

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Principal Facts for Gravity Stations of the
Broadwater Geothermal Area, Montana

by

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This report is preliminary and has not
been reviewed for conformity with
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Introduction

On August 18-19, 1979, 67 gravity stations were established at the Broadwater Hot Springs area 5 km west of Helena, Montana (Fig. 1). The gravity data were obtained as part of the U.S. Geological Survey's program to evaluate geothermal resource areas. These data complement a 1978 gravity survey by M. Senterfit (1979) and a telluric profile done by K. Christopherson (1979). This report presents the principle facts for the 1979 gravity data.

Data Collection

Gravity observations were made with the LaCoste-Romberg gravity meter, G-235. The International Gravity Standardization Net (IGSN), 1971, established by the Defense Mapping Agency Aerospace Center (1974) was used as the datum for the U.S. Geological Survey gravity base at Helena, Montana. A secondary base, which was tied to the Helena base, was established in the study area. Base descriptions are given in Appendices A and B detail at the end of the present report. Gravity loops were started and closed daily by observations at these bases.

Elevation Control

The Broadwater geothermal area is located in the area covered by the Helena quadrangle, scale 1/62,500. Station elevations were surveyed using a Hewlett-Packard Total Station distance meter. The elevations were tied to a known elevation of 233.62 m at the Broadwater Bridge Base (BR-2), determined by R. Leonard (oral communication, 1978). The elevation differences obtained with this instrument in this terrain were estimated to

have a precision of 0.15 m for distances less than 2 km. This precision translates to uncertainties in Bouguer values of 0.03 (milligals). Horizontal distance at this range is also accurate to within 0.15 m.

Data Reduction

Computer programs on the USGS Honeywell Multics computer system were used to obtain principle facts and terrain corrected gravity values. A program by D. A. Dansereau (USGS, unpublished) was used to calculate earth-tide and linear meter-drift corrected observed gravity values. The theoretical gravity value was calculated using the 1967 formula of the Geodetic Reference System (International Association of Geodesy, 1967). Another unpublished program by R. H. Godson computed terrain corrections for the area from each station out to 166.7 km, using the method of Plouff (1977). The program uses mean elevation data on a 15-second grid for corrections from 0 to 5 km; 1-minute terrain data for corrections from 5 to 21 km; and 3-minute terrain data for corrections from 21 to 166.7 km. An assumed density of 2.67 g/cm^3 is used for terrain corrections. This program also calculates earth-curvature corrections and complete (terrain-corrected) Bouguer anomaly values. Corrections for terrain ranged from 0.89 to 3.18 mgal. Two complete Bouguer anomaly values per station were calculated assuming average rock densities of 2.67 g/cm^3 and 2.45 g/cm^3 . The corrections and anomaly values are listed in Appendix C. A hand contoured Bouguer gravity map is included in Appendix D.

References

- Christopherson, K. 1979, Telluric profile and location map for the Broadwater Hot Springs area, Montana: U.S. Geological Survey Open-File Report, 79-1670.
- Defense Mapping Agency Aerospace Center, 1974, World relative gravity reference network, North America, Part 2: DMAAC Reference Publication 25, with supplement updating gravity values to the International Gravity Standardization Net 1971, 1635 p.
- International Association of Geodesy, 1967, Geodetic reference system, 1967: International Association of Geodesy Special Publication 3, 74 p.
- Plouff, D., 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report, 77-535.
- Senterfit, R. M., 1979, Principal facts for gravity stations of the Broadwater, Montana geothermal area: U.S. Geological Survey Open-File Report, 79-1624.

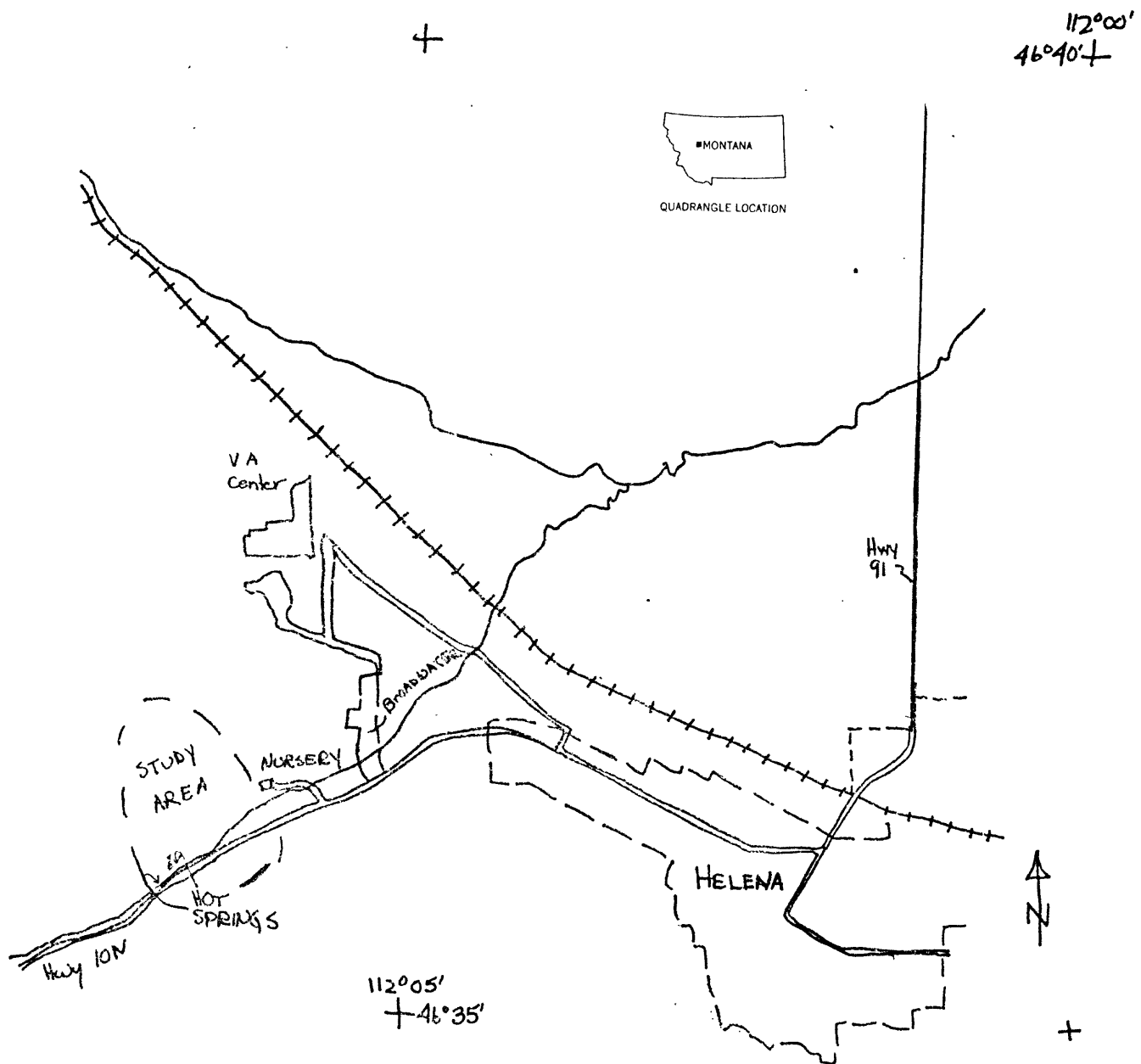


Fig. 1 - Index Map
Broadwater Hot Springs, Montana

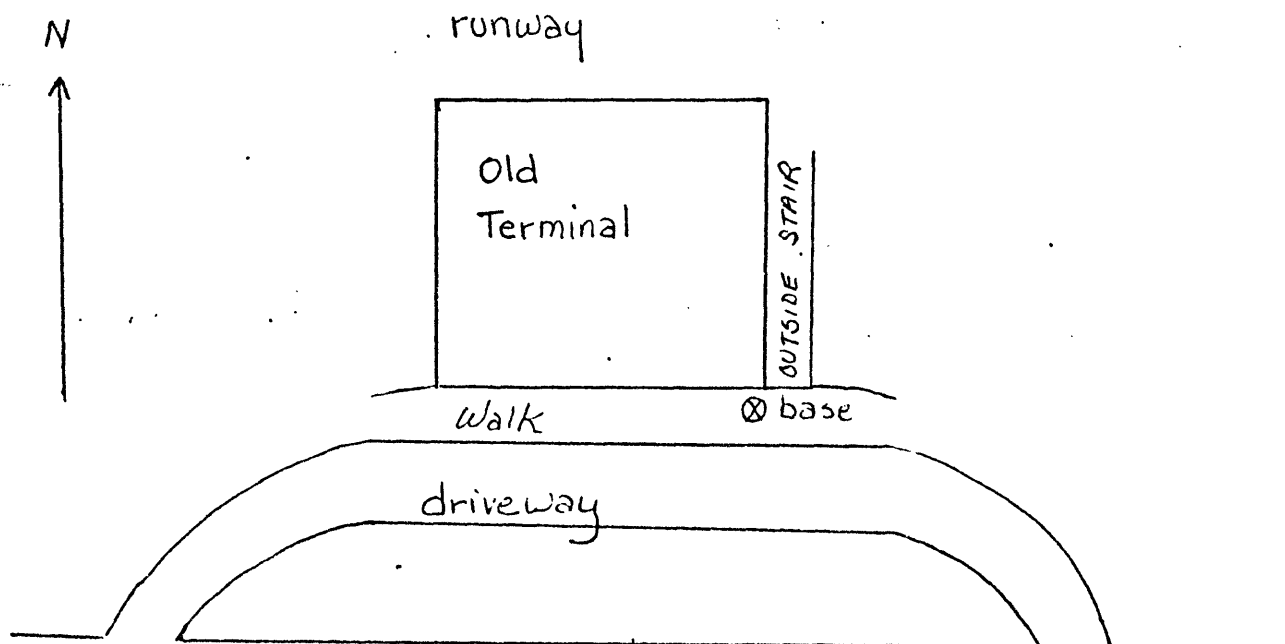
Appendix A

U.S. GEOLOGICAL SURVEY
GRAVITY BASE STATION

STATE/COUNTRY		STATION DESIGNATION		OBSERVED GRAVITY
Montana		Helena Airport		980363.26 mgals
NEAREST TOWN		LONGITUDE		LATITUDE
Helena		111° 59.50'		46° 36.50'
ELEVATION		TOPOGRAPHIC MAP(S)		
1180.3 m (3872')		White Sulphur Springs 1/250,000		
DATE	OBSERVER	METER	REFERENCE STATION	REFERENCE VALUE
7/2/77	Kleinkopf	Worden E-134	Helena airport DOD	980363.50 mgals

DESCRIPTION/SKETCH

Base is on concrete walk at southeast corner of the airport terminal building, to west side of outside stairway - "employee entrance". Note the DOD location is on north side of the terminal in the security area.



BOUGUER GRAVITY DATA

broadwater gravity file
 bankey and patton 1979
 Meter ID: 9-235

Date: 11/27/79

STATION IDENTIFICATION		L O C A T I O N		G R A V I T Y		C O R R E C T I O N S		A N O M A L I E S				
proj	sta-id	LATITUDE deg	LONGITUDE deg	ELE min	ST (in ft)	OBSERVED	THEORETICAL	TERRAIN BOUGUER	CURV SPECIAL	FREE AIR	COMPLETE-BOUGUER d1=2.67 d2=2.45	SPEC FIELDS
north :	br42	46 35.72	-112 6.58	4114.1	mt	980343.65	980763.38	2.07	-140.32	-1.28	0.00	0.00
north :	br43	46 35.70	-112 6.66	4101.2	mt	980343.92	980763.35	2.32	-139.88	-1.28	0.00	0.00
north :	br44	46 35.91	-112 6.51	4103.8	mt	980345.47	980763.67	1.64	-139.97	-1.28	0.00	0.00
north :	br45	46 35.87	-112 6.55	4095.1	mt	980345.98	980763.61	1.68	-139.67	-1.28	0.00	0.00
north :	br46	46 35.94	-112 6.64	4130.8	mt	980344.45	980763.72	1.58	-140.89	-1.28	0.00	0.00
north :	br47	46 36.39	-112 6.44	4427.0	mt	980328.77	980764.39	2.19	-150.99	-1.33	0.00	0.00
north :	br48	46 36.37	-112 6.47	4388.7	mt	980331.11	980764.37	1.63	-149.69	-1.33	0.00	0.00
north :	br49	46 36.36	-112 6.31	4306.6	mt	980336.16	980764.35	1.32	-146.89	-1.31	0.00	0.00
north :	br50	46 36.32	-112 6.47	4268.1	mt	980338.40	980764.29	1.09	-145.57	-1.31	0.00	0.00
north :	br51	46 36.31	-112 6.31	4192.7	mt	980343.01	980764.27	1.19	-143.00	-1.29	0.00	0.00
north :	br52	46 36.24	-112 6.43	4191.2	mt	980342.52	980764.17	1.27	-142.95	-1.29	0.00	0.00
north :	br53	46 36.22	-112 6.27	4109.6	mt	980347.57	980764.14	1.34	-140.17	-1.28	0.00	0.00
north :	br54	46 36.17	-112 6.36	4128.7	mt	980345.96	980764.06	1.31	-140.82	-1.28	0.00	0.00
north :	br55	46 36.14	-112 6.22	4057.1	mt	980350.23	980764.02	1.48	-138.38	-1.27	0.00	0.00
north :	br57	46 36.07	-112 6.41	4114.7	mt	980345.86	980763.91	1.40	-140.34	-1.28	0.00	0.00
north :	br58	46 35.99	-112 6.36	4034.0	mt	980349.86	980763.79	1.76	-137.59	-1.27	0.00	0.00
north :	br59	46 35.94	-112 6.45	4071.7	mt	980347.42	980763.72	1.65	-138.87	-1.27	0.00	0.00
north :	br60	46 35.93	-112 6.30	4012.8	mt	980350.74	980763.70	1.89	-136.86	-1.26	0.00	0.00
north :	br61	46 35.83	-112 6.07	4108.5	mt	980345.61	980763.55	1.79	-140.13	-1.28	0.00	0.00
north :	br62	46 35.77	-112 6.18	4149.0	mt	980342.50	980763.46	1.87	-141.51	-1.29	0.00	0.00
north :	br63	46 35.74	-112 6.34	4150.2	mt	980341.55	980763.41	1.77	-141.55	-1.29	0.00	0.00
north :	br64	46 35.64	-112 6.41	4158.1	mt	980340.82	980763.27	2.00	-141.82	-1.29	0.00	0.00
north :	br65	46 35.90	-112 6.11	4074.3	mt	980347.89	980763.66	1.67	-138.96	-1.27	0.00	0.00
north :	br66	46 35.93	-112 6.16	4034.8	mt	980349.61	980763.70	1.69	-137.62	-1.27	0.00	0.00
north :	br67	46 35.84	-112 6.43	4026.6	mt	980349.06	980763.56	2.07	-137.34	-1.26	0.00	0.00

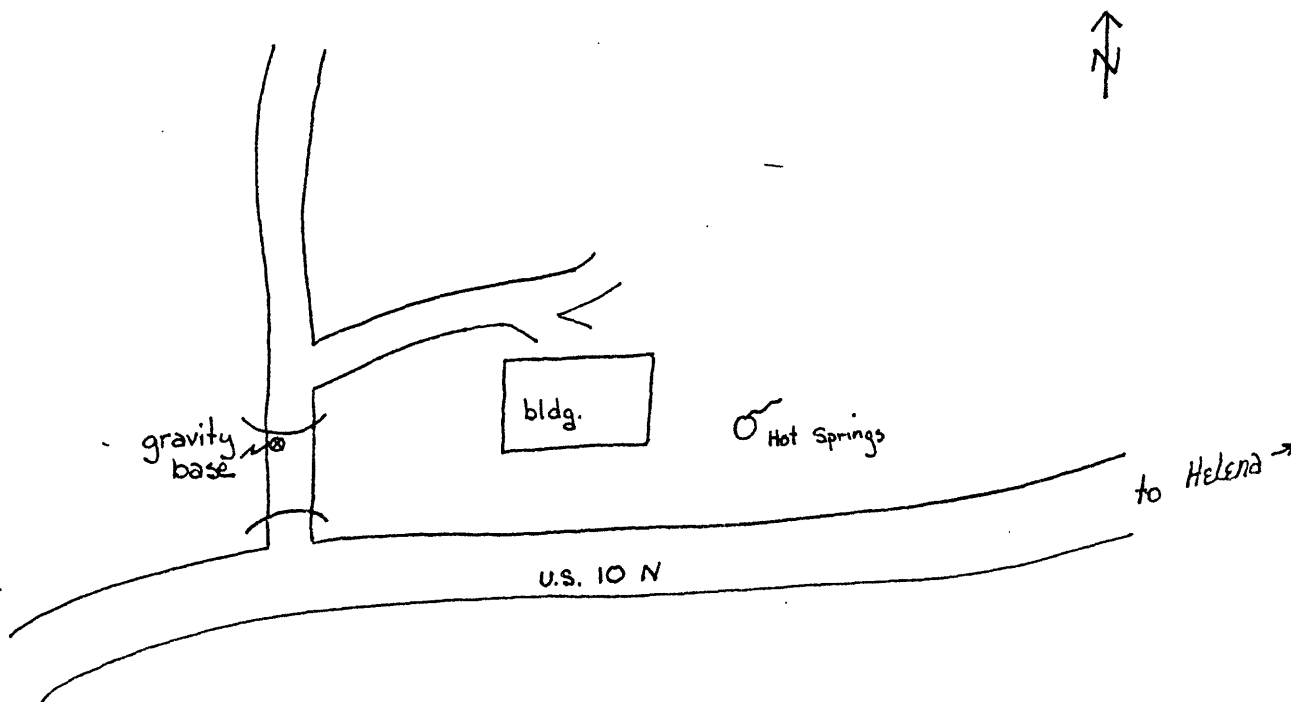
Appendix B

U.S. GEOLOGICAL SURVEY
GRAVITY BASE STATION

STATE/COUNTRY		STATION DESIGNATION		OBSERVED GRAVITY
Montana		Broadwater		980347.42 mgal.
NEAREST TOWN		LONGITUDE		LATITUDE
Helena		112° 06.74'		46° 35.74'
ELEVATION		TOPOGRAPHIC MAP(S)		
4047.3 feet (1234 m)		Helena 15', Butte 2°		
DATE	OBSERVER	METER	REFERENCE STATION	REFERENCE VALUE
8/19/79	Bankey	G-235	Helena Airport	980363.26 mgal.

DESCRIPTION/SKETCH

Base is approximately one mile past turnoff to State Nursery, west of Helena on Highway U.S. 10N. Base is on northwest corner of bridge at turnoff to hot springs area which is being made into a resort.



Appendix C: Principal Facts of Gravity Data

Explanation of headings

identification

proj	Project name.
sta-id	Gravity station identification number.

location

latitude	North latitude, in degrees, minutes, and hundreths of minutes.
longitude	West longitude, in degrees, minutes, and hundredths of minutes.
elev f	Station elevation, in feet.
st	State in which survey area is located.
observed gravity	Observed gravity, in milligals.
theoretical gravity	Theoretical gravity.

corrections

terrain	Terrain correction to 166.7 km in milligals.
Bouguer	Elevation corection, in milligals.
curv	Earth curvature correction, in milligals.
special	Not used.

anomalies

free air	Free-air anomaly, in milligals.
complete-Bouguer	Complete Bouguer anomaly, in milligals for designated densities.
spec fields	Not used.

Date: 11/27/79

BOUGUER GRAVITY DATA

STATION IDENTIFICATION		L U C A T I O N S		G R A V I T Y		C O R R E C T I O N S		A N O M A L I E S					
proj	sta-id	LATITUDE deg min	LONGITUDE deg min	ELE (in ft)	OBSERVED	THEORETICAL	TERRAIN BOUGUER	CURV SPECIAL	FREE AIR	COMPLETE-BOUGUER d1=2.67 d2=2.45	SPEC FIELDS		
north :	br1	46 36.25	-112 7.26	4596.5 MT	980317.65	980764.18	2.46	-156.77	-1.36	0.00	-14.41	-170.08	-157.26
north :	br2	46 35.74	-112 6.74	4047.3 MT	980347.42	980763.41	2.51	-138.04	-1.27	0.00	-35.48	-172.28	-161.01
north :	br4	46 36.14	-112 6.63	4218.6 MT	980340.49	980764.02	1.19	-143.88	-1.30	0.00	-26.92	-170.91	-159.04
north :	br5	46 36.14	-112 6.50	4170.6 MT	980343.24	980764.02	1.39	-142.25	-1.29	0.00	-28.68	-170.83	-159.11
north :	br6	46 36.15	-112 6.81	4272.6 MT	980337.60	980764.03	1.15	-145.73	-1.31	0.00	-24.75	-170.63	-158.61
north :	br7	46 36.15	-112 7.07	4328.0 MT	980334.63	980764.03	1.03	-147.62	-1.32	0.00	-22.51	-170.41	-158.23
north :	br8	46 36.15	-112 7.20	4395.6 MT	980330.45	980764.03	0.91	-149.92	-1.33	0.00	-20.34	-170.67	-158.29
north :	br9	46 36.04	-112 7.25	4401.5 MT	980329.83	980763.87	0.98	-150.12	-1.33	0.00	-20.24	-170.71	-158.31
north :	br10	46 35.96	-112 7.19	4397.0 MT	980329.25	980763.75	1.24	-149.97	-1.33	0.00	-21.12	-171.18	-158.81
north :	br11	46 35.98	-112 7.08	4296.6 MT	980335.62	980763.77	1.18	-146.54	-1.31	0.00	-24.22	-170.90	-158.81
north :	br12	46 36.01	-112 6.95	4229.1 MT	980339.43	980763.82	1.45	-144.24	-1.30	0.00	-26.80	-170.89	-159.02
north :	br13	46 36.06	-112 7.00	4272.1 MT	980337.35	980763.90	1.33	-145.71	-1.31	0.00	-24.91	-170.59	-158.59
north :	br14	46 36.31	-112 6.98	4558.7 MT	980320.16	980764.27	2.77	-155.48	-1.35	0.00	-15.54	-169.60	-156.91
north :	br15	46 36.15	-112 7.47	4512.4 MT	980324.78	980764.03	1.19	-153.91	-1.35	0.00	-15.03	-169.09	-156.40
north :	br16	46 36.27	-112 7.50	4427.0 MT	980330.38	980764.21	0.90	-150.99	-1.33	0.00	-17.64	-169.06	-156.58
north :	br17	46 36.35	-112 7.47	4380.2 MT	980333.65	980764.34	0.89	-149.40	-1.32	0.00	-18.89	-168.72	-156.38
north :	br18	46 36.15	-112 7.32	4520.8 MT	980323.07	980764.03	1.52	-154.19	-1.35	0.00	-15.95	-169.97	-157.28
north :	br19	46 36.22	-112 6.92	4383.8 MT	980331.45	980764.14	1.04	-149.52	-1.33	0.00	-20.55	-170.36	-158.01
north :	br20	46 35.97	-112 6.61	4139.2 MT	980344.04	980763.76	1.54	-141.18	-1.28	0.00	-30.58	-171.50	-159.89
north :	br21	46 36.01	-112 6.72	4176.8 MT	980342.24	980763.82	1.44	-142.46	-1.29	0.00	-28.90	-171.21	-159.48
north :	br22	46 35.99	-112 6.82	4170.4 MT	980342.55	980763.79	1.57	-142.24	-1.29	0.00	-29.17	-171.13	-159.43
north :	br23	46 35.94	-112 6.91	4179.5 MT	980341.78	980763.72	1.53	-142.55	-1.29	0.00	-29.00	-171.31	-159.59
north :	br24	46 35.04	-112 6.99	4056.6 MT	980346.96	980763.27	3.18	-138.36	-1.27	0.00	-34.92	-171.37	-160.13
north :	br25	46 35.80	-112 6.92	4128.6 MT	980343.87	980763.51	1.94	-140.81	-1.28	0.00	-31.49	-171.65	-160.10
north :	br26	46 35.83	-112 6.87	4116.4 MT	980344.64	980763.55	2.00	-140.40	-1.28	0.00	-31.91	-171.59	-160.08
north :	br27	46 35.77	-112 6.81	4059.8 MT	980347.38	980763.46	2.48	-138.47	-1.27	0.00	-34.39	-171.65	-160.34
north :	br28	46 35.83	-112 6.76	4067.3 MT	980347.27	980763.55	2.16	-138.72	-1.27	0.00	-33.89	-171.73	-160.37
north :	br29	46 35.79	-112 6.70	4034.2 MT	980348.69	980763.49	2.45	-137.59	-1.27	0.00	-35.53	-171.94	-160.70
north :	br30	46 35.83	-112 6.65	4039.2 MT	980348.73	980763.55	2.25	-137.77	-1.27	0.00	-35.07	-171.85	-160.58
north :	br31	46 35.82	-112 6.61	4031.6 mt	980348.97	980763.54	2.30	-137.51	-1.27	0.00	-35.53	-172.01	-160.76
north :	br32	46 35.82	-112 6.58	4030.9 mt	980349.07	980763.54	2.27	-137.48	-1.27	0.00	-35.50	-171.98	-160.73
north :	br33	46 35.82	-112 6.55	4031.0 mt	980349.04	980763.54	2.21	-137.49	-1.27	0.00	-35.52	-172.06	-160.81
north :	br34	46 35.81	-112 6.60	4033.6 mt	980348.80	980763.52	2.29	-137.57	-1.27	0.00	-35.50	-172.05	-160.80
north :	br35	46 35.78	-112 6.63	4041.6 mt	980348.17	980763.48	2.35	-137.85	-1.27	0.00	-35.33	-172.10	-160.83
north :	br36	46 35.79	-112 6.53	4039.3 mt	980348.34	980763.49	2.21	-137.77	-1.27	0.00	-35.39	-172.22	-160.94
north :	br37	46 35.88	-112 6.69	4093.6 mt	980346.23	980763.63	1.79	-139.62	-1.28	0.00	-32.53	-171.64	-160.18
north :	br38	46 35.89	-112 6.60	4107.4 mt	980345.41	980763.64	1.63	-140.09	-1.28	0.00	-32.07	-171.81	-160.30
north :	br39	46 35.67	-112 6.66	4180.5 mt	980339.21	980763.31	1.75	-142.59	-1.29	0.00	-31.07	-173.20	-161.49
north :	br40	46 35.69	-112 6.58	4206.4 mt	980338.02	980763.34	1.61	-143.47	-1.30	0.00	-29.85	-173.01	-161.21
north :	br41	46 35.79	-112 6.49	4205.5 mt	980338.54	980763.49	1.71	-143.44	-1.30	0.00	-29.57	-172.60	-160.81