A Research Observatory for a Sustainable Future

Newberry Geothermal Energy

Establishment of the Frontier Observatory for Research in Geothermal Energy (FORGE) at Newberry Volcano, Oregon

Appendix D

Site Characterization Data Inventory

April 27, 2016

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Acronyms and Abbreviations

°C	degree(s) Celsius
DOE	U.S. Department of Energy
EGS	enhanced geothermal system(s)
FORGE	Frontier Observatory for Research in Geothermal Energy
ft	foot (feet)
kph	kilometer(s) per hour
L	liter(s)
LiDAR	light detection and ranging
m	meter(s)
m^2	square meter(s)
mg	milligram(s)
mS/m	millisiemens per meter
MSA	Microseismic array
MT	magnetotelluric
NA	not applicable
NEWGEN	Newberry Geothermal Energy
psi	pressure per square inch
psig	pressure per square inch gauge
ROP	rate of penetration
SU	standard unit(s)
TD	total depth
WHP	wellhead pressure

Appendix D

Site Characterization Data Inventory

D.1 Summary

Newberry Geothermal Energy (NEWGEN) is generating a robust updated site characterization data inventory that supports the geological model (see Appndix A) presented in view of the establishment of the Frontier Observatory for Research in Geothermal Energy (FORGE) at Newberry Volcano. The existing data inventory has been validated and submitted to the U.S. Department of Energy (DOE) Geothermal Data Repository (see Appendix B).

D.2 Site Characterization Data Inventory Goals

The site characterization data inventory for NEWGEN FORGE reflects all updates to existing data realized during Phase 1 supporting the Conceptual Geologic Model and the suitability of the site to meet the DOE's Geothermal Technologies Office/FORGE goals and objectives.

D.3 Resource Characteristics

The proposed NEWGEN FORGE project site is **a greenfield enhanced geothermal system (EGS)** project site. There are multiple existing geothermal wells, none of which have ever produced significantly useful amounts of geothermal fluids.

D.4 Thermal Characteristics

D.4.1 Reservoir and Subsurface Characterization

Table D.1. Reservoir and subsurface characteristization data.

CHARACTERISTIC	YEAR(S) OF DATA COLLECTION	VALUE/ FIGURE OR TABLE IN APPENDICES A OR D	TOOL/METHODOLOGY/ SOURCE	SECTIONS OF APPENDIX A WHERE VALUES ARE DETAILED
Depth to resource	2011	175°C – 225°C between 1750 m and 2250 m depth	Kuster temperature tool and distributed temperature sensing (AltaRock 2011; Spielman and Finger 1998)	A.2.10
Reservoir planar area	2014	> 9.4 km2 (2340 acres) and 4.1 km3 volume	Temperature	A.5.1.2/ A.5.11
Stratigraphy/strati-graphic columns	1984-2014	See Figure A.5	Geologic mapping	A.2.6.1
Lithology	1984-2014	See Table D.5	There is a mud log for each well drilled at Newberry	A.2.11
Stress state	2001, 2010, 2012, 2014	See Figure A.3	Basin and Range Oregon: Crider (2001); Cladouhos et al. (2011); Davatzes and Hickman (2011), AltaRock (2015)	A.2.5.1

Table D.1. (contd)

CHARACTERISTIC	YEAR(S) OF DATA COLLECTION	VALUE/FIGURE OR TABLE IN APPENDICES A OR D	TOOL/METHODOLOGY/ SOURCE	SECTIONS OF APPENDIX AWHERE VALUES ARE DETAILED
Permeability data	2008, 2012, 2014	See Table D.8	Cold water injection and nitrogen gas lift/flow test	A.2.10.4
Porosity	1984	See Table D.7	On cores (Balckwell 1994)	A.2.10.4
Existing features Fracture location Fracture orientation Fracture aperture	2011	See Figure A.3 and Figure A.4	Cladouhos et al. (2011a)	A.2.5
Existing faults (location, proximity, activity)	2011	See Figure A.3	Phase 1 Newberry Report	A.2.5
Lithology logs	1984-2014	See Figure A.41	Cladouhos et al. (2011a)	A.4.3.2
Subsurface data	1984-2014	See Table D.5	There is a mud log for each well drilled at Newberry Volcano	A.2.11
Existing faults, gravity data, MT surveys, seismic reflection resistivity	1998; 2007; 2012 2013 2012-2015		Data are detailed in the Newberry EGS Demonstration Phase 1 Report (AltaRock 2011)	A.2.9
Geochemistry geothermometry fluid chemistry	Not applicable – no geofluids have been encountered at depth in the heat reservoir; the geochemistry of fluids injected during FORGE activities will be monitored for mineral stability			
Mechanical behavior of reservoir	2011-2013		(Wang et al. 2016) “Mechanical Properties of Intact Rock and Fractures in Newberry Welded Tuff" (AltaRock 2011, 2014)	A.3
Geologic mapping	1982; 2001; 2006		MacLeod et al. 1982; Gannet et al. 2001; Jensen 2006	A.2.3 / A.2.6.1
Conceptual model	2011		Newberry EGS Phase 1 report (AltaRock 2011)	A.4

D.4.2 Surface Data

Table D.2. Surface data.

CHARACTERISTIC	YEAR(S) OF DATA COLLECTION	VALUE/FIGURE OR TABLE IN APPENDICES A OR D	TOOL/METHODOLOGY/ SOURCE	SECTIONS OF APPENDIX AWHERE VALUES ARE DETAILED
Thermal characteristics, average ground surface temperature, surface heat flow, regional heat flow (i.e., the heat flow from below the radioactive layer)	2008	See Table A.6	Frone (2015)	A.2.10
Gravity data	1988		Gettings and Griscom 1988 This study.	A.2.9.4
Chemistry	1978-2014	Ground and surface water chemistry, Table D.8	AltaRock 2014	A.2.7
Aerial photography	2011		Aerial imagery with 1 m resolution is available from the National Agricultural Imagery Program.	
Remote sensing	2010	LiDAR, Figure A.4	Oregon LiDAR Consortium	A.2.4

D.4.3 Geologic Data

Table D.3. Geologic data.

CHARACTERISTIC	YEAR(S) OF DATA COLLECTION	VALUE/FIGURE OR TABLE IN APPENDICES A OR D	TOOL/METHODOLOGY/ SOURCE	SECTIONS OF APPENDIX AWHERE VALUES ARE DETAILED
Regional stress direction and magnitude:	2011	Minimum stress and direction of extension is east-west based on orientation of dikes, vents, fault scarps, and well borehole breakouts; see Table A.1	Cladouhos et al. 2011	A.2.4
35 years of seismic data from seismic array in place:	1980-present; 2010-2012	-	Pacific Northwest Seismic Network; Newberry Volcano EGS Demonstration Project microseismic array	A.2.8
Seismic array in place:	2010-present	Microseismic array (MSA) with a detection sensitivity of M > 0.5 consists of 7 surface and 8 downhole seismic monitoring stations	Newberry Volcano EGS Demonstration Project	A.3
Paleo-seismic data:	20,022,004	-	Geologic mapping	A.2.3
Distance to existing faults, type of fault and size:	2004	Four caldera ring fractures have been mapped on the northwest flank of Newberry Volcano 3+ km from the NEWGEN FORGE site	Sherrod et al. 2004	A.2.5
Level of seismic activity:	1980-present	No events >M 5.0 within 100 km before 1980; six events ML ≥ 3.0 within 100 km since 1980; four small events ML ≤ 2.2 within 10-15 km at 4 to 8 km depth; no events within 10 km	Pacific Northwest Seismic Network; Newberry Volcano EGS Demonstration Project microseismic array; Wong et al. 2010	A.2.8

Table D.3. (contd)

CHARACTERISTIC	YEAR(S) OF DATA COLLECTION	VALUE/FIGURE OR TABLE IN APPENDICES A OR D	TOOL/METHODOLOGY/ SOURCE	SECTIONS OF APPENDIX AWHERE VALUES ARE DETAILED
Stress state/tectonic stress Stress suA-parameters in areas of extension (e.g., fault orientation, presence or absence of a fault, Coulomb stress change). Occurrence of a structural zone including compression and/or dilatation.			Oregon LiDAR Consortium	A.2.4

D.4.4 Existing Well Data

Table D.4. Existing well data.

CHARACTERISTIC	YEAR(S) OF DATA COLLECTION	VALUE/FIGURE OR TABLE IN APPENDICES A OR D OR D	TOOL/METHODOLOGY/ SOURCE	SECTIONS OF APPENDIX AWHERE VALUES ARE DETAILED
Depth of existing wells	1984-2012	See Table D.5	Newberry Volcano EGS Demonstration Report (AltaRock 2011)	A.2.10 / A.2.11
Type (full sized, core hole, shallow gradient holes)	1984-2012	See Table D.5	Newberry Volcano EGS Demonstration Report (AltaRock 2011)	A.2.10 / A.2.11
Well-integrity logs and/or testing	1984-2012	See Table D.5	Newberry Volcano EGS Demonstration Report (AltaRock 2011)	A.2.11
Ease of drilling (select those that apply), easy drilling (High ROP), moderate drilling (medium ROP, some history of drilling trouble), difficult drilling (low ROP, history of trouble)	2012	Moderate, see Figure D.1	Daily drilling reports for existing wells and boreholes (AltaRock 2014)	A.2.11

D.4.5 Additional Tables

Table D.5. Existing well and borehole inventory, NEWGEN FORGE site area.

WELL/BOREHOLE ID (ALTERNATE ID)	TYPE	YEAR OF INSTALLATION	STATUS	TYPES OF SURVEYS PERFORMED	TOTAL DEPTH (m)	BHT (°C)
CE 23-22	Full sized geothermal well	1995	abandoned	Dip Meter, Caliper, Lithology, Micro-Scanner, Mud, Temperature	2,927	294
CE 76-15	TG corehole	1995	abandoned	Mud	1,634	177
CE 86-21	Full sized geothermal well	1995	abandoned	Directional, Mud, PTS, Flow Test (attempt)	2,804	317
CE 88-21	TG corehole	1995	abandoned	Temperature gradient	1,486	211
CE-NA-4	TG borehole	1986	abandoned	Temperature gradient	1,226	90
GEO N-1	TG borehole	1984	abandoned	Temperature gradient (thermal conductivity, porosity, density on cores)	1,409	117
GEO N-2	TG borehole	1984	abandoned	Temperature gradient (thermal conductivity, porosity, density on cores)	1,337	196
GEO N-3	TG borehole	1984	abandoned	Temperature gradient	1,239	88
GEO N-5	TG borehole	1984	abandoned	Temperature gradient (thermal conductivity, porosity, density on cores)	987	84
SF 72-03	TG corehole	1983	abandoned	Temperature gradient	931	152
SF 01	TG borehole	1984	abandoned	Temperature gradient	1,219	172
NN07 (TG-17N)	TG borehole/ seismic monitoring	2011	active	Temperature gradient	253	
NN09 (TG-19N)	TG borehole/ seismic monitoring	2011	active	Temperature gradient	266	
NN17	Seismic and groundwater monitoring well	2012	active	Water level	218	
NN18 (CE water well 2)	Seismic and groundwater monitoring	1995	active		248	

Table D.5. (contd)

WELL/BOREHOLE ID (ALTERNATE ID)	TYPE	YEAR OF INSTALLATION	STATUS	TYPES OF SURVEYS PERFORMED	TOTAL DEPTH (m)	BHT (°C)
NN19	Seismic monitoring	2012	active	Temperature gradient	241	
NN21	Seismic monitoring	2012	active	Temperature gradient	211	
NN24	Seismic monitoring	2012	active	Temperature gradient	212	
NN32 (TG-32S)	TG borehole/ seismic monitoring	2011	active	Temperature gradient	289	
NWG 46-16	Full sized geothermal	2008	active	Caliper, Density, Dip Meter, Directional Survey, Flow Test (attempt), Gamma Ray, Lithology, Mud, Neutron, Porosity, PTS, Resistivity, Temperature	3553	288
NWG 55-29	Full sized geothermal	2008	active	Caliper, Borehole Televiewer, Density, Dip Meter, Directional Survey, Flow Test (attempt), Gamma Ray, Lithology, Mud, Neutron, Porosity, PTS, Resistivity, Temperature	3066	337
TG-5S	TG borehole/ seismic monitoring	2010	active	Temperature gradient	211	
TG-7S	TG borehole/ seismic monitoring	2011	active	Temperature gradient	149	
TG-19S	TG borehole/ seismic monitoring	2011	active	Temperature gradient	214	
TG-16S	TG borehole/ seismic monitoring	2010	active	Temperature gradient	210	

BHT = bottom-hole temperature
PTS = pressure temperature spinner
TG = thermal gradient

Table D.6. Temperature, thermal conductivity, and calculated heat flow in Well NWG 55-29, Newberry geothermal area.

SAMPLE INTERVAL		FINAL K	LOG TEMP. (°C)	CORRECTED K	AVE. GRADIENT	HEAT FLOW (mW/m^2)	CORRECTED HEAT FLOW (mW/m^2)	DIFF. FROM AVE. HEAT FLOW (mW/m^2)	DIFF. FROM AVE CORRECTED HEAT FLOW (mW/m^2)
TOP (ft)	BOTTOM (ft)								
3750	4300	1.46	136.6	1.46	121.4	177.1	177.2	-69.3	-34.9
4850	5150	1.85	175.8	1.85	110.3	203.9	204.1	-42.5	-8.1
5150	5500	2.87	185.9	2.47	108.6	311.9	268.2	65.4	56.1
5650	6000	2.19	201.9	2.09	102	222.9	213.2	-23.6	1.0
6050	6300	2.37	214.4	2.09	103.8	245.8	216.9	-0.7	4.8
6300	6450	2.62	222.3	2.30	110.3	289.1	253.7	42.6	41.5
6500	7000	2.27	228.8	1.99	95.1	215.6	189.2	-30.9	-22.9
7000	7500	2.43	243.2	1.99	100.8	244.6	200.6	-1.9	-11.6
7550	7650	2.92	260.0	2.30	99.5	290.6	228.9	44.1	16.7
7800	8150	2.93	267.2	2.30	99.1	290.3	227.9	43.8	15.8
8400	8600	2.17	285.0	1.99	97.4	211.0	193.8	-35.5	-18.3
8650	8850	2.89	292.3	2.26	98.5	284.7	222.6	38.2	10.5
9250	9400	2.89	310.1	2.26	95	274.5	214.7	28.0	2.5
9750	10000	2.36	324.9	1.99	79.9	188.8	159.0	-57.7	-53.1

Average Heat Flow		Standard Error	
246.5	212.2	11.70	7.65

Conductivities corrected using figures from Birch and Clark 1940

Table D.7. Porosity, density and thermal Conductivity at wells GEO-N1, GEO-N2, GEO-N4 and GEO-N5 (Blackwell 1994)

WELL	DEPTH (ft)	POROSITY (%)	DENSITY (g/cm^3)	THERMAL CONDUCTIVITY (W/(mk))
GEO-N1	1801	39.6	1.28	0.92
GEO-N2	458	2.65	2.77	1.82
	542	4.25	2.46	1.98
	1556	4.52		1.50
	1907	5.39	2.37	1.84
	1994	5.60	1.67	1.22
	2600	9.10	2.39	1.31
	2999	6.82	2.37	1.47
	3400	5.16	2 .50	1.79
	3500	2.39	2.53	1.53
	3700	4.67	2.44	1.59
	3900	12.11	2.36	1.71
	4150	1.80	2.59	1.86
GEO-N4	1401	14.5	2.43	1.88
	1800	1.2	2.86	2.19
	1978	1.8	2.83	2.09
	2097	1.4	2.81	2.19
	2301	2.0	2.76	2.02
GEO-N5	1900	0.4	2.81	1.98
	2044	5.8	2.17	2.44
	2098	5.5	2.31	2.13
	2135	3.4	2.39	2.21
	2248	4.2	2.16	1.78
	2305	7.1	2.50	1.73
	2350	22.3	1.80	1.39
	2548	16.9	1.89	1.23
	2650	27.0	1.69	1.32
	2673	14.6	1.87	1.07
	2750	1.7	2.21	1.39
	2850	28.4	1.63	1.11
	3147	10.2	2.28	2.09

Table D.8. Well data and injectivity test results (AltaRock 2009).

WELL	TOTAL DEPTH (m)	MAX STATIC TEMP (°C)	BOTTOM-HOLE GRADIENT (°C/km)	INJECTION RATE (kph)	WHP (psig)	INJECTIVITY (kph/psi)	PERMEABILITY (m^2)
CE 76-15 TCH	1634	177	NA	1-2	300	0.0015-0.0031	NA
CE 88-21 TCH	1486	211	NA	NA	NA	NA	NA
CE 23-22	2927	294	86-98	40-60	1350-2000[a]	0.024-0.026	2.6×10^{-16}
CE 86-21	2804	317	86-98	25-42.5	50-800[a]	0.022-0.026	NA
NWG 55-29(b) 08/2008 09/2010 10/2010	 3066 “ “	 331 “ “	 ~93[c] “ “	 NA 5 10.5	 970 751 1153	 NA 0.007 0.014	NA

(a) Liquid head at zero wellhead pressure (WHP) was assumed to be 2.3 MPa (333 psi) based on water levels of 236 m (775 ft) in the wells (Spielman and Finger 1998).

(b) NWG 55-29 injection test from July 2008, and September and October 2010. Results of the later two test periods are presented.

(c) Average gradient from 2966 m to TD (bottom 100 m).

NA = not available.

Table D.9. Average ground and surface water quality sample results, 2011–2013 (AltaRock 2014).

MONITORING LOCATION	SAMPLE TYPE	NUMBER OF SAMPLES	FIELD PARAMETERS					LABORATORY ANALYTICAL RESULTS				
			TEMP, (°C)	pH (SU)	COND. (mS/m)	ORP (mV)	TURBIDITY (NTU)	pH (SU)	TEMP. (°C)	TA (mg/L $CaCO_3$)	Al (mg/L)	NH4 (mg/L N)
PLHS	SW	10	46.3	6.6	197.6	122.8	0.25	7.525	20.15	588.5	<0.05	<0.1
ELHS	SW	14	42.2	6.65	22.35	64.25	7.6	7.47	19.8	331	<0.05	0.175
NEWW	GW	12	8.85	7.35	0.2	132.5	0.325	7.82	19.8	57	<0.05	<0.1
PAD-16	GW	3	6.89	7.95	-32.5	146	0.52	7.845	19.95	40.5	<0.05	0.1
PAD-29	GW	9	17.15	7.45	-20.45	79.95	0.05	7.845	19.9	246	<0.05	0.15
NN-17	GW	9	8.85	7.85	-3.25	-41.5	36.15	8.275	20.65	237	<0.05	0.2
NN-18	GW	9	8.7	8.05	5.2	87.6	6.8	8.375	20.7	181	<0.05	0.1

MONITORING LOCATION	LABORATORY ANALYTICAL RESULTS											
	AS (mg/L)	BA (mg/L)	B (mg/L)	CA (mg/L)	CS (mg/L)	CL (mg/L)	CR (mg/L)	F (mg/L)	FE (mg/L)	LI (mg/L)	MG (mg/L)	MN (mg/L)
PLHS	0.007	0.132	0.815	49.35	0.002	6.35	46.3	0.75	0.13	0.195	46	1.2175
ELHS	0.0045	0.0145	0.96	57.4	<0.002	1.75	42.2	0.2	0.245	0.025	26.5	0.3155
NEWW	<0.002	0.0035	<0.05	7.55	<0.002	2.25	8.85	0.2	0.1	<0.1	4.5	0.002
PAD-16	<0.002	0.0025	<0.05	5.1	<0.001	0.8	6.89	0.2	0.085	<0.1	3.75	0.002
PAD-29	0.0157	0.008	0.57	19.1	<0.001	3.6	17.15	0.65	0.085	<0.1	25	0.003
NN-17	0.00525	0.0055	0.54	17.85	<0.002	3.2	8.85	0.7	0.2	<0.1	24	0.061
NN-18	0.014	0.0115	0.88	10.25	<0.002	6.3	8.7	0.45	0.145	<0.1	11.5	0.0105

Table D.9. (contd)

MONITORING LOCATION	LABORATORY ANALYTICAL RESULTS											
	HG (mg/L)	NO_3 (mg/L N)	P (mg/L)	K (mg/L)	RB (mg/L)	SIO_2 (mg/L)	NA (mg/L)	SR (mg/L)	SO_4 (mG/L)	TDS (mg/L)	Δ2H	Δ18O
PLHS	<0.0001	1.3	0.15	13.2	0.0345	172.465	112.15	0.18	6	682.5	-106.75	-14.195
ELHS	0.0003	<0.5	0.12	7.075	0.017	96.9	45.8	0.18	51.25	467.5	-94.1	-11.35
NEWW	<0.0002	1.3	0.21	1.4	0.002	44.5	9.85	<0.05	1.45	99.5	-120.25	-15.785
PAD-16	<0.0001	1.3	0.165	1.22	0.0025	42.25	8.225	<0.05	0.875	86.25	-120.25	-15.785
PAD-29	<0.0001	0.21	0.175	4.89	0.0066	59	44.25	0.075	2.5	279	-110.59	-14.71
NN-17	<0.0001	<0.5	0.1	4.15	0.0065	52.5	39.05	0.08	1.95	258	-111.82	-14.93
NN-18	<0.0001	2.2	0.095	6.575	0.0135	62.5	46.35	<0.05	6.85	229	-112.89	-15.17

Cond. = conductivity
ELHS = East Lake Hot Springs
GW = groundwater
NTU = Nephelometric Turbidity Unit
P = post-stimulation chemistry
PLHS = Paulina Lake Hot Springs
SW = surface water
TA = Total Alkalinity
Temp. = temperature
< – constituent was not detected above the laboratory reporting limit

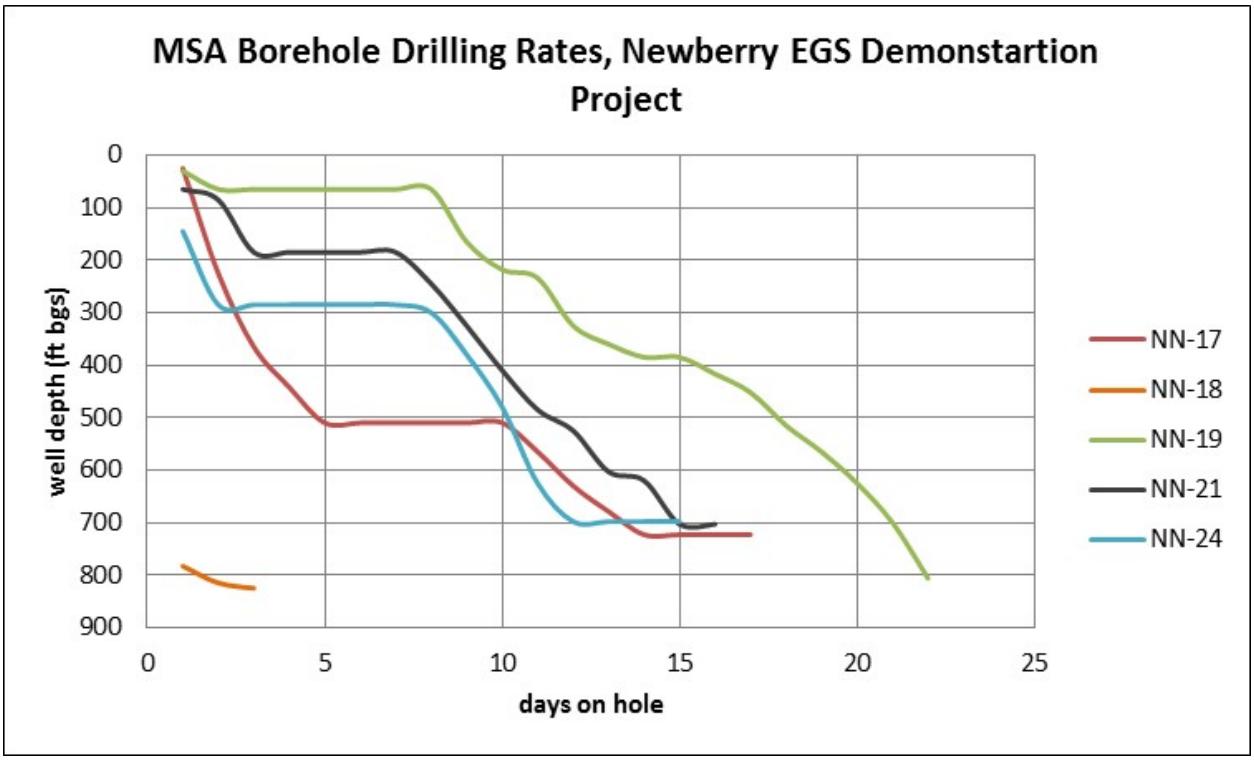

Figure D.1. Comparison of MSA borehole drilling rates at Newberry Volcano.

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