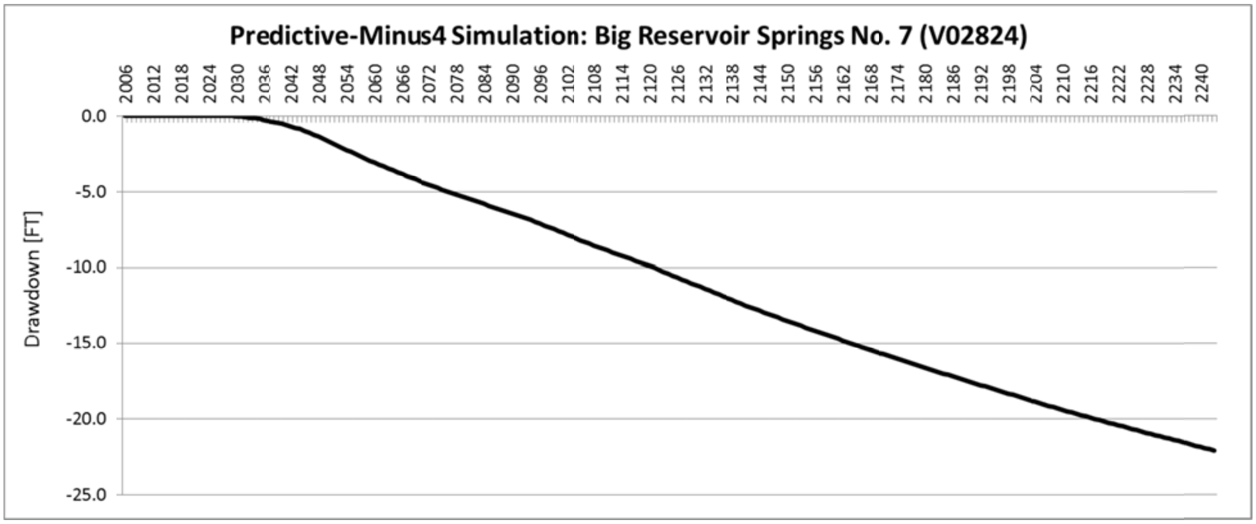
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240


Predictive-Minus4 Simulation: Big Reservoir Springs No. 7 (V02824)
Drawdown [FT]
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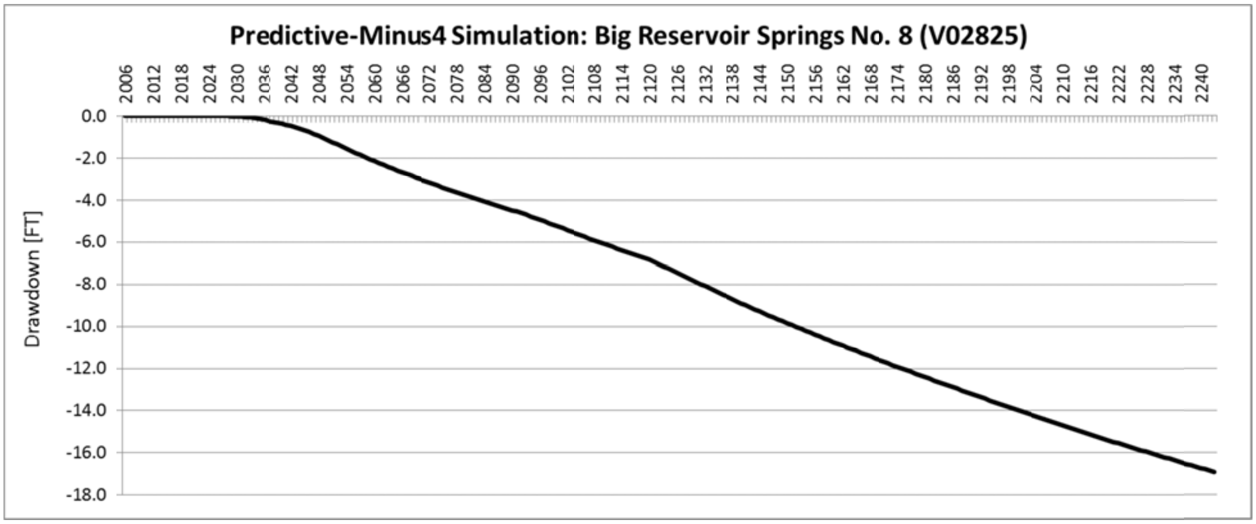
-5.0
-10.0
-15.0
-20.0
-25.0
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240


Predictive-Minus4 Simulation: Big Reservoir Springs No. 8 (V02825)
Drawdown [FT]
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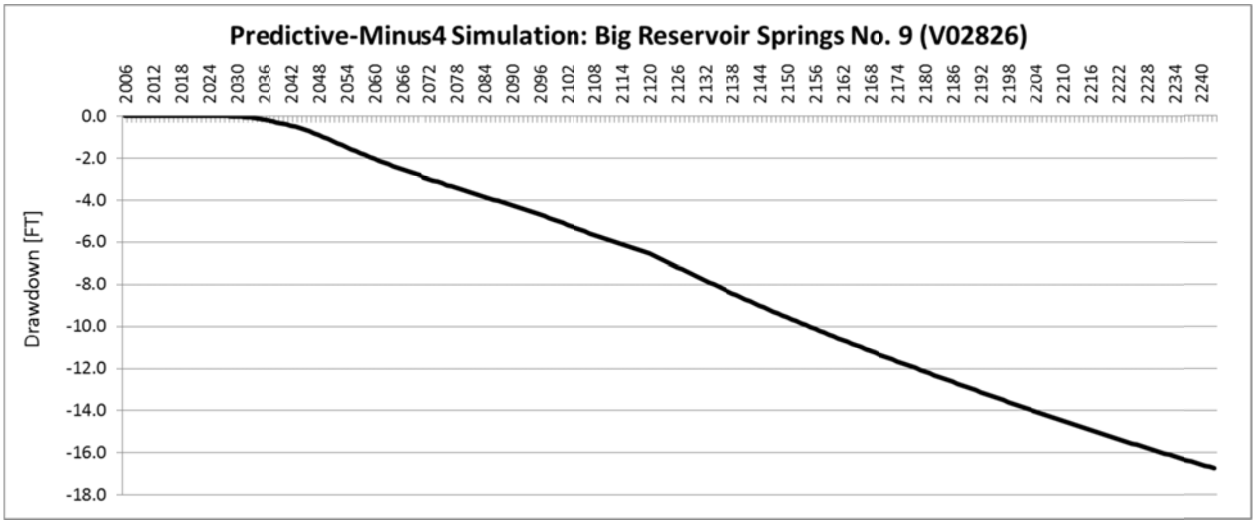
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
2006 2012 2018 2024 2030 2036 2042 2048 2054 2060 2066 2072 2078 2084 2090 2096 2102 2108 2114 2120 2126 2132 2138 2144 2150 2156 2162 2168 2174 2180 2186 2192 2198 2204 2210 2216 2222 2228 2234 2240


Predictive-Minus4 Simulation: Big Reservoir Springs No. 9 (V02826)
Drawdown [FT]
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-2.0
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-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
2006
2012
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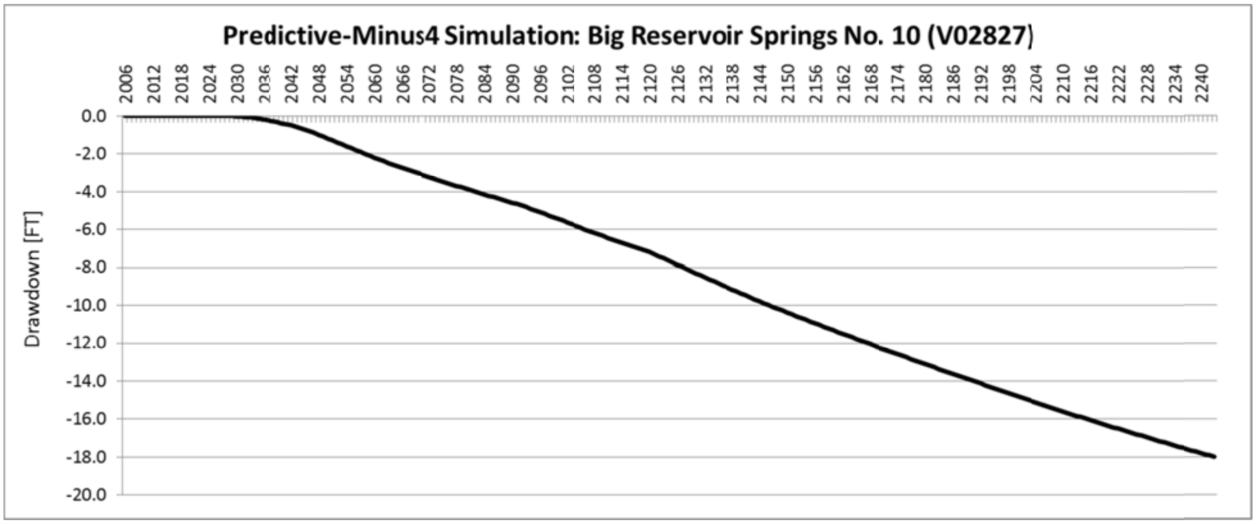
Predictive-Minus4 Simulation: Big Reservoir Springs No. 10 (V02827)
Drawdown [FT]
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-2.0
-4.0
-6.0
-8.0
-10.0
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2006
2012
2018
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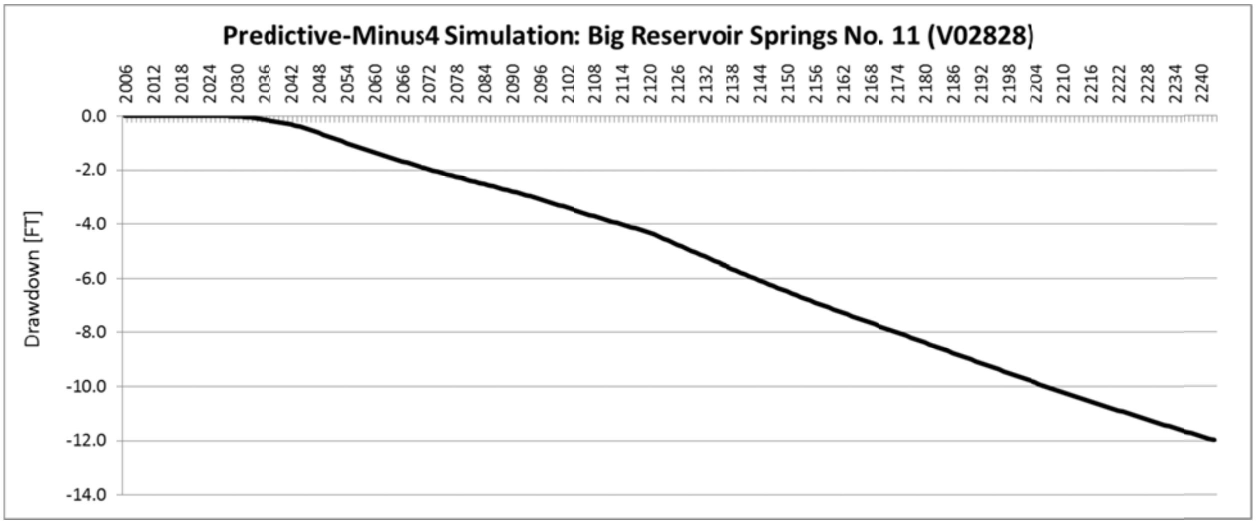
Predictive-Minus4 Simulation: Big Reservoir Springs No. 11 (V02828)
Drawdown [FT]
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
2006
2012
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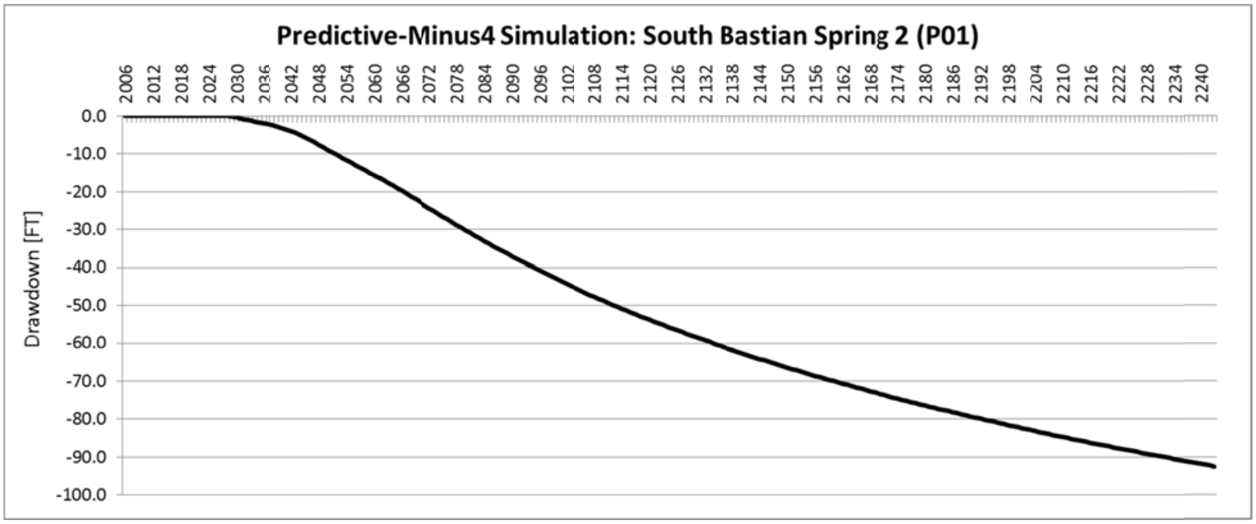
Predictive-Minus4 Simulation: South Bastian Spring 2 (P01)
Drawdown [FT]
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-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
2006
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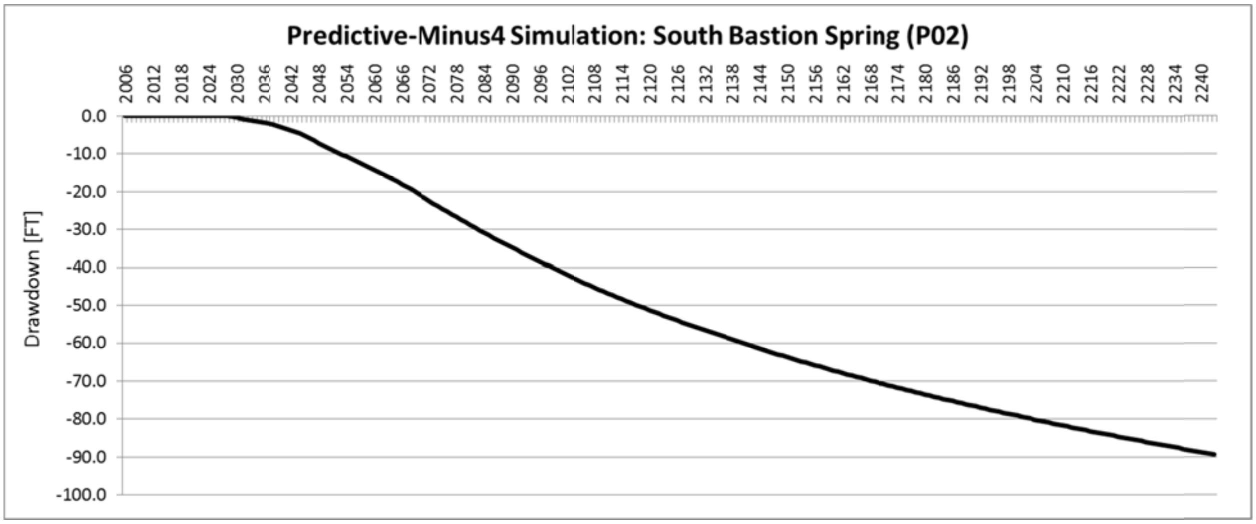
Predictive-Minus4 Simulation: South Bastion Spring (P02)
Drawdown [FT]
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-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
2006
2012
2018
2024
2030
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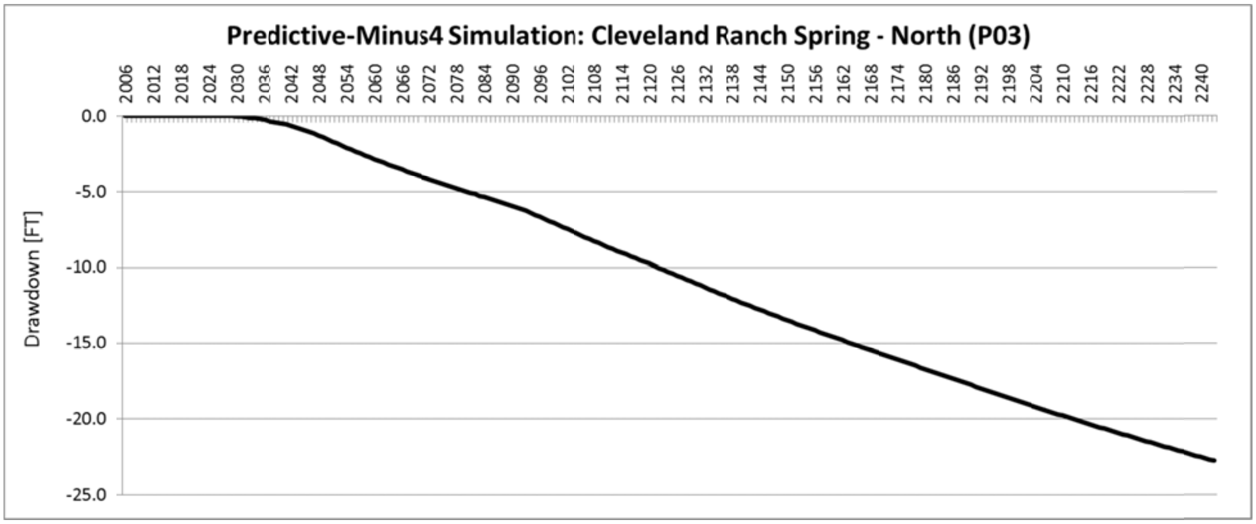
Predictive-Minus4 Simulation: Cleveland Ranch Spring - North (P03)
Drawdown [FT]
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
2006
2012
2018
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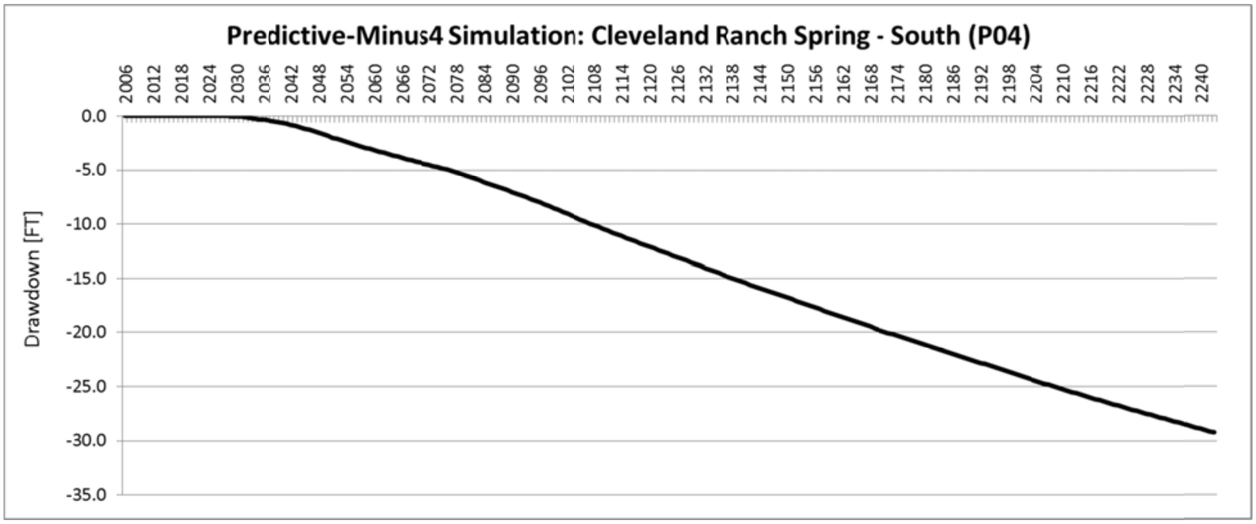
Predictive-Minus4 Simulation: Cleveland Ranch Spring - South (P04)
Drawdown [FT]
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-10.0
-15.0
-20.0
-25.0
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-35.0
2006
2012
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2030
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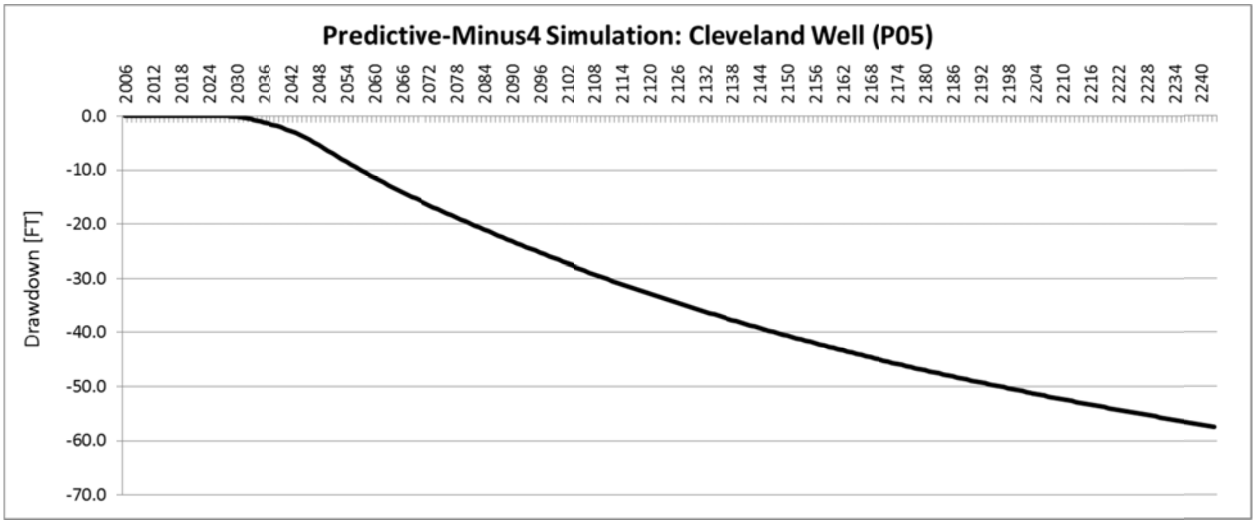
Predictive-Minus4 Simulation: Cleveland Well (P05)
Drawdown [FT]
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
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2006
2012
2018
2024
2030
2036
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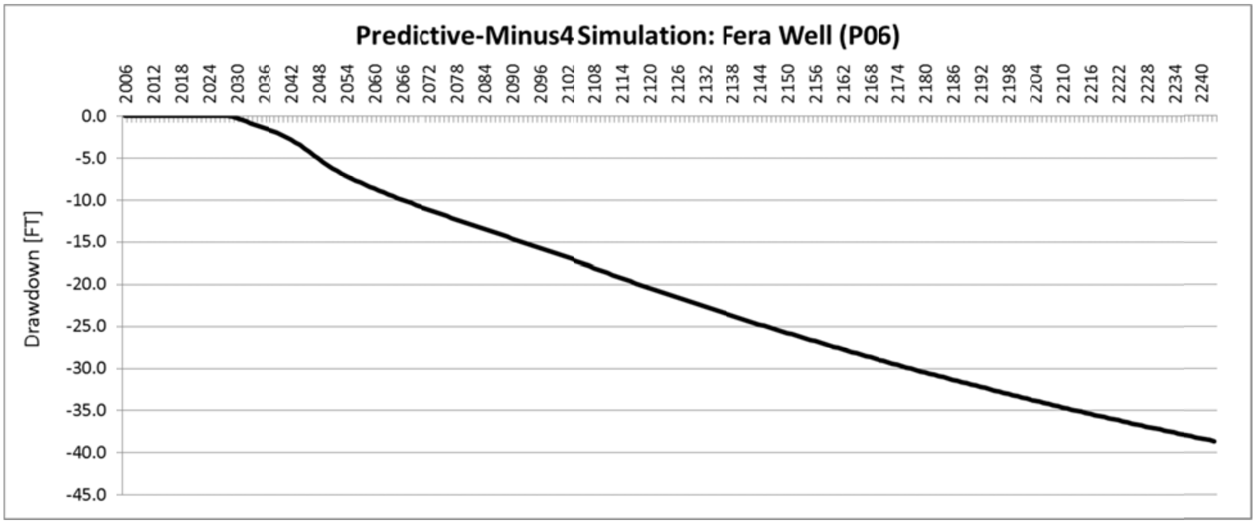
Predictive-Minus4 Simulation: Fera Well (P06)
Drawdown [FT]
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
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2012
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2024
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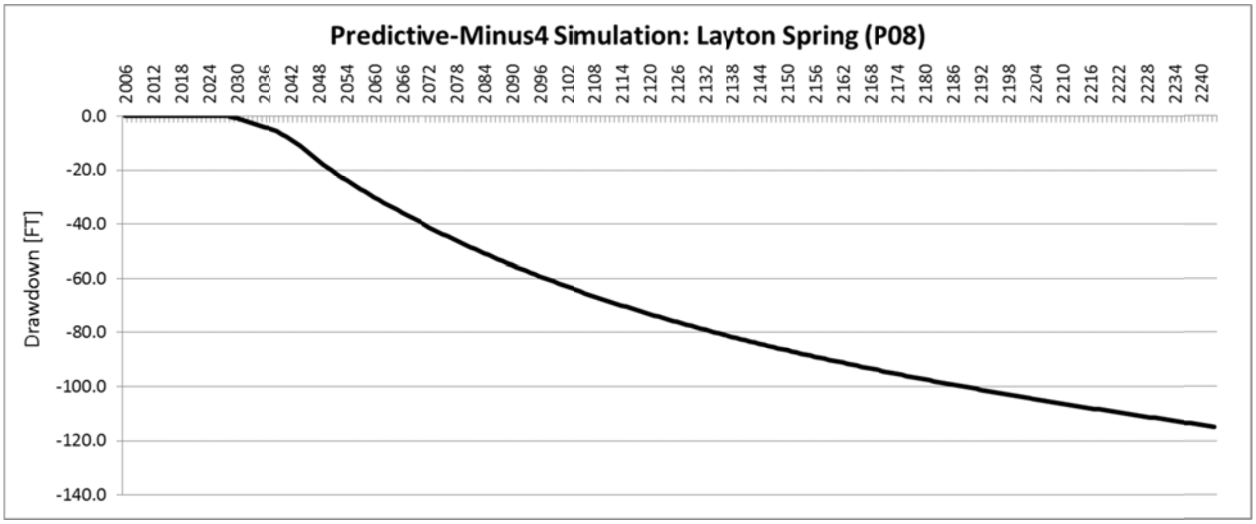
Predictive-Minus4 Simulation: Layton Spring (P08)
Drawdown [FT]
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-40.0
-60.0
-80.0
-100.0
-120.0
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2006
2012
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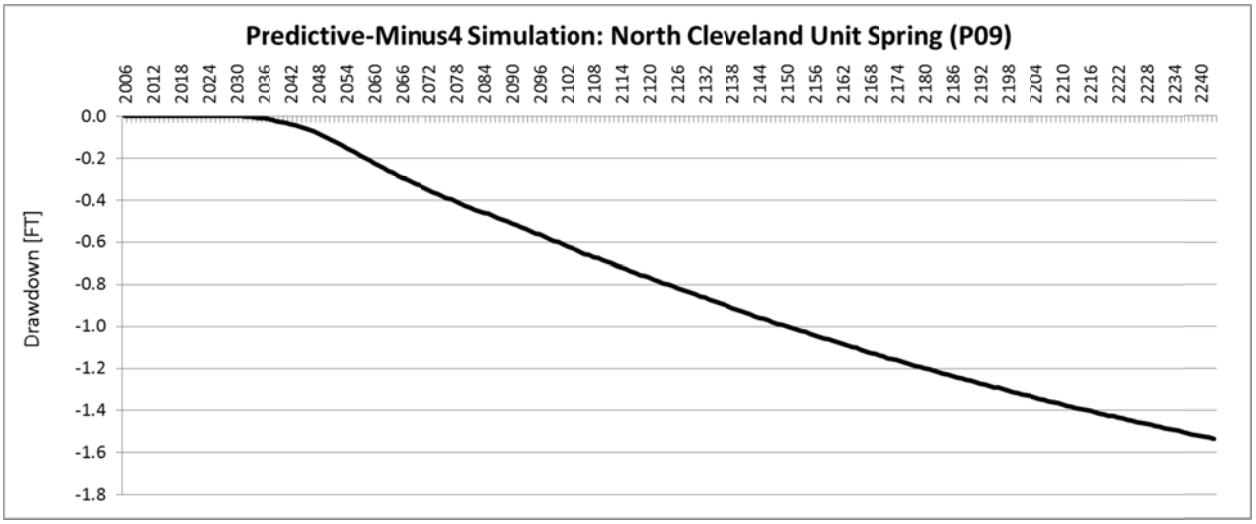
Predictive-Minus4 Simulation: North Cleveland Unit Spring (P09)
Drawdown [FT]
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-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
2006
2012
2018
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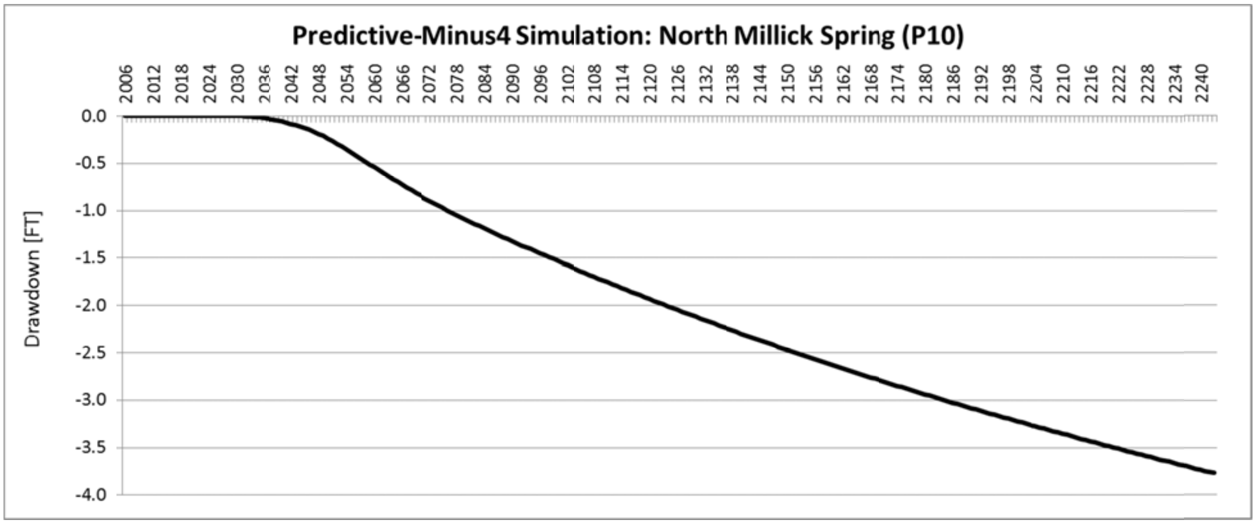
Predictive-Minus4 Simulation: North Millick Spring (P10)
Drawdown [FT]
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-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
2006
2012
2018
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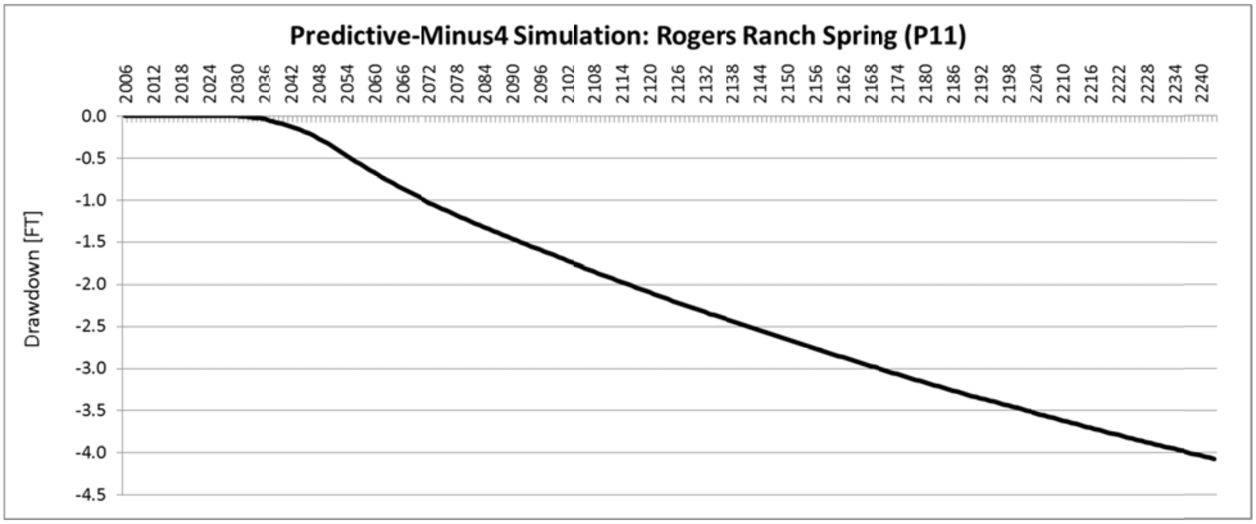
Predictive-Minus4 Simulation: Rogers Ranch Spring (P11)
Drawdown [FT]
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-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
2006
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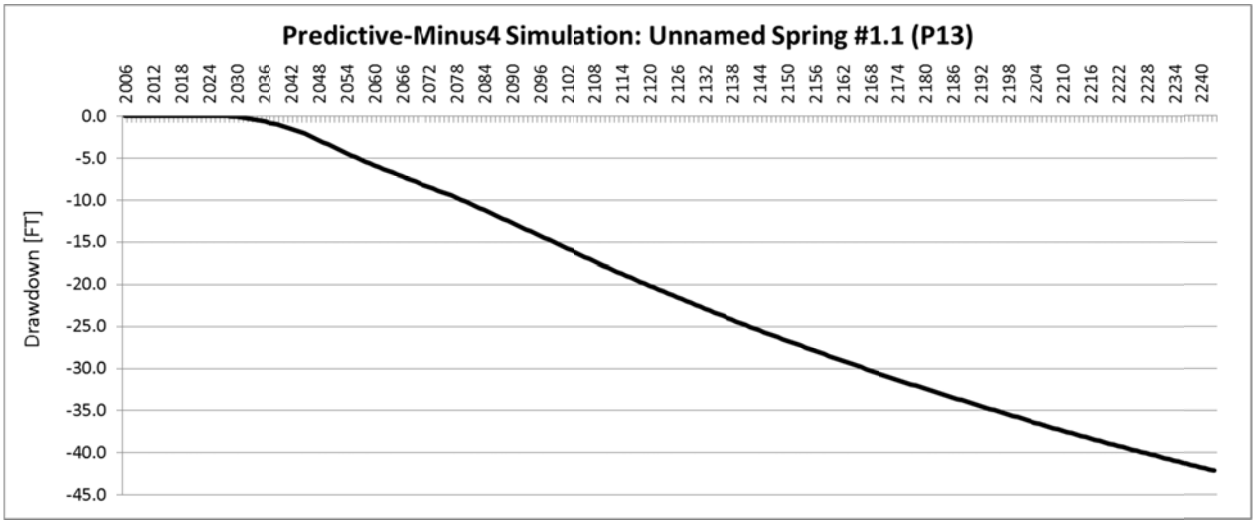
Predictive-Minus4 Simulation: Unnamed Spring #1.1 (P13)
Drawdown [FT]
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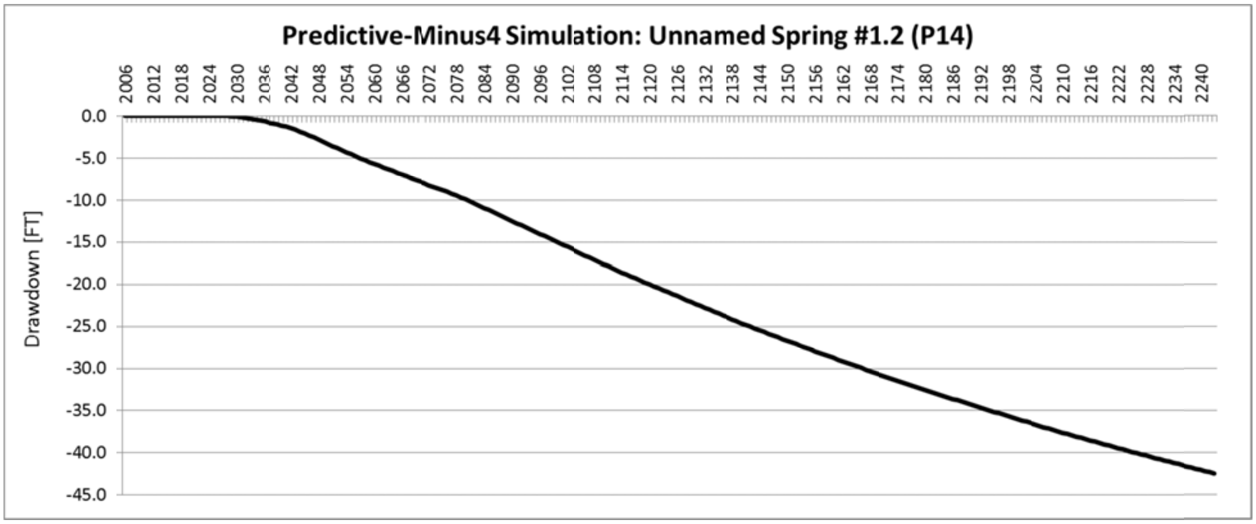
Predictive-Minus4 Simulation: Unnamed Spring #1.2 (P14)
Drawdown [FT]
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-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
2006
2012
2018
2024
2030
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2054
2060
2066
2072
2078
2084
2090
2096
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2126
2132
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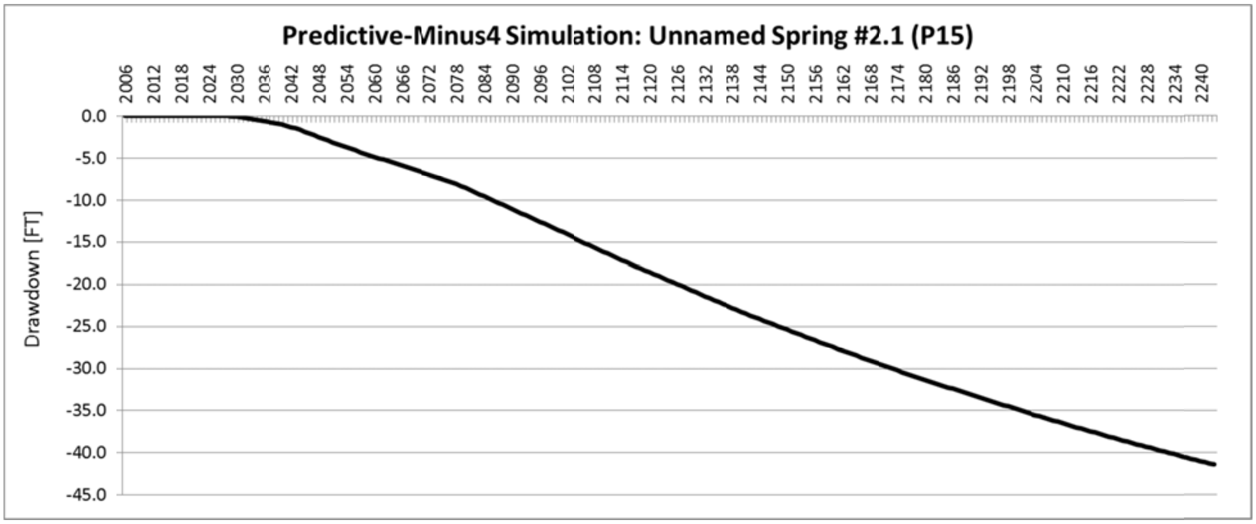
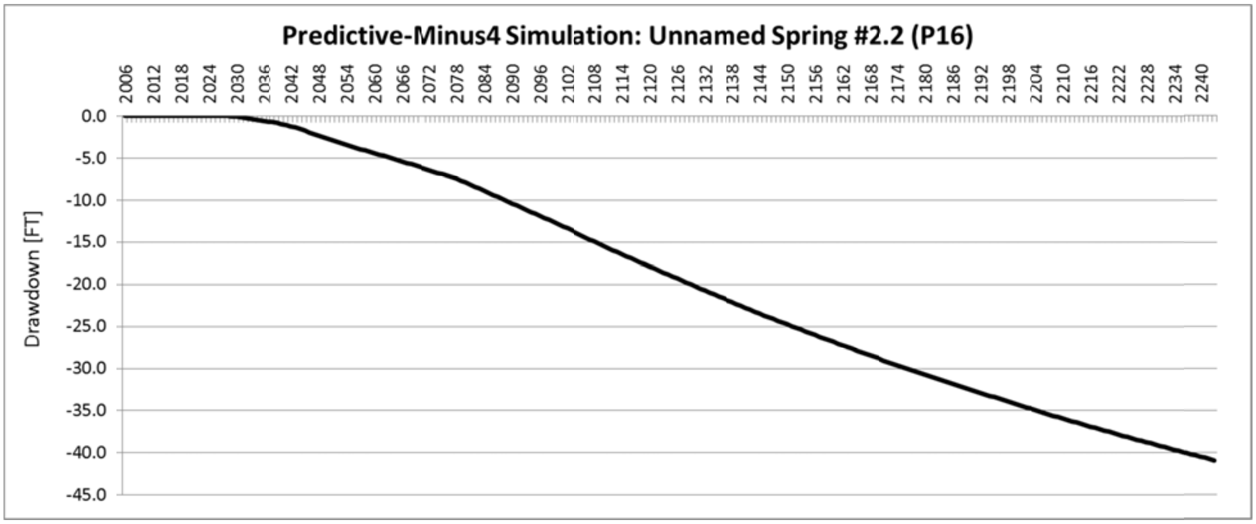
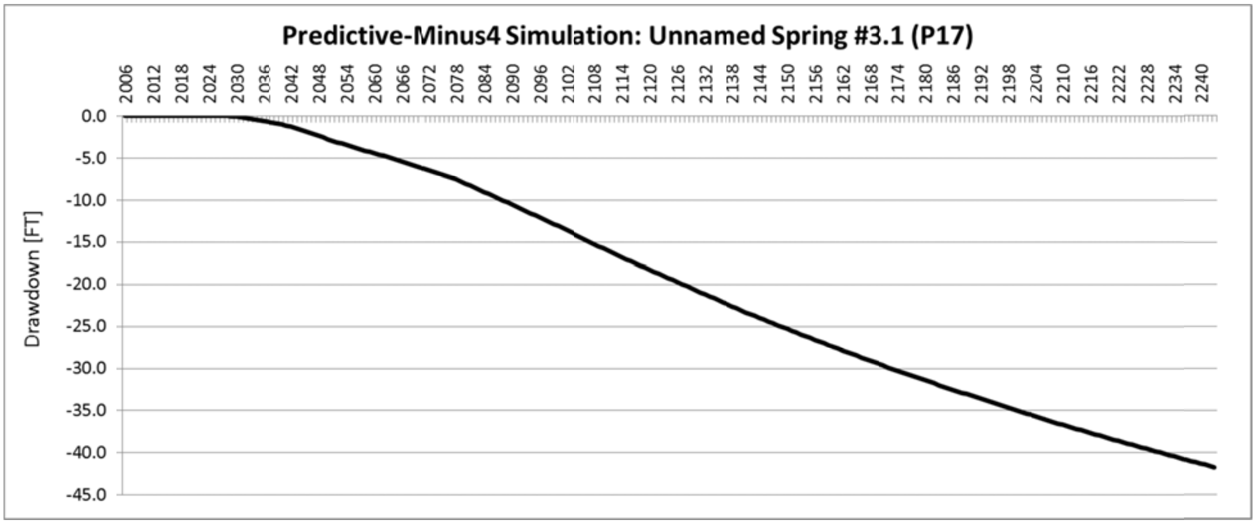


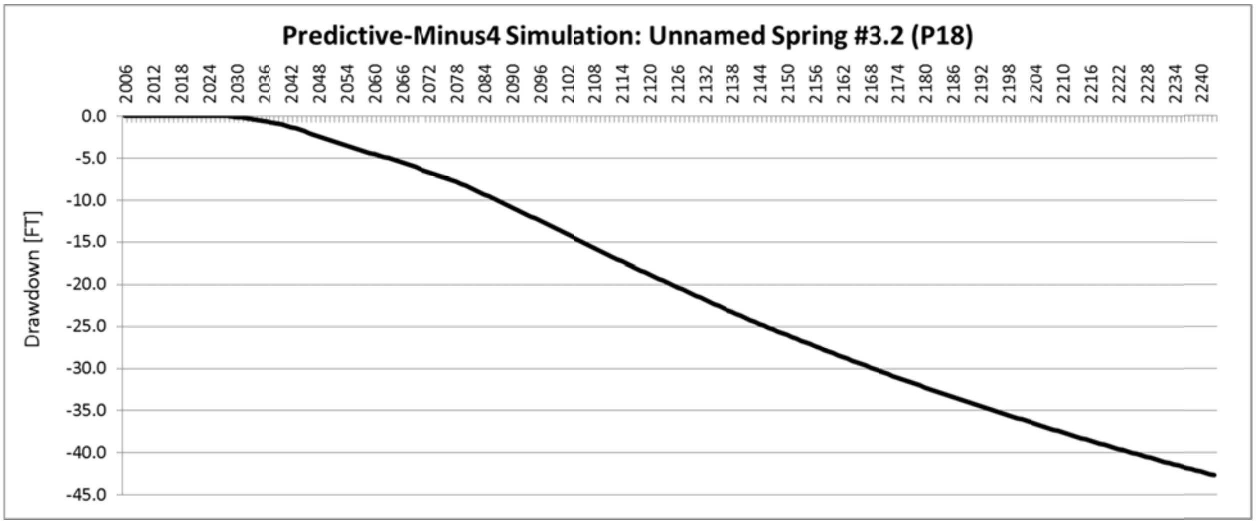
Predictive-Minus4 Simulation: Unnamed Spring #2.1 (P15)



Predictive-Minus4 Simulation: Unnamed Spring #2.2 (P16)



Predictive-Minus4 Simulation: Unnamed Spring #3.1 (P17)


Predictive-Minus4 Simulation: Unnamed Spring #3.2 (P18)
Drawdown [FT]
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-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
2006
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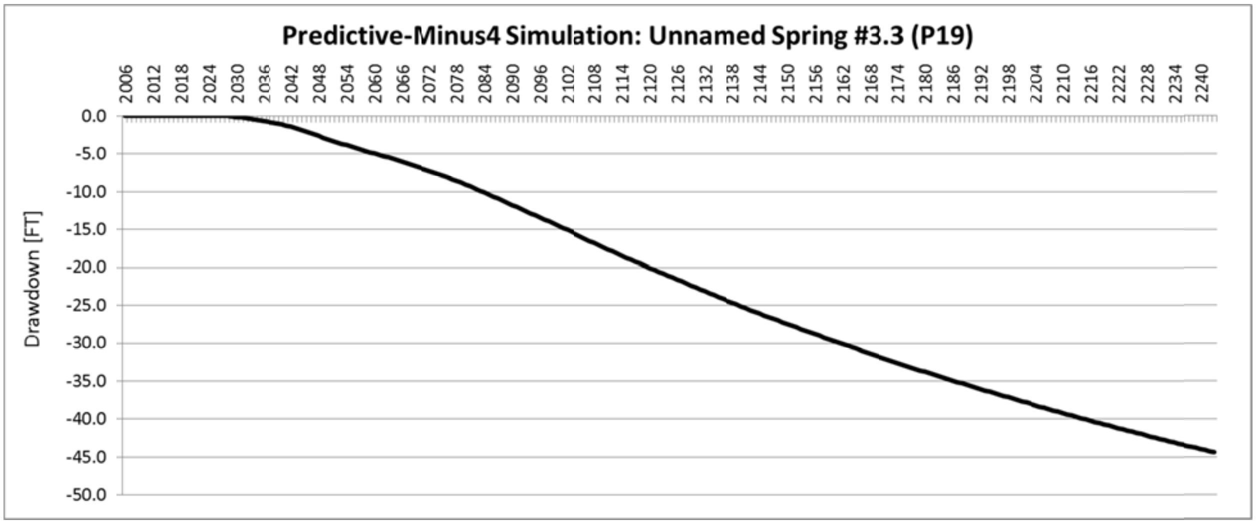
Predictive-Minus4 Simulation: Unnamed Spring #3.3 (P19)
Drawdown [FT]
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-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
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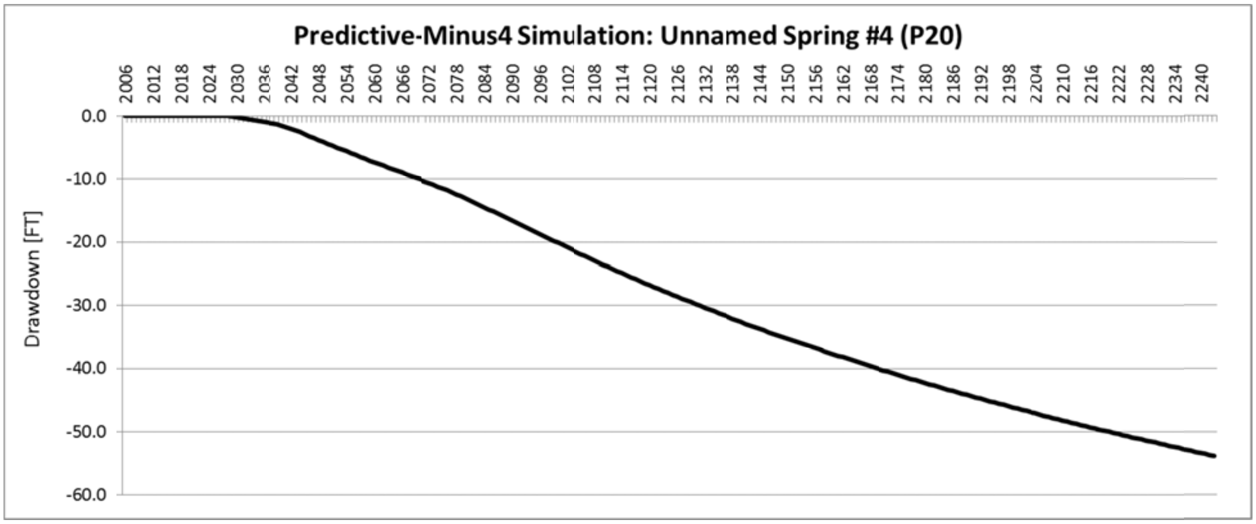
Predictive-Minus4 Simulation: Unnamed Spring #4 (P20)
Drawdown [FT]
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-10.0
-20.0
-30.0
-40.0
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-60.0
2006
2012
2018
2024
2030
2036
2042
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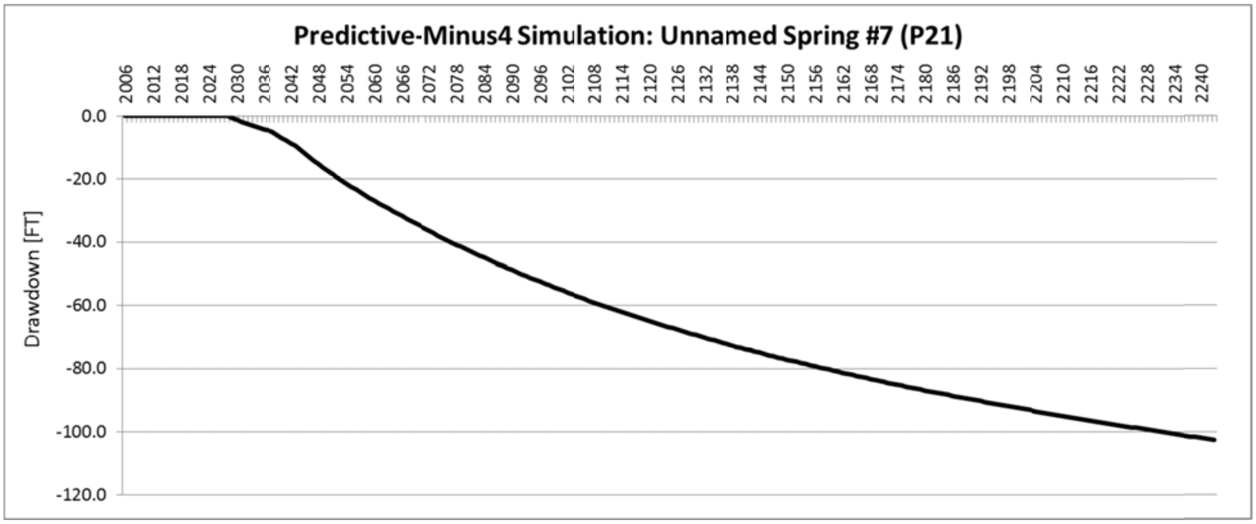
Predictive-Minus4 Simulation: Unnamed Spring #7 (P21)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
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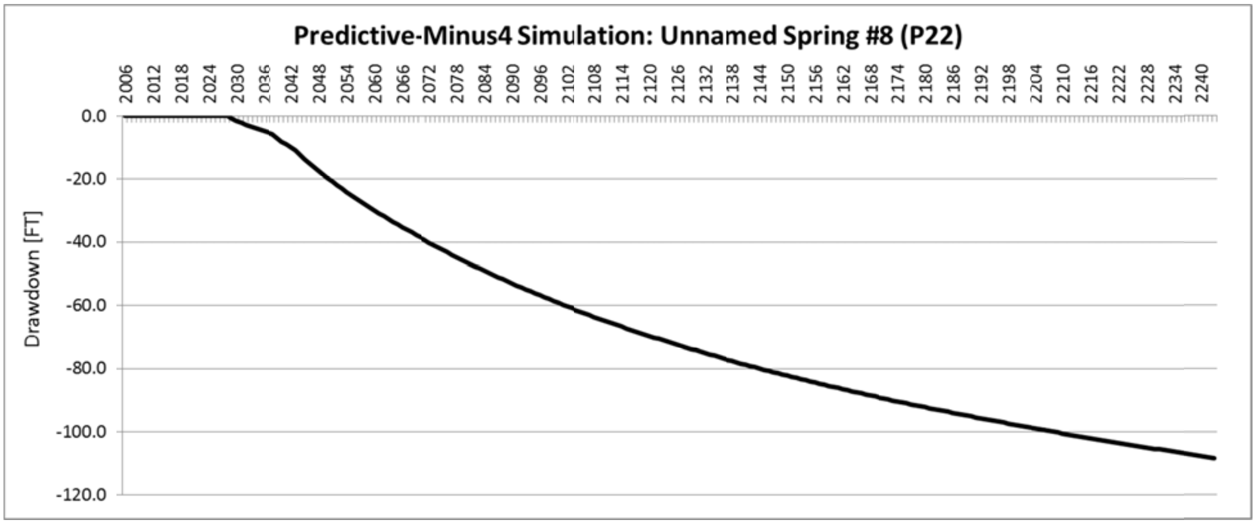
Predictive-Minus4 Simulation: Unnamed Spring #8 (P22)
Drawdown [FT]
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
2006
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