WOODRUFF CREEK DAM

PHASE II
GEOLOGY & SEISMIC REPORT

PRELIMINARY

DIVISION OF WATER RESOURCES

1636 WEST NORTH TEMPLE, SUITE 310
SALT LAKE CITY, UT 84116-3156

#1076

WOODRUFF CREEK DAM

PHASE II
GEOLOGY & SEISMIC REPORT

PRELIMINARY

DIVISION OF WATER RESOURCES
Engineering Geology Section
1636 West North Temple
Suite 310
Salt Lake City, Utah 84116

GEOLOGY/SEISMIC REPORT

October 27, 1994

TO: Dennis Strong
Assistant Director
FROM: Ben Everitt
Chief Engineering Geologist
Dan Aubrey
Engineering Geologist
SUBJECT: Woodruff Creek Dam - Phase II Geology & Seismic Report

Location & Introduction

Woodruff Creek reservoir is located on the Woodruff Creek drainage, about 9 miles upstream from the town of Woodruff in Rich County, Utah (Figure 1). The dam is located on the Meachum Ridge 7 1/2 minute topographic map in the SW 1/4 of Section 31, T9N, R6E, SLB&M. The dam is operated by the Woodruff Irrigation Company.

Following site investigation in 1967 and 1968, plans were prepared by the Utah Division of Water Resources and the consulting engineering firm of Rollins, Brown, and Gunnell. The dam was constructed in 1969 through 1971 and was dedicated in September of 1971. Since its completion, no major alterations have been undertaken (U.S.Army, 1979). The dam is described as a homogeneous earthfill with a chimney drain and rock toe. The crest is 103 feet above the streambed and has a crest length of 605 feet and a crest width of 30 feet (U.S.Army, 1979 & Figure 2).

Regional & Reservoir Basin Geology

The Quaternary units, in the area immediately around the dam, consist of various fluvial and colluvial units which vary in thickness (unit Qac on Figure 3). Marsell, (1968) described the overburden as "poorly sorted cobbles, gravels, sand, silt and some clay". These deposits originated as colluvium derived from the Wasatch and Twin Creek formations, which underlie adjacent slopes, and as fluvial sediments deposited as terraces (Marsell, 1968).

The Tertiary Wasatch Formation, in this area has been measured as being a thousand feet or more in thickness (Hintze, 1988). This unit is exposed over much of the area surrounding the reservoir. Marsell, whose mapping is the most detailed available in the area, described the Wasatch (which he referred to as both Wasatch and Knight conglomerate) as consisting of "a coarse, thick-bedded red conglomerate with abundant cobbles and boulders of quartzite and cherty limestone embedded in a red, silty matrix". He noted that the boulders were all well rounded and were as large as 8-10 inches in diameter. This led him to recommend the Wasatch as a potential source for rip rap (Marsell, 1964).

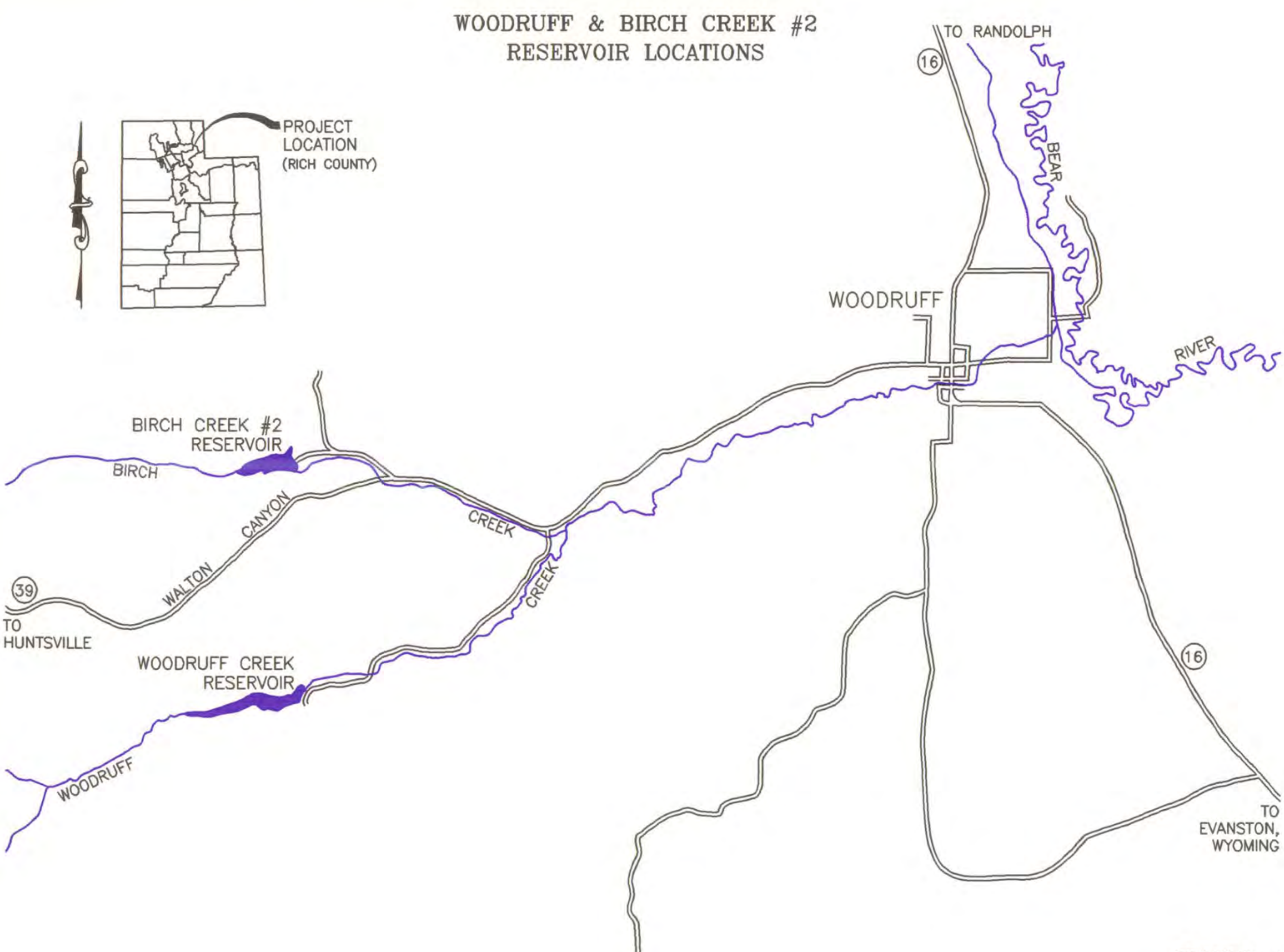

WOODRUFF & BIRCH CREEK #2
RESERVOIR LOCATIONS
PROJECT
LOCATION
(RICH COUNTY)
TO RANDOLPH
16
BEAR
RIVER
WOODRUFF
BIRCH CREEK #2
RESERVOIR
BIRCH
CREEK
WALTON
CANYON
39
TO
HUNTSVILLE
CREEK
WOODRUFF CREEK
RESERVOIR
WOODRUFF
16
TO
EVANSTON,
WYOMING

FIGURE 1

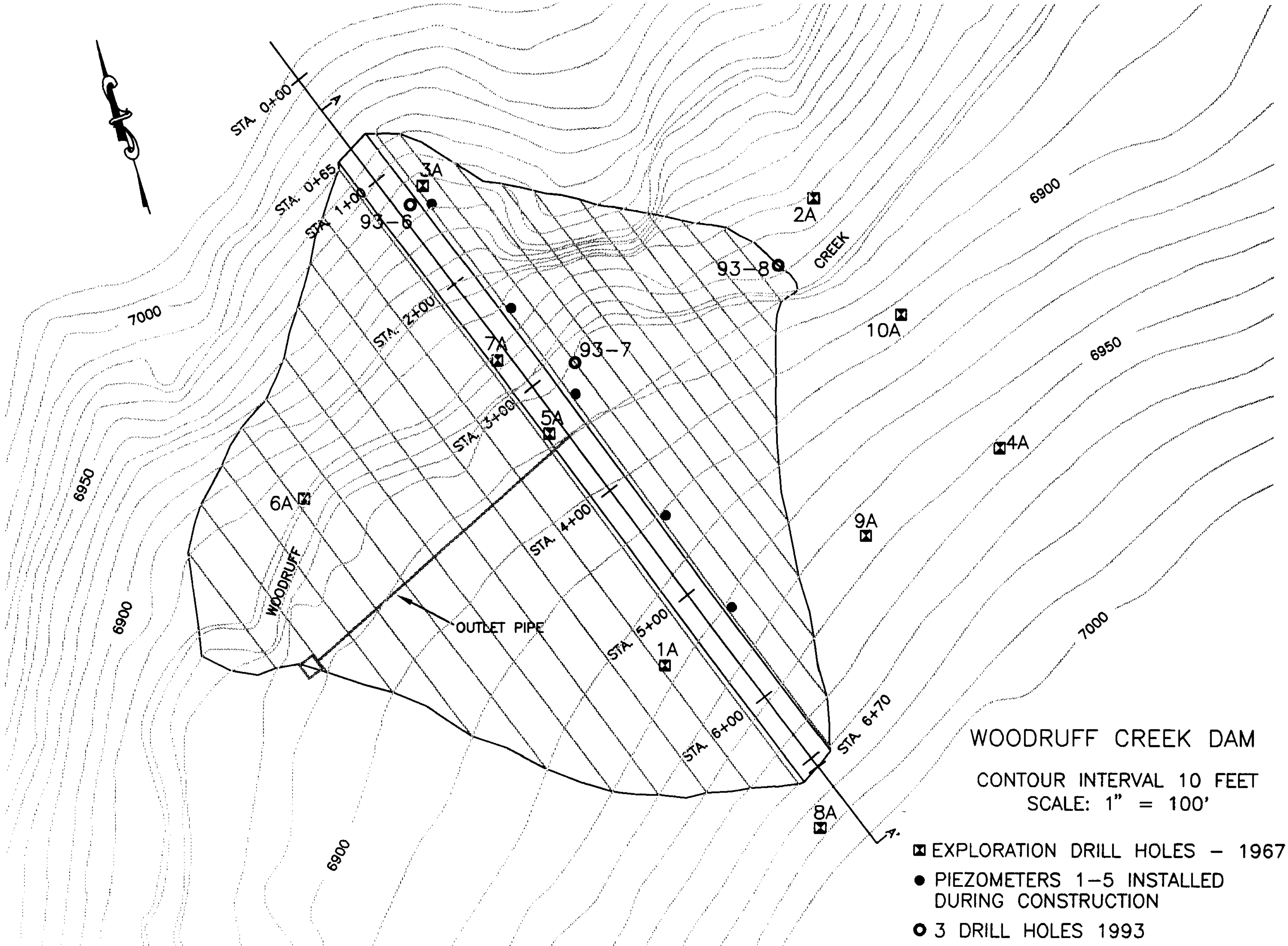
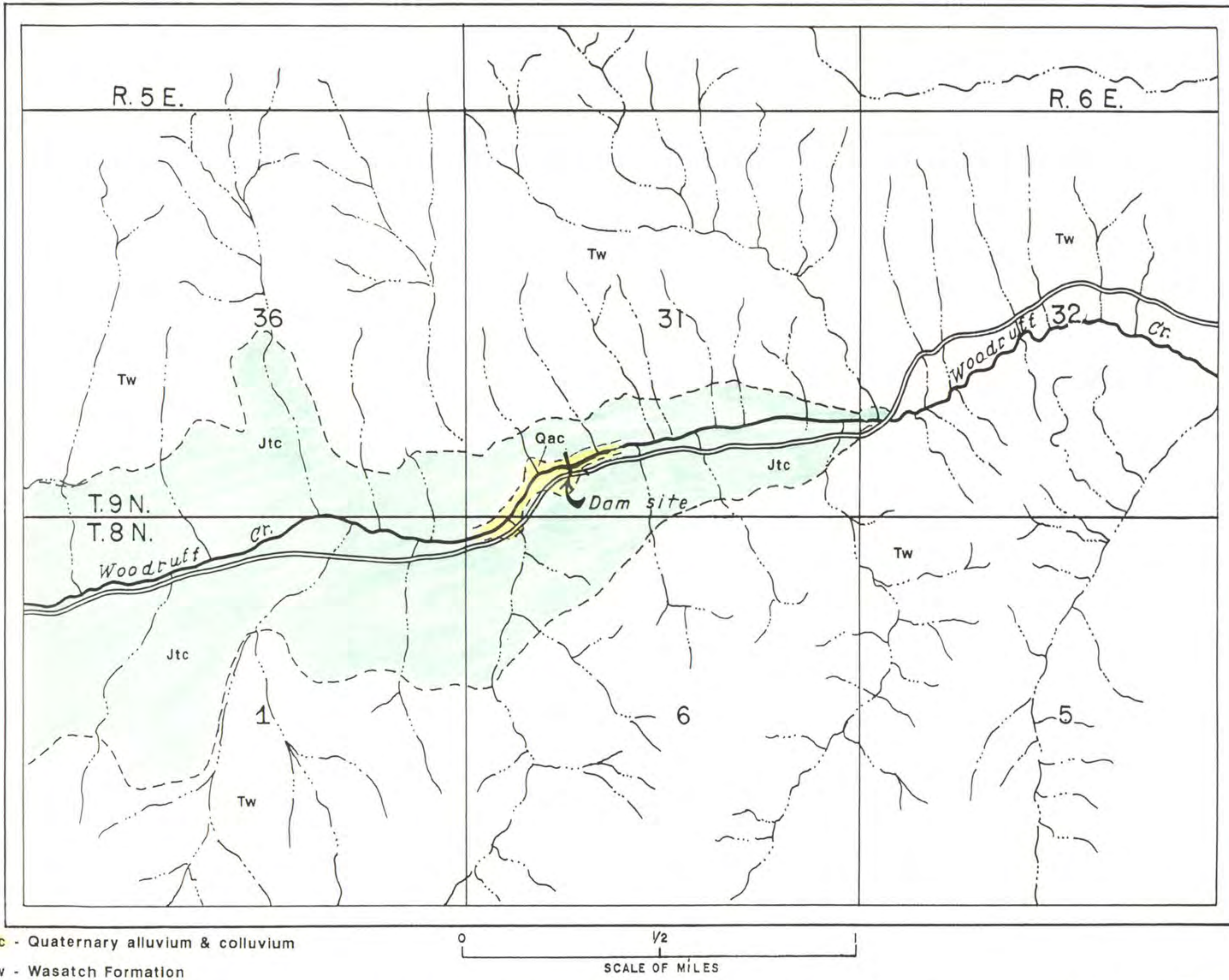

STA. 0+00
STA. 0+65
STA. 1+00
STA. 2+00
STA. 3+00
STA. 4+00
STA. 5+00
STA. 6+00
STA. 6+70
A
A
3A
93-6
2A
93-8
CREEK
10A
7A
93-7
5A
4A
6A
9A
WOODRUFF
OUTLET PIPE
1A
8A
7000
6950
6900
6900
6900
6950
7000
WOODRUFF CREEK DAM
CONTOUR INTERVAL 10 FEET
SCALE: 1" = 100'
EXPLORATION DRILL HOLES - 1967
PIEZOMETERS 1-5 INSTALLED DURING CONSTRUCTION
3 DRILL HOLES 1993

FIGURE 2



Qac - Quaternary alluvium & colluvium

Tw - Wasatch Formation

Jtc - Jurassic Twin Creek Formation

Geologic Sketch Map Woodruff Creek Dam Site **Figure 3**

The Jurassic Twin Creek Limestone, which underlies the dam and reservoir basin, is measured at 2,300 feet thick, and consists of both shaly limestone and calcareous shale (Hintze, 1988) that regionally is "generally highly folded, bent, crumpled, and broken" (Marsell, 1964 & 1968). Outcrops of this formation in the immediate area around the reservoir are observed to consist of thin to very thin-bedded, highly jointed to splintery, shaly limestone. Most of the joints are vertical (normal to bedding), however, there are several large joints which are observed to strike normal to the canyon and dip upstream at about 45° (Figure 4). Close observation of these large joints reveals a possible minor reverse offset.

<u>1993 Investigation</u>

Using a CME 55 drilling rig, RB&G Engineering Inc. of Provo, Utah started drilling at Woodruff Creek dam on September 8, 1993. By September 23rd, three holes had been drilled (DH 93-6 through 93-8 in figure 2) and five piezometers installed.

The embankment was drilled dry using 4 1/2" I.D. hollow stem augers with 7 1/2" O.D. flights. Drive samples were recovered at least every 5 feet using a 2" split spoon. Where encountered (DH 93-6 & 93-8) the alluvium was drilled and cased using NX size, rotary wash rock bits and casing. Bedrock was drilled using an NX diamond bit and wireline core barrel. Percolation tests were conducted every 5 feet in unconsolidated foundation material (alluvium) while packer tests were run at 10 foot intervals in the consolidated foundation (Twin Creek Limestone).

Based on the drill hole logs (see Appendix A), select samples were sent to Dames & Moore for laboratory testing (Gradation & Atterberg Limits). The results are found in Appendix B and summarized in Table 1. To allow a down hole shear wave analysis of the embankment, one of the piezometers in DH 93-6 was specially constructed using 2" PVC and bentonite as backfill. Shear wave velocities ranged from 677 ft/sec to 1282 ft/sec with an average of 1108ft/sec, see Appendix C for details.

<u>Geology of the Foundation</u>

The local geology is well documented by Prof. Ray Marsell, who acted as a consultant for the Division of Water Resources. His preconstruction report of 1968 indicates that the abutments are in thin bedded carbonaceous rocks of the Jurassic Twin Creek Limestone. The Twin Creek Limestone, which elsewhere in the region is steeply dipping to overturned, is mostly horizontal to gently dipping at the damsite. In outcrop (particularly in the left abutment) numerous joint sets have broken the rock into small sliver shapes resembling pencils.

As part of the initial subsurface investigation ten holes (numbered 1A-10A) were drilled at the site, see Figure 2 for drill hole locations and Figure 5 for drill hole logs. During drilling it was observed that the joints in bedrock at both the left abutment and maximum section diminished with depth indicating a probable origin connected in part to weathering. The joints in the right abutment, however, continued with depth which indicates deeper weathering and/or a structural influence in their origin.

The current round of drilling confirmed the findings of the investigation drilling concerning the existence of a narrow, 50 foot deep, sediment-filled inner canyon (see Figure 6). The sediment that fills this deep, narrow inner canyon consists of mixtures of silty, clayey sand and

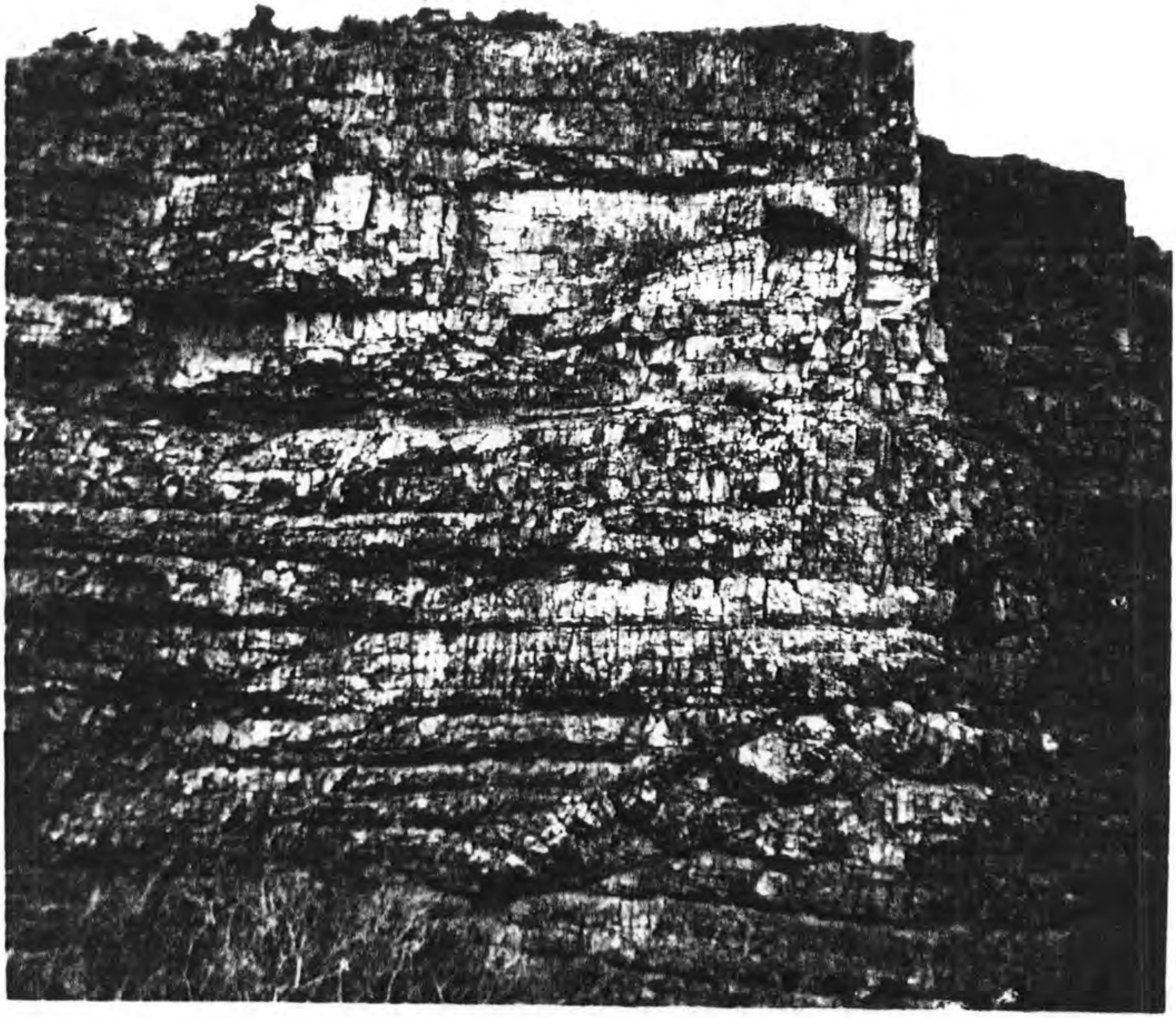


Figure 4 Exposure of Twin Creek limestone in cliff face downstream of left abutment. Note: horizontal bedding, at least two sets of closely spaced vertical joints, voids, and several low angle joints which are dipping upstream. Sagebrush top of cliff or top of trees lower left photo for scale. (Photo Credit: Ray Marsell, 1968)

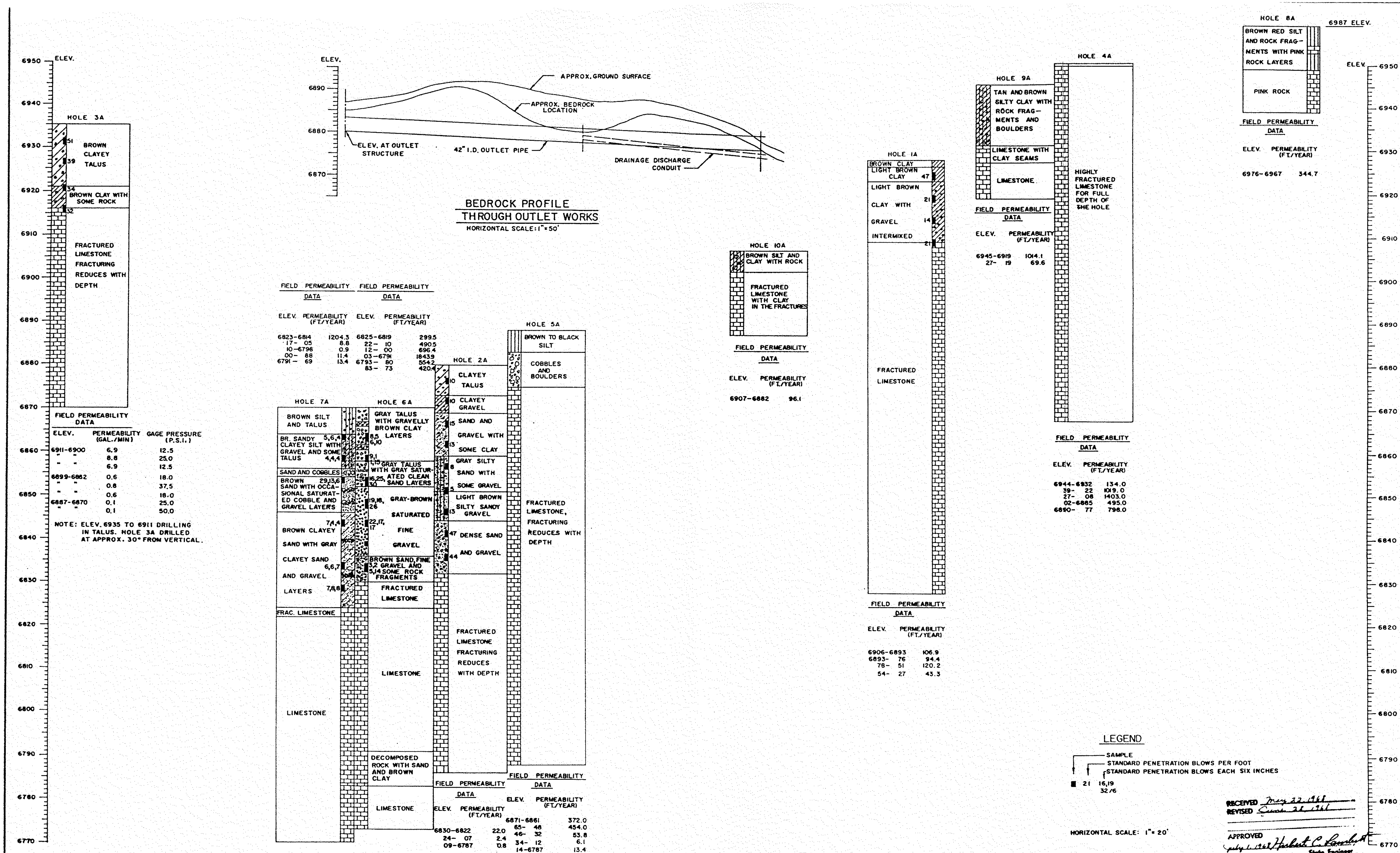
SUMMARY OF LABORATORY TEST DATA - WOODRUFF CREEK DAM

HOLE	DEPTH (feet)	DESCRIPTION	ATTERBERG LIMITS %*			SIEVE ANALYSIS %			UNIFIED SOIL CLASSIFICATION
			LL	PL	PI	SLT/CL	SAND	GRAVEL	
93-6	15-16.5	Embankment				27.9	32.7	39.4	GM
	35-36.5	Embankment-Chimney Drain				5.4	45.3	49.3	GP
93-7	15-16.5	Embankment				33.0	28.5	38.5	GC
	45-46.5	Embankment				21.9	29.2	48.9	GC
	65-66.5	Embankment				22.4	22.0	55.6	GC
	90-91.5	Embankment				12.0	36.2	51.8	GP
93-8	19-20.5	Alluvial Foundation				12.1	37.4	50.5	GP
	44-45.5	Alluvial Foundation				5.6	26.4	68.0	GW

* Atterbergs performed according to ASTM 4318; on minus #40 fraction.

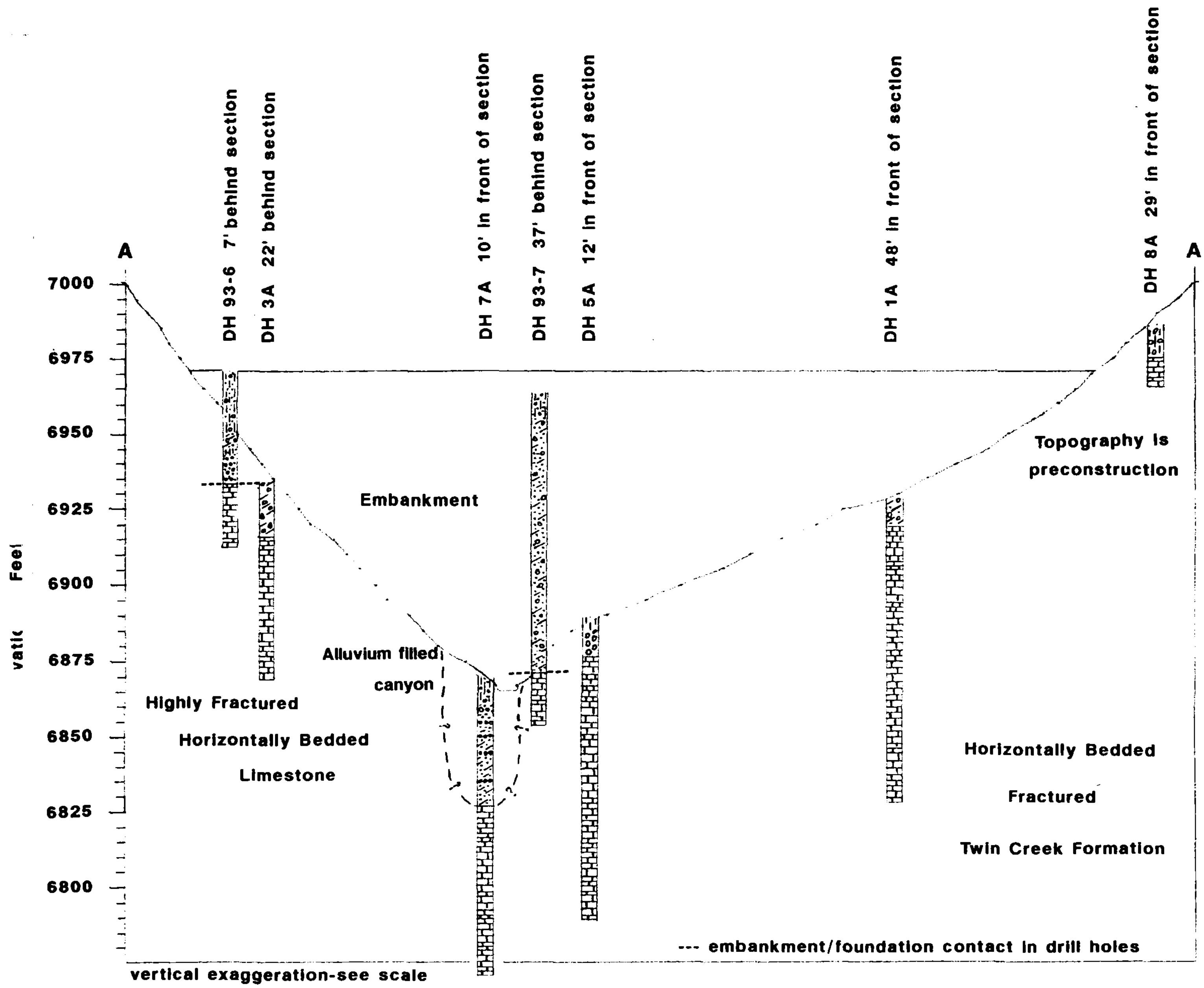
DIVISION OF WATER RESOURCES

Table 1



NO.	REVISION	BY	DATE	DESIGNED RLR CHECKED · DRAWN DFW DATE · APPROVED · LICENSE NO.	ROLLINS, BROWN AND GUNNELL CONSULTING ENGINEERS 295 WEST 100 NORTH, PROVO, UTAH	WOODRUFF IRRIGATING COMPANY WOODRUFF, UTAH	LOG OF BORINGS AND PERMEABILITY DATA FOR WOODRUFF DAM	SHEET 3

Figure 5



WOODRUFF CREEK DAM

CROSS-SECTION A-A'

LOOKING DOWNSTREAM

Scale

Vertical 1"=50'

Horizontal 1"=100'

Figure 6

Cross-Section On Crest Of Dam See Figure 2

gravel, see Figure 5 for logs of DH's 2A, 6A, & 7A. K values (hydraulic conductivity) for the alluvium range from less than 1 foot per year (DH 7A) to 18,439 feet per year (DH 6A). In DH 93-8 K values ranged from 34 feet per year to 6,151 feet per year. Thus the aquifer characteristics of the alluvium would be described as heterogeneous and anisotropic. Information in Tables 1 & 2 help to characterize the alluvial foundation materials as sampled in DH 93-8.

Embankment Characterization

Based on the 1993 drilling and laboratory test results the embankment materials classify as very dense (based on an average of 60 blows/foot) gravel with an average of 23.5% fines and 29.7% sand (see Tables 1 & 3).

Seismotectonic Setting

Woodruff Creek dam is located in north-central Utah and very near the northeastern margin of the Basin and Range province. Here the intermountain seismic belt is composed of north-trending normal faults which have formed in response to east-west Neogene extension superimposed on the Cretaceous-early Tertiary compressional fold and thrust belt (McCalpin, 1992). The Uniform Building Code of 1988 assigns this area to seismic zone 3. Algermissen and others (1982) assign an acceleration of 0.40g with a 90% probability of not being exceeded in 250 years.

Historic Earthquakes

Table 4 lists all earthquakes which have occurred within a 15 mile radius of the dam. The largest earthquake to occur, at a radius of 14.5 miles, was a magnitude 2.8 in September of 1986.

Table 5 lists all earthquakes greater than magnitude 4 that have occurred within a radius of 75 miles. The largest earthquake to occur in this region, was the 1884 quake near Bear Lake, see Figure 7. Table 5 indicates this quake was estimated to have a magnitude of 6.3 and occur at a distance of 36-37 miles from the damsite. A second quake estimated at magnitude 6.3 occurred in 1909 at a distance of 72-73 miles from the damsite.

On February 3, 1994 a series of earthquakes, including a shock of moment magnitude (M_w) 5.8-5.9 occurred in a mountainous area near the Idaho-Wyoming border (Arabasz et al. 1994), approximately 79 miles north of the Woodruff Creek dam. Although beyond the 75 mile radius it is interesting to note that its correlation with known normal faults is uncertain (Arabasz & others, 1994). The nearest major Quaternary normal fault to this activity, is the Star Valley fault which lies about 11 miles east of the mainshock epicenter.

Potential Seismic Sources

The following is a description of the known (mapped) faults in the vicinity of Woodruff Creek Dam, taken from Hecker, 1993. See Figure 7 for the location of these faults in relation to the dam.

Crawford Mountain Fault - This fault lies on the west side of the Crawford Mountains. Goter (1990) maps this fault as Pleistocene to late Quaternary. Hecker, 1993 indicates that the age of most recent movement (involving surface rupture) is about 70,000 years ago. A swarm of earthquakes in 1884 (pre-instrumental) with estimated magnitude 2.0 were attributed to this fault (Cook & Smith, 1967).

Saleratus Creek Fault (?) - Identified by Hecker (1993, #11-06), it is the closest fault to Woodruff Creek dam, its northern end lying 9 miles east

<u>Table 2</u>

Alluvial Foundation Characterization

Drill Hole 93-8 (Located On Downstream Toe)

Sample Depth	Blows Per Foot	Density	Perm. Ft./Yr.	Laboratory Classification % Fines	% Sand	% Gravel
5-6.5′	57	V. Dense				
10-11.5′	27	Md. Dense	235			
14-15.5′	38	Dense	235			
19-20.5′	45	Dense	1340	12.1	37.4	50.5
34-35.5′	40	Dense	3164			
39-40.5′	22	Md. Dense	3164			
44-45.5′	44	Dense	6151	5.6	26.4	68.0
49-50.5′	35	Dense	34			

Table 3

Embankment Materials Characterization

Drill Holes	Sample Depth	Blows Per Foot	Density	Laboratory Classification % Fines	% Sand	% Gravel
93-6	5-6.5′	43	Dense			
	10-11.5′	42	Dense			
	15-16.5′	44	Dense	27.9	32.7	39.4
	20-21.5′	28	Md. Dense			
	25-26.5′	103	V. Dense			
	Chimney Drain					
	30-31.5′	29	Md. Dense			
	35-36.5′	22	Md. Dense	5.4	45.3	49.3
93-7	5-6.5′	42	Dense			
	10-11.5′	24	Md. Dense			
	15-16.5′	59	V. Dense	33.0	28.5	38.5
	20-21.5′	35	Dense			
	25-26.5′	92	V. Dense			
	30-31.5′	41	Dense			
	35-36.5′	133	V. Dense			
	40-41.5′	123	V. Dense			
	45-46.5′	56	V. Dense	21.9	29.2	48.9
	50-51.5′	48	Dense			
	55-56.5′	66	V. Dense			
	60-61.5′	61	V. Dense			
	65-66.5′	53	V. Dense	22.4	22.0	55.6
	70-71.5′	67	V. Dense			
	75-76.5′	64	V. Dense			
	80-81.5′	58	V. Dense			
	85-86.5′	41	Dense			
	90-91.5′	118	V. Dense	12.0	36.2	51.8

Table 4

All Earthquakes Within a Radius of 15.00 Miles
About Center 473,500 East and 4,590,500 North
Indexed by Magnitude

Report From UofU Earthquake Database

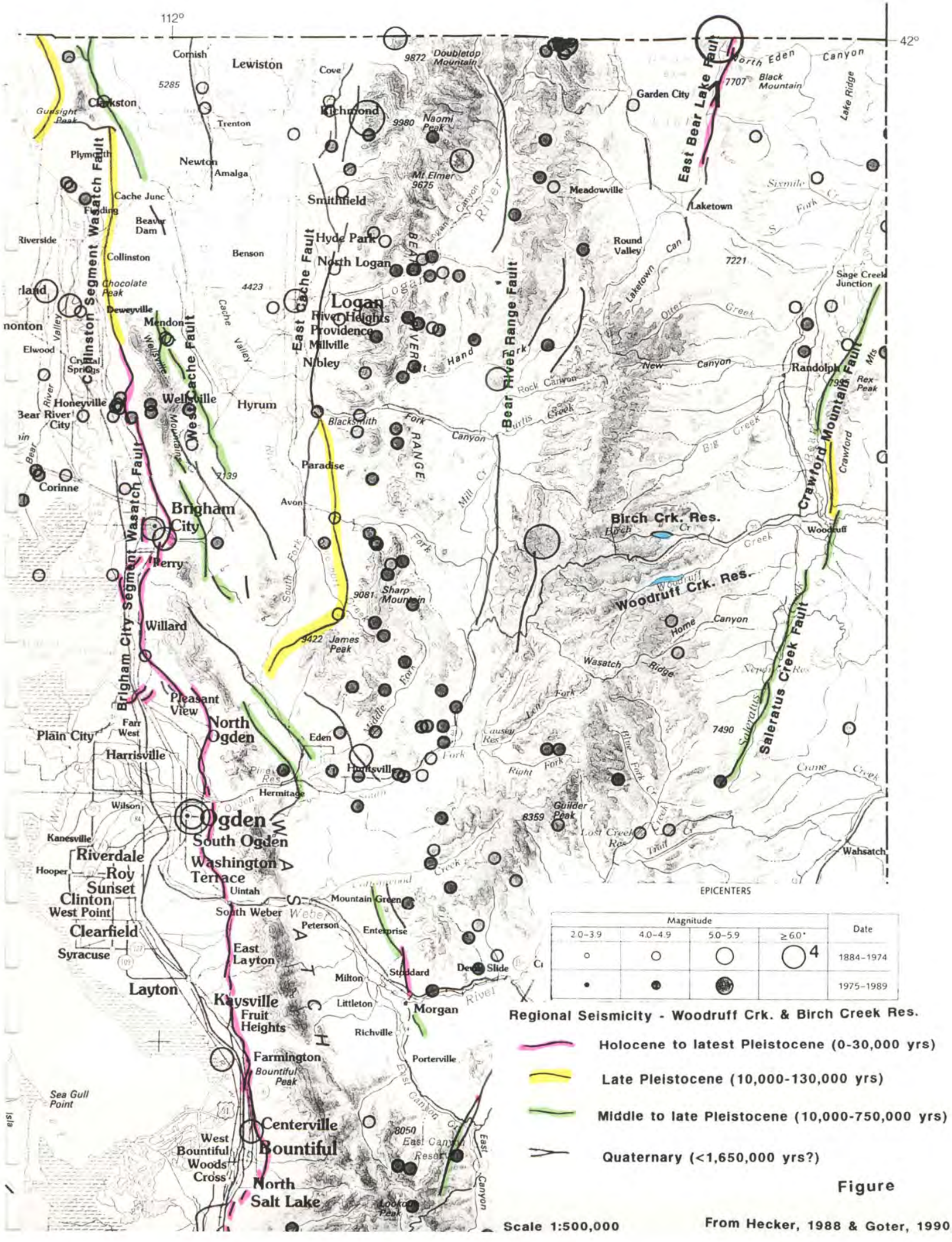
Year	Date MoDa	East Coord UTMs	North Coord UTMs	Latitude Deg. Min.	Longitude Deg. Min.	Magn	Radius Miles
1986	914	460256.58	4571290.92	41 17.64	111 28.48	2.80	14.50
1976	227	477997.05	4567866.65	41 15.83	111 15.76	2.70	14.34
1967	501	472756.71	4585165.90	41 25.17	111 19.56	2.40	3.35
1986	108	466743.40	4567724.35	41 15.73	111 23.82	2.10	14.76
1990	710	471181.82	4581415.90	41 23.14	111 20.68	2.00	5.83
1990	1013	468307.34	4570973.83	41 17.49	111 22.71	1.90	12.55
1971	406	461627.30	4598150.26	41 32.16	111 27.60	1.90	8.78
1984	1223	486975.71	4607367.01	41 37.19	111 9.38	1.82	13.41
1971	822	454625.00	4583462.03	41 24.20	111 32.57	1.80	12.52
1987	206	489578.21	4572910.47	41 18.57	111 7.47	1.75	14.81
1985	1127	464617.02	4581185.94	41 23.00	111 25.39	1.67	8.00
1983	807	468013.44	4580282.01	41 22.52	111 22.95	1.60	7.21
1976	313	467238.69	4603026.01	41 34.81	111 23.58	1.60	8.70
1975	1228	459589.67	4594294.13	41 30.07	111 29.05	1.60	8.96
1987	1119	461848.72	4608437.18	41 37.72	111 27.48	1.52	13.29
1984	923	464841.32	4604314.08	41 35.50	111 25.31	1.38	10.13
1982	409	468494.77	4572360.71	41 18.24	111 22.58	1.36	11.69
1980	403	454239.53	4579782.28	41 22.21	111 32.83	1.30	13.70
1987	1129	460646.75	4609516.90	41 38.30	111 28.35	1.25	14.26
1982	118	472287.12	4597083.71	41 31.61	111 19.93	1.23	4.16
1971	822	461369.01	4596652.84	41 31.35	111 27.78	1.20	8.45
1986	914	458406.72	4572374.44	41 18.22	111 29.81	1.03	14.66
1982	821	486476.99	4607978.55	41 37.52	111 9.74	1.00	13.53
1982	821	483976.02	4607151.03	41 37.07	111 11.54	0.97	12.22
1980	1216	472663.61	4608332.38	41 37.69	111 19.69	0.90	11.09
1978	816	462687.41	4596127.80	41 31.07	111 26.83	0.90	7.57
1983	226	460857.14	4571380.18	41 17.69	111 28.05	0.90	14.24
1979	1120	479420.03	4596911.79	41 31.53	111 14.80	0.80	5.42
1980	1021	476103.09	4573571.38	41 18.91	111 17.13	0.80	10.64
1978	829	460926.50	4579077.04	41 21.85	111 28.03	0.80	10.56
1978	1130	485617.73	4573805.34	41 19.05	111 10.31	0.70	12.82
1979	1218	484861.25	4585630.03	41 25.44	111 10.87	0.70	7.68
1978	713	466383.77	4613318.06	41 40.37	111 24.23	0.70	14.85
1978	1005	454189.96	4582965.17	41 23.93	111 32.88	0.70	12.88
1978	1115	481977.00	4596257.34	41 31.18	111 12.96	0.60	6.37
1978	1115	472078.55	4597084.51	41 31.61	111 20.08	0.60	4.19
1976	114	462683.40	4606082.81	41 36.45	111 26.87	0.60	11.79
1979	124	484032.73	4588851.30	41 27.18	111 11.47	0.20	6.62
1978	1216	482366.29	4579085.73	41 21.90	111 12.65	0.20	8.98
1978	1222	466558.97	4582231.39	41 23.57	111 24.00	0.10	6.71

Table 5

All Earthquakes > 4.00 Magnitude and Radius 75.00 Miles
About Center 473,500 East and 4,590,500 North
Indexed by Radius

Report From UofU Earthquake Database

Year	Date MoDa	East Coord UTMs	North Coord UTMs	Latitude Deg. Min.	Longitude Deg. Min.	Magn	Radius Miles
1966	317	453333.80	4612077.28	41 39.66	111 33.63	4.60	18.35
1964	1018	439324.05	4619380.52	41 43.55	111 43.77	4.10	27.80
1923	607	430908.30	4620770.69	41 44.26	111 49.85	4.30	32.47
1950	102	416534.43	4594534.13	41 30.00	112 0.00	4.30	35.49
1920	918	415226.14	4595678.24	41 30.61	112 0.95	4.30	36.35
1920	919	415226.14	4595678.24	41 30.61	112 0.95	4.30	36.35
1920	1120	415226.14	4595678.24	41 30.61	112 0.95	4.30	36.35
1884	1110	477914.68	4649597.07	42 0.00	111 16.00	6.30	36.82
1988	1119	460892.60	4649207.88	41 59.75	111 28.33	4.80	37.31
1906	524	419603.86	4563873.38	41 13.45	111 57.55	4.30	37.35
1894	718	419603.86	4563873.38	41 13.45	111 57.55	5.00	37.35
1914	513	419603.86	4563873.38	41 13.45	111 57.55	5.70	37.35
1988	1119	460499.39	4650486.92	42 0.44	111 28.62	4.30	38.14
1962	830	438664.23	4653751.24	42 2.12	111 44.46	5.70	44.87
1914	408	422884.97	4537099.63	40 59.00	111 55.00	4.30	45.72
1946	506	406018.24	4620202.93	41 43.80	112 7.80	4.30	45.81
1909	1117	403378.26	4621829.73	41 44.66	112 9.72	4.30	47.72
1915	730	403378.26	4621829.73	41 44.66	112 9.72	4.30	47.72
1955	512	426116.33	4529332.05	40 54.82	111 52.64	4.30	48.08
1942	418	391494.29	4594867.20	41 30.00	112 18.00	4.30	51.03
1938	630	428311.24	4511029.62	40 44.94	111 50.95	4.30	56.81
1949	307	428311.24	4511029.62	40 44.94	111 50.95	5.00	56.81
1910	522	428311.24	4511029.62	40 44.94	111 50.95	5.70	56.81
1989	705	385904.95	4617904.02	41 42.40	112 22.28	4.60	57.03
1955	202	421246.13	4514912.95	40 47.00	111 56.00	4.30	57.10
1989	703	385738.25	4617888.17	41 42.39	112 22.40	4.80	57.13
1989	621	385740.32	4618017.70	41 42.46	112 22.40	4.10	57.15
1960	820	475271.06	4682915.33	42 18.00	111 18.00	4.30	57.43
1959	104	467028.06	4682949.22	42 18.00	111 24.00	4.30	57.59
1880	712	398092.94	4647666.69	41 58.58	112 13.80	4.30	58.80
1983	1008	416195.19	4511045.73	40 44.88	111 59.56	4.30	60.87
1934	414	374800.66	4595137.54	41 30.00	112 30.00	5.60	61.40
1960	807	458850.34	4694096.25	42 24.00	111 30.00	5.00	65.01
1962	905	408031.31	4507515.82	40 42.92	112 5.33	5.20	65.68
1943	410	408756.50	4505804.53	40 42.00	112 4.80	4.30	66.24
1943	222	408756.50	4505804.53	40 42.00	112 4.80	5.00	66.24
1972	1001	470472.07	4483768.05	40 30.36	111 20.91	4.30	66.35
1913	412	417569.82	4683355.91	42 18.00	112 0.00	4.30	67.36
1953	524	457631.86	4483163.80	40 30.00	111 30.00	4.30	67.42
1906	1019	467132.61	4705156.30	42 30.00	111 24.00	4.30	71.35
1924	1125	458915.74	4705199.90	42 30.00	111 30.00	4.30	71.85
1960	810	458915.74	4705199.90	42 30.00	111 30.00	4.30	71.85
1909	1006	361461.49	4624999.20	41 46.00	112 40.00	6.30	72.84
1975	329	374329.67	4654378.52	42 2.00	112 31.09	4.70	73.30
1975	328	373849.99	4657663.55	42 3.77	112 31.48	6.00	74.67
1978	1130	376682.63	4661889.67	42 6.08	112 29.48	4.60	74.75



Regional Seismicity - Woodruff Crk. & Birch Creek Res.

Figure

From Hecker, 1988 & Goter, 1990

of the dam. It appears to be the extension of the Crawford Thrust fault, with possible extensional back-sliding. Its sparce geomorphic expression suggests a classification of low to extremely low activity (slemons, 1977, see Fig. 8), with a slip rate less than 0.01 cm/yr and a recurrence interval greater than 100,000 yr. For puposes of this assessment, it can be considered inactive.

Eastern Bear Lake Fault - The southern end of this fault (near Laketown) is 26 miles north of the dam. Recently completed studies which included trenching, indicate that the most recent movement on the fault was approximately 2,100 years ago. Based on the amount of surface rupture, determined from trenching, and the rupture length this fault is thought capable of producing a 7.1 magnitude event.

Bear River Range Faults - Physiographic evidence suggests that late Quaternary displacements have occurred on these faults. These faults are located about 20 miles west of the dam.

East Cache Fault - The southern segment of this fault zone is located about 20 miles from the dam. A maximum earthquake magnitude of 7.2 has been calculated based on fault length. Hecker, 1993 has indicated that the age of most recent movement is between 6,000-9,000 years ago. She has calculated a slip rate of between 0.16 - 0.28 mm/yr.

Brigham City Segment - This segment of the Wasatch fault lies due west of the dam, at a distance of 33 miles. Based on fault length a maximum earthquake magnitude of 7.1 can be calculated. Trenching studies from near the center of the segment, at Brigham City, suggests that this segment is overdue for a surface faulting earthquake (Hecker, 1993).

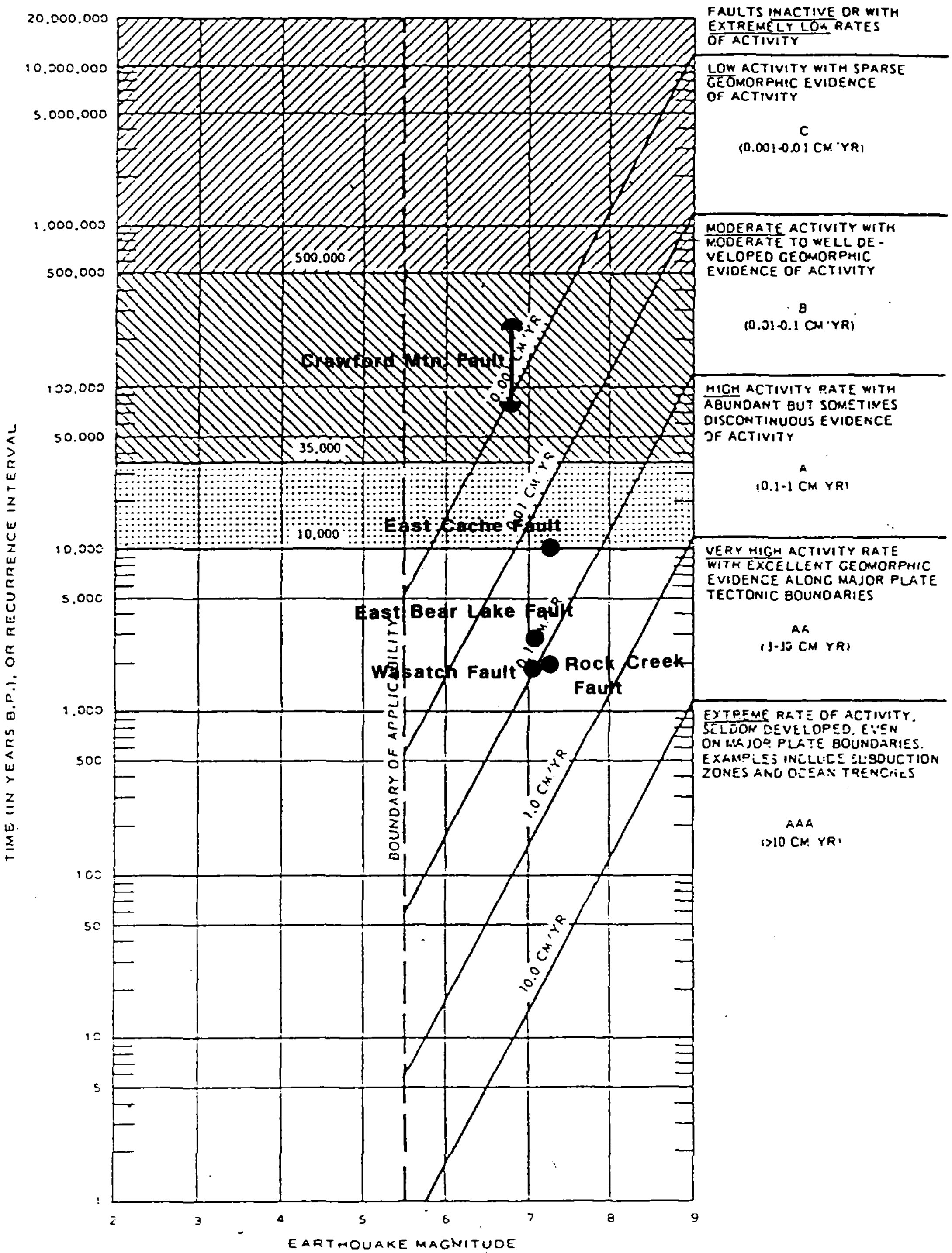
Weber Segment - This segment of the Wasatch fault lies 35 miles to the south and west of the dam. A maximum earthquake magnitude of 7.2 has been calculated based on rupture length. This segment is the longest segment in the Wasatch fault zone and indications are that individual faulting events may not have ruptured the entire segment.

Wyoming Faults - Based on a map of seismic source zones in Wyoming (Case and others, 1990) the nearest fault known or suspected to have been active in the Quaternary is 51 miles east-northeast of Woodruff Creek dam. This fault called the Rock Creek fault, which is in Lincoln Co., Wyoming is 21 miles long. Based on this length and offset (determined from trenching studies) it is assumed capable of producing a quake of magnitude 7.2 (McCalpin, 1992). A quake of this magnitude at a distance of 51 miles would produce ground shaking at the dam having a peak horizontal acceleration of approximately 0.10 g.

Two other faults, the Star Valley and Grey's River faults fall outside the 75 mile radius but are included on Table 6 because of the recent seismicity (Feb.-Apr., 1994) in the area. Details on these faults can be found in McCalpin, 1992.

Deterministic Earthquakes

The primary sources and their pertinent information are listed in Table 6. Mean peak site accelerations have been calculated for each source using both the curves of Seed and Idriss (1983, Figure 17), and Equation 5 of Campbell (1987, p. L-46). The two methods agree well for nearby sources, but diverge somewhat for distant sources. Campbell's relation was developed specifically for northern Utah. Both methods are based on California



Relation between time or recurrence interval (in years), strain rates across fault zones (in cm/yr), and earthquake magnitude.

From: Slemmons, 1977, Fig. 2

Figure 8

TABLE 6
Design Earthquakes

Source	Length (mi)	Offset <35,000 (yrs)	Offset Mult. Offset[1]	Quaternary Slip rate mm/yr	Activity Class.[2]	MCE	Dist. (mi)	Peak Site Acc'n(g) S&I[3]	Peak Site Acc'n(g) Campbell[4]	Duration (sec)[5]
Crawford Mountain	16	N	Y	?	low	6.8	11	0.33	0.25	5
Saleratus Creek	18	N	N	?	inactive	6.8	8.5	0.38	0.34	4
East Bear Lake	20	Y	Y	0.8	moderate	7.1	27	0.18	0.15	7
Bear River Range	13	N	?	?	?	6.7	13	0.29	0.18	4
East Cache	34	Y	Y	0.28	moderate	7.2	27	0.19	0.15	8
Wasatch Fault										
Brigham City Seg.	40	Y	Y	0.8-1.3	high	7.1	34	0.18		8
Weber Segment	61	Y	Y	1.0-3.0	high	7.2	33	0.18		8
Faults in Wyoming										
Rock Creek	21	Y	Y	1.27	high	7.2	51	0.10		9
Star Valley	21	Y	Y	0.63	moderate	7.2	83	0.04		11
Grey's River	35	Y	Y	1.75	high	7.3	91	0.05		12

1 Multiple offsets in the last 500,000 years (NRC active fault criterion).
2 From Figure 8.
3 Bedrock accelerations from Seed & Idriss, 1983, Figure 17. Shortest hor. dist. to source.
4 Accelerations from Campbell, 1987, equation 5, using K_1=0 (normal faulting), K_2=0 (no source directivity), K_3=1 (upper bound for site effects. consolidated rock), e_3=0.41, and gamma=0.0059. Source distance taken as distance from site to nearest point on surface trace of fault.
5 Krinitzsky, 1989, Figure 23.

earthquakes, and assume California-like attenuations. The largest estimated acceleration is 0.38g, from the Saleratus Creek Fault (Table 6). This fault is classified as inactive by the State Engineers criterion of no offset within 35,000 years, but does belong to the family of north-south trending normal faults, many of which have been active during that time. The largest acceleration from a fault known to have been active in late Pleistocene or Holocene time is 0.19g, from both the East Cache Fault and the East Bear Lake Fault.

The results of the deterministic estimate of the largest expected ground motion is considerably lower than the probabilistic estimate of Algermissen and others (1982), who give a value of 0.40g as the acceleration with a 90% probability on non-exceedence (in other words, a 10% probability of exceedence) in 250 years. The method of Algermissen and others divides the country into source areas on the basis of geology, and distributes earthquakes randomly within each source area. It is meant to be applied at a small scale. It may overestimate accelerations for sites like Woodruff or Birch Creek Dams which lie between, and some distance from , geologically identifiable earthquake sources. Therefore we recommend using the deterministic MCE and its associated acceleration as input to the stability and settlement analyses. It is well to keep in mind, however, that there is no reason to expect that all potential earthquake sources have been identified. why ?

MCE

A conservative approach to the maximum credible earthquake would use the Crawford Mountain Fault as a source. The average of the 2 methods yields a site acceleration of 0.29g, which would be appropriate for new construction. Under the current State Engineer's definition of active fault, the East Cache earthquake is controlling, and produces a site acceleration of 0.19g. This earthquake has an estimated recurrence of 10,000 years (Figure 7), or a probabality of 1 in 10,000 of occurring in any given year.

OBE

The operating basis earthquake (OBE) for this site is taken from Algermissen and others, 1982. This event would have an acceleration of 0.17g at the dam and a 90 percent probability of not being exceeded in 50 years, which is roughly equivalent to a return period of 475 years (Youngs and others, 1987).

Seismic Stability

The fill was compacted during construction by modern earth-moving equipment. Based on the 1993 drilling, blow counts in the dam averaged 60 blows per foot which translates on a scale of relative density to a very dense classification.

Based on the California comparative method Woodruff Creek dam falls into Zone 7 (Babbitt et. al., 1983, p.106) as shown in Table 7. Cases that fall into this zone will normally not present any problems.

Table 7

Density Class	Acceleration Low 0-0.2	Acceleration Medium 0.21-0.39	Acceleration High >0.40
Loose	1	2	4
Med. Dense	7	3	5
Dense	7	7	6
Very Dense	7	7	7

Geologic Hazards

Table 8 is a summary of those geologic hazards having the potential to impact the dam.

Earthquake Hazards

Ground Shaking - Due to the dam's location relative to active faults capable of producing moderate to large earthquakes, it is reasonable to expect that ground shaking could affect the site. If the MCE associated with the East Cache Fault were to occur, structural damage caused by the resulting ground shaking could result.

Liquefaction - The current round of drilling (DH's 93-6 thru 93-8) has confirmed that the much of the dam's footprint rests directly upon bedrock. However, the alluvium which does exist under the dam is granular in nature (sand & gravel) and is located in areas of least confining (overburden) pressure (upstream & downstream toes). The lowest blow counts per foot in the alluvium encountered in DH 93-8 is 22 at a depth of 40 feet (Table 2). Liquefaction failure of the dam does not seem likely because of the narrowness of the filled canyon, the small volume of alluvium remaining beneath the dam, and the high gravel content (Table 1).

Slope Failure - Depending on the degree of ground shaking experienced at the dam it is not unreasonable to assume that some rockfall might result. This is especially true near the left abutment and at various places around the reservoir basin where fractured to highly fractured bedrock (Twin Creek Limestone) is exposed in steep slopes (Figure 4).

Slope Failure Hazard (Non-Seismic)

Of the three categories under this heading only rockfall is considered a possible hazard.

Rockfall - High angle slopes together with moderate to intense fracturing of the bedrock (Twin Creek Limestone) combine to create a possible hazard for this category. Due to the close joint spacing very large, intact blocks are not expected to be produced, but areas composed of smaller joint blocks could become destabilized and thus jeopardize the integrity of the dam or reservoir.

Hazards Related to Foundation/Embankment Problems

The nine categories under this heading are all rated as unlikely hazards. The subsurface investigation to date, including laboratory testing of selected samples has not identified soils or bedrock, either in the embankment or the foundation which would present these hazards.

Hydrologic Hazards

Shallow ground-water and Springs/Seeps - The fractured nature of the bedrock foundation ensures that the regional water table will be graded to the stream and/or the reservoir. The mitigative measures discussed below appear to be controlling reservoir induced seepage.

TABLE # 8

SUMMARY OF GEOLOGIC HAZARDS

Woodruff Creek Dam & Reservoir

	Hazard Rating* Probable Hazard	Possible Hazard	Unlikely Hazard	Further Study Recommended**
Earthquake				
Ground shaking	E			G-SIP
Liquefaction		DST & UST		
Surface faulting			X	
Tectonic deformation			X	
Slope failure		A & RB		
Seiche			X	
Slope Failure (Non-seis)				
Rock fall		A & RB		
Landslide			X	
Debris flow			X	
Found/Embank Problems				
Collapsible soils			X	
Expansive clays			NA	
Sensitive clays			X	
Organic soils			NA	
Soluble salts			NA	
Pipable/Erodible			BF	
Karst			BF	
Differential settlement			X	
Non-engineered fill			X	
Hydrologic				
Shallow ground-water			X	
Springs/Seeps			X	
Flooding				
Stream/Lake		X		H-SIP
Upstream dam failure			NA	
Spillway capacity		X		H-SIP
Dam overtopping			X	

*Hazard Rating - Probable-evidence is strong that the hazard exists and mitigation measures should be taken. Possible-hazard may exist, but evidence is uncertain and further study is recommended. Unlikely-no evidence was found to indicate that the hazard is present.

Abbreviations; E = embankment, F = foundation, AF = alluvial foundation, BF = bedrock foundation, A = abutments, RB = reservoir basin, SL = shore line, DST = down stream toe, UST = up stream toe, DSF = down stream face, USF = up stream face, SP = spillway, & NA = Not applicable.

**Further Study (S-soil/foundation, G-geotecnical/engineering, H-hydrologic, SIP-study in progress, MIP-mitigation measures in progress) is recommended to address the hazard (see Conclusions and Recommendations).

Flooding - Two of the four categories related to flooding appear to be possible hazards:

Stream flooding, and Spillway capacity - Based on the size of the drainage basin above the reservoir and the capacity of the spillway it is possible that a flood could present a hazard to the dam. (These hazards will be dealt with in greater detail in the Hydrologic Report).

Conclusions & Recommendations

Repair--Under current conditions the structure is performing well and there is no need for immediate repair. The dam was designed to the state-of-the-art at the time, and appears with our present knowledge, to be functioning adequately. There is no immediate concern for safety.

Foundation Conditions--The dam is built on a foundation of moderately to highly fractured limestone. This condition was mitigated by construction of an abutment to abutment grout curtain with grout cap, filter wells in the right abutment, and French drains in the left abutment. Existing piezometers (installed as the dam was raised) have not been consistently monitored. However, the absence of seepage over the years is a good indication that the mitigative measures must be working.

Stability analysis--An assessment of the static and seismic stability of the dam should wait until we have information on material properties (see Appendix B) and pore pressures in the embankment and foundation. This includes reading piezometers through at least one filling and spilling cycle.

References Cited

Algermissen, S.T., Perkins, D.M., Thenhous, P.C., Hanson, S.L., & Bender, B.L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey, Open-File Report 82-1033, 99p.

Arabasz, W.J., Pechmann, S.J., Nava, S.J., and Smith, R.B., 1994, The Magnitude (M_w) 5.8-5.9 Earthquake in SE Idaho of February 3, 1994, and Associated Shocks: Preliminary Earthquake Report, Univ. of Utah Seismograph Stations, 5p.

Babbitt, D.H., Bennett, W.J., and Hart, R.D., 1983, California's seismic reevaluation of embankment dams. In Howard, T.R., 1983, Seismic design of embankments and caverns, ASCE Geotechnical Engineering Division symposium proceedings, p. 96-112.

Case, J.C., Larsen, L.L., Boyd, C.S., & Cannia, J.C., 1990, Earthquake epicenters and suspected active faults with surficial expression in Wyoming, Geological Survey of Wyoming, Map, 1:1,000,000

Cook, K.L., & Smith, R.B., 1967, Seismicity in Utah, 1850 through June 1965, Bulletin of the Seismological Society of America, vol. 57, no. 4, p. 687-718.

Goter, Susan, K., 1990, Earthquakes in Utah, 1884-1989, U.S. Geological Survey, National Earthquake Data Center, 1:500,000.

Hecker, Suzanne, M., 1993, Quaternary Tectonics of Utah with Emphasis on Earthquake-Hazard Characterization, Utah Geological Survey, Bulletin 127, 157p.

Hintze, Lehi, F., 1980, Geologic Map of Utah, Utah Geological and Mineral Survey, 1:500,000.

______1988, Geologic History of Utah: Brigham Young University Geology Studies, Special Publication 7, 202p.

Krinitzsky, E.L., 1989, Empirical earthquake ground motions for an engineering site with fault sources: Tooele Army Depot, Utah. Bulletin of the Association of Engineering Geologists, vol. XXVI, no. 3, p. 283-308.

Marsell, Ray, 1964, Geologic Reconnaissance of Proposed Woodruff Creek Dam Site: Division of Water Resources, 3p.

______1968, Geology of the Upper Woodruff Creek Dam Site: Division of Water Resources, 10p.

McCalpin, J.P., 1993, Neotectonics of the northeastern Basin and Range margin, Western USA: Z.Geomorph.N.E., Suppl.-Bd. 94, pg. 137-157.

Slemmons, David, B., 1977, Faults and Earthquake Magnitude, Report 6 in State-of-the-art for assessing earthquake hazards in the United States, U.S. Army Corps of Engineers Waterways Experiment Station Misc. Paper S-73-1.

U.S.Army Corps of Engineers, 1979, Phase I Inspection Report National Dam Inspection Program - Woodruff Creek Reservoir Dam Rich Co., Utah: Utah Division of Water Rights, 39p.

Youngs, R.R., Swan, F.H,. Power, M.S., Schwartz, D.P., and Green, R.K.,Probabilistic Analysis of Earthquake Ground Shaking Hazard along the Wasatch Front, Utah: in Gori, P.L., and Hays, W.W., eds., 1987, Assessment of Regional Earthquake Hazards and Risks Along the Wasatch Front, Utah, Volume II: U.S. Geological Survey, Open-File Report 87-585.

APPENDIX A

<u>DRILL HOLE LOGS</u>

<u>FOR HOLES 93-6 THRU 93-8</u>

LOG OF TEST BORING

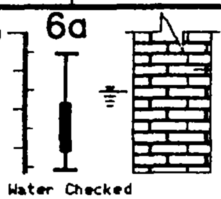
PROJECT: WOODRUFF CREEK DAM – PHASE II DATE: 9/20/93
BORING NO.: 93-6 ELEV.: 6971
BORING LOCATION: Left Abut.-DS edge of crest
DRILL METHOD: Auger to 37'; DC to 58.3'
CONTRACTOR: RB&G Engineering LOGGED BY: DAN
DEPTH TO WATER: 54.1' (9/29/93) DATE CHECKED:

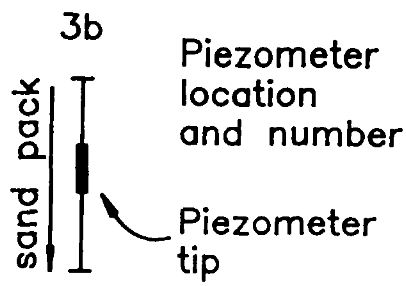
ELEV / DEPTH	SOIL SYMBOLS SAMPLER SYMBOLS AND FIELD TEST DATA	USCS	Description	Rec	Rock Qual	K ft/yr
6980						
6970 / 0		SP-SM	Silty SAND w/gravel, cobbles, & boulders to 2'			
	16/6 15/6 28/6		Poorly Graded SAND w/Silt & Gravel, lt brn, dense, dry to damp. Sand fine Gravel to 1"; subround to angular.	7"		
6960 / 10	13/6 24/6 18/6		Poorly Graded SAND w/Silt & Gravel; med brn, dense, dry-damp. Sand fine; Gravel to 3/4"; subround to angular	9"		
	18/6 22/6 22/6		..med red-brn, poorly graded, dense, damp. Occasional cobbles	14"		
6950 / 20	15/6 16/6 12/6	SC	Clayey SAND w/Gravel; med yel-brn to red brn, poorly graded, damp, med dense. Gravel to 1/2".	10"		
FILL	18/6 51/6 52/6	SP-SM	Poorly Graded SAND w/Silt & Gravel; med brn, very dense, damp. Sand fine; Gravel to 3/4", subangular-angular.	9"		
CH DRN / 6940 / 30	13/6 16/6 13/6	SP	Poorly Graded SAND w/Gravel; lt – med brn, med dense, damp. Sand med-coarse Gravel fine to 2"; subround to round	6"		
CH DRN	6/6 7/6 15/6			7"		
ROCK			Twin Creek Formation LIMESTONE; med gry, horiz-high angle fractures, FeOx on high angle fractures	2.2/2.5	0.3	
6930 / 40				1.0/1.3	0	
				2.0/2.3	0.2	
			..many small angular pieces	2.0/2.0	0.5	
				1.0/1.1	0	
				0.75/0.9	0	
				0.8/1.0	0	
				1.7/1.7	0.5	
6920 / 50			..vertical fractures filled with brown mud	1.0/1.0	0.7	24

Boring continues

LOG OF TEST BORING

PROJECT:WOODRUFF CREEK DAM - PHASE II DATE:9/20/93
BORING NO.: 93-6 ELEV.:6971
BORING LOCATION:Left Abut.-DS edge of crest
DRILL METHOD:Auger to 37'; DC to 58.3'
CONTRACTOR:RB&G Engineering LOGGED BY:DAN
DEPTH TO WATER:54.1' (9/29/93) DATE CHECKED:

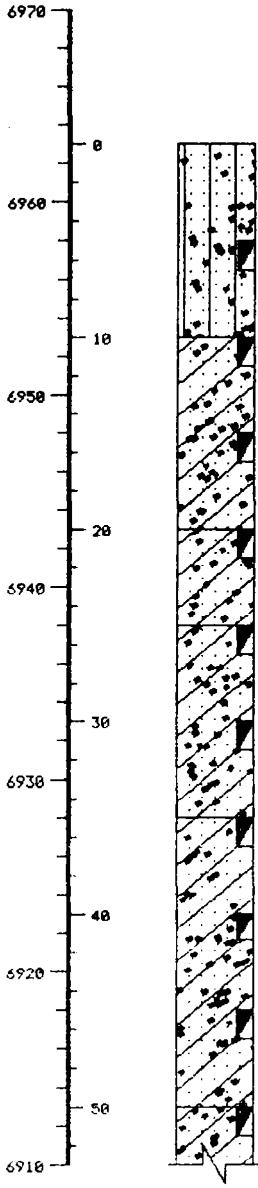
ELEV / DEPTH	SOIL SYMBOLS SAMPLER SYMBOLS AND FIELD TEST DATA	USCS	Description	Rec	Rock Qual	K ft/yr
6920				2.3/2.3	0.95	
				4.8/5.0	0.94	



Page Number 2

LOG OF TEST BORING

PROJECT: WOODRUFF CREEK DAM - PHASE II
DATE: 9/8-17/93
BORING NO.: 93-7
ELEV.: 6963 approx.
BORING LOCATION: Max Sect @ 20' DS of crest
DRILL METHOD: Auger to 90'; DC to 108.8'
CONTRACTOR: RB&G Engineering
LOGGED BY: TOM/DAN
DEPTH TO WATER: 82' (9/29/93)
DATE CHECKED:



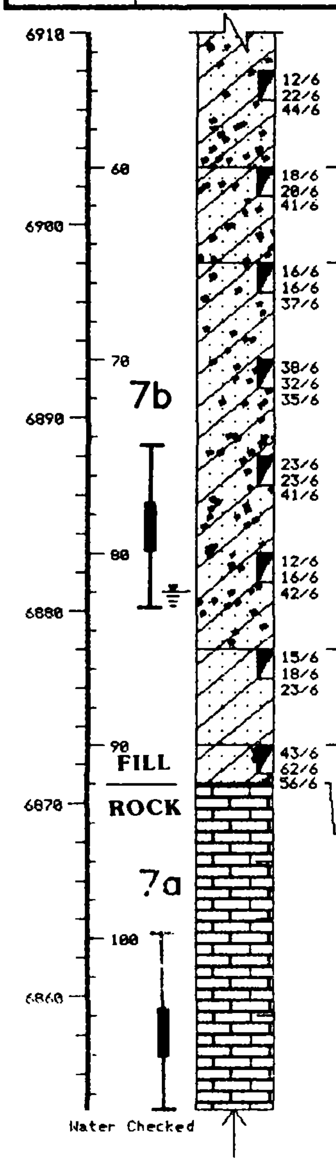
ELEV / DEPTH	SOIL SYMBOLS SAMPLER SYMBOLS AND FIELD TEST DATA	USCS	Description	Rec	Rock Qual	K ft/yr
0		SP-SM	Poorly Graded SAND w/Silt & Gravel; lt brn, lots of cobbles in top 3 feet			
	15/6 20/6 22/6		.lt-med red-brn, poorly graded, ~~dense~~ dry-damp. Sand fine; Gravel to 1", subang-round. Slightly calcareous.	16"		
10	6/6 10/6 14/6	SC	Clayey SAND w/Gravel; med brn, poorly graded, med dense, dry-damp. Occ. cobbles	17"		
	14/6 24/6 35/6		..med yel & red-brn, very dense, Gravel to 1 1/2", ang to rounded	13"		
20	25/6 17/6 18/6	SP-SC	Poorly Graded SAND w/Clay & Gravel; yellowish & reddish brn, dense, dry. Occasional cobbles.	14"		
	70/6 32/6 60/6	SC	Clayey SAND w/Gravel; red-brn, poorly graded, very dense, damp. Sand fine.	13"		
30	8/6 21/6 20/6		..yel-brn to brn, dense. Gravel to 2" subang to subround. Occasnl cobbles	16"		
	17/6 35/6 90/6	SP-SC	Poorly Graded SAND w/Clay & Gravel; yellowish brn-brn, very dense, dry-damp. Sand fine; Gravel to 2 1/2"	17"		
40	20/6 43/6 80/3.5		..yellowish & reddish brn, damp to moist, gravel to 1 1/2"	18"		
	24/6 23/6 33/6		..yellowish brn to brn. Gravel to 1"	18"		
50	15/6 16/6 32/6	GC	Clayey GRAVEL w/Sand; med brn, poorly graded, dense, damp to moist.	17"		

Boring continues

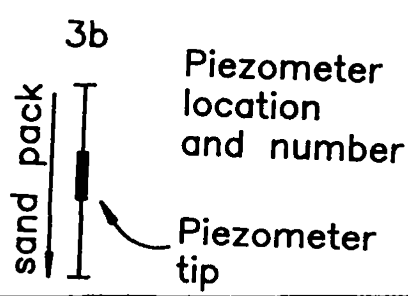
Utah State - Division of Water Resources

LOG OF TEST BORING

PROJECT:WOODRUFF CREEK DAM - PHASE II — DATE:9/8-17/93
BORING NO.: 93-7 — ELEV.:6963 approx.
BORING LOCATION:Max Sect @ 20' DS of crest
DRILL METHOD:Auger to 90'; DC to 108.8'
CONTRACTOR:RB&G Engineering — LOGGED BY:TOM/DAN
DEPTH TO WATER:82' (9/29/93) — DATE CHECKED:

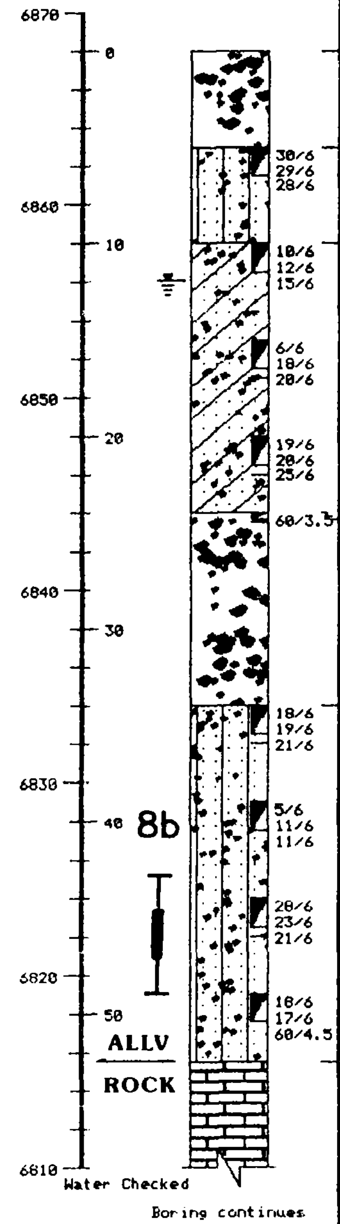


Field Test Data	USCS	Description	Rec	Rock Qual	K ft/yr
12/6 22/6 44/6		..gravel to 1 3/4"; very dense, sub-angular to subround	18"		
18/6 20/6 41/6	SP-SC	Poorly Graded SAND w/Clay & Gravel; yel-brn/brn, very dense, damp. Sand fine; grav to 2 1/2", subang-subround	12"		
16/6 16/6 37/6	SC	Clayey SAND w/Gravel; red-brn, very dense, damp. Purplish gravel to 2".	17"		
30/6 32/6 35/6		..fine sand, gravel to 2"	9"		
23/6 23/6 41/6		..very moist	4"		
12/6 16/6 42/6			15"		
15/6 18/6 23/6		..brn, dense, damp, no gravel	4"		
43/6 62/6 56/6	SP-SC	Poorly Graded SAND w/Clay & Gravel; grayish brn, very dense, very moist. Turns into gry angular sandy gravel	18" 0.9/2.3	 0	
		Twin Creek Formation LIMESTONE; gry, angular fragments	0.8/1.2 2.8/2.8	0 0.53	
		..horiz, vert, & diag joints; clay in joints	4.7/5.0	0.7	7
			5.0/5.0	0.9	



LOG OF TEST BORING

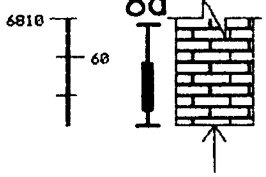
PROJECT: WOODRUFF CREEK DAM – PHASE II — DATE: 9/22-23/93
BORING NO.: 93-8 — ELEV.: 6868
BORING LOCATION: Max Section – Downstream Toe
DRILL METHOD: Auger to 10'; TC to 52.5'; DC to 63.6'
CONTRACTOR: RB&G Engineering — LOGGED BY: DAN
DEPTH TO WATER: 11.9' (9/29/93) — DATE CHECKED:

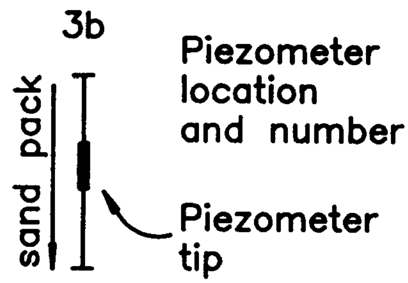


USCS	Description	Rec	Rock Qual	K ft/yr
	GRAVEL & COBBLES			
GM	Silty GRAVEL w/Sand; lt gry & brn, poorly graded, very dense, dry. Sand fine, gravel to 1 1/2" subrnd-ang	9"		
GC	Clayey GRAVEL w/Sand; med-dk brn-gry, poorly graded, med dense, saturated Gravel is mostly lms, subang-ang	7"		
	..poorly graded, dense, saturated. Gravel mostly angular to 1 1/2"	7"		235
	Clayey GRAVEL w/Sand; med gry, poorly graded, dense, saturated. Gravel to 1", subangular to angular	8"		1340
	GRAVEL & COBBLES	3" 0.66/4.0	0	
		0/5	0	
GW	Well Graded GRAVEL w/Sand & trace of Silt; med brn, dense, saturated. Sand fine-coarse; Gravel to 1", subangular	9"		3164
GW	to rounded	6"		
GW-GM	..w/Silt & Sand, gravel to 2 1/2"	11"		6151
	..med gry-brn, dense to very dense	8"		34
	LIMESTONE of the Twin Creek Formation med gry, horizontal joints	1/1.1 4.5/5	0.6 0.5	
	..lt-med gry & brn-gry			

LOG OF TEST BORING

PROJECT: WOODRUFF CREEK DAM - PHASE II — DATE: 9/22-23/93
BORING NO.: 93-8 — ELEV.: 6868
BORING LOCATION: Max Section - Downstream Toe
DRILL METHOD: Auger to 10'; TC to 52.5'; DC to 63.6'
CONTRACTOR: RB&G Engineering — LOGGED BY: DAN
DEPTH TO WATER: 11.9' (9/29/93) — DATE CHECKED:

ELEV / DEPTH	SOIL SYMBOLS SAMPLER SYMBOLS AND FIELD TEST DATA	USCS	Description	Rec	Rock Qual	K ft/yr
6810 / 60	 8a		..hi angle & vertical jnts coated w/ yel-brn & red clay and filled w/wht calcite	5.0/5.0	0.7	6190



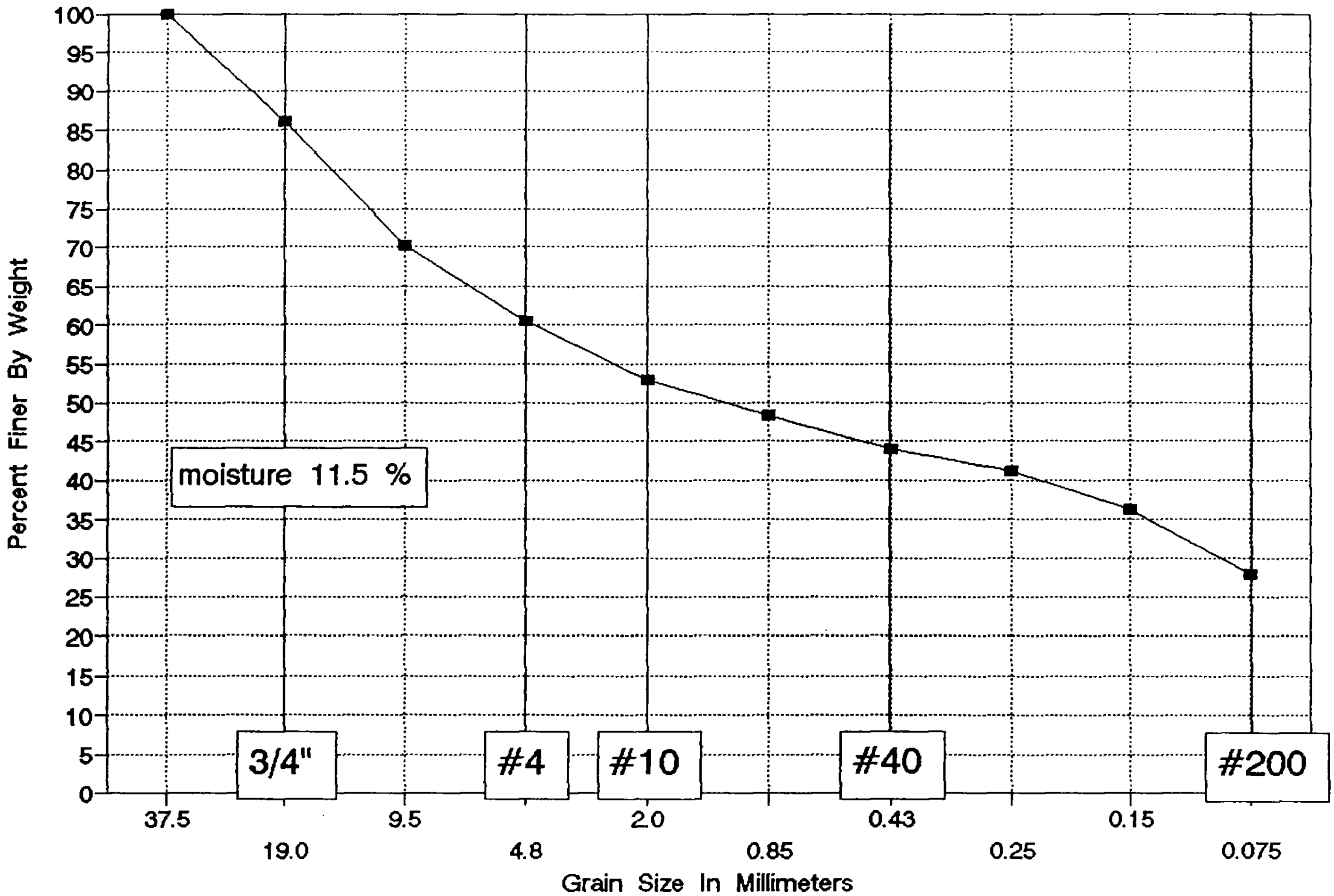
APPENDIX B

LABORATORY TEST RESULTS

DRILL HOLE SAMPLES

GRADATION CURVE

Boring DH-6, sample at 15 to 16.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-6	Wet soil & dish	702.4
Sample	bag	Dry soil & dish	649.4
Depth	15-16.5 feet	Dish	190.2

Moisture Content = 11.5

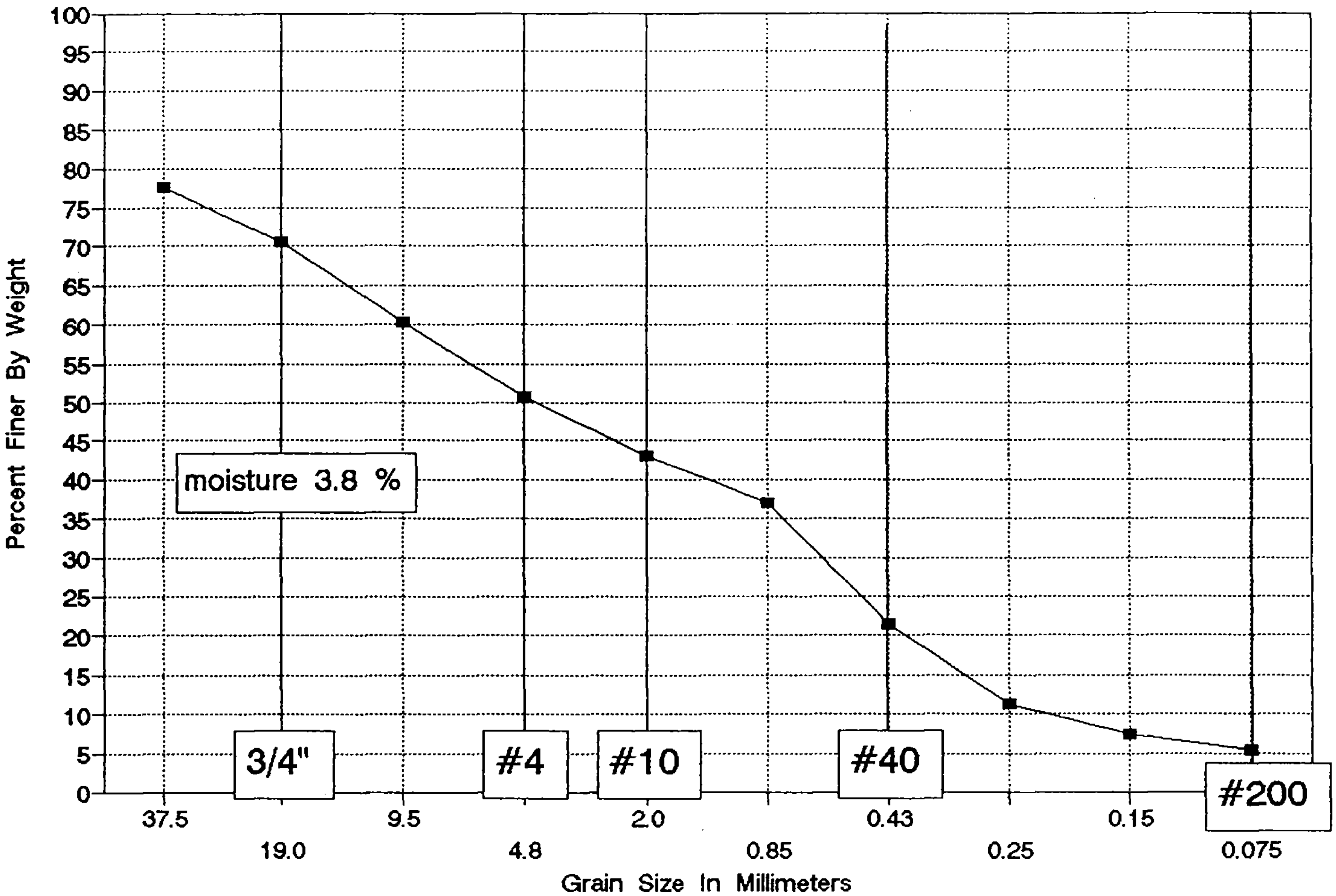
SIEVE ANALYSIS

Dry weight of total sample= 459.2

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	0	100.00%	100.0	37.5
3/4 inch	63.4	86.19%	86.2	19.0
3/8 inch	136.8	70.21%	70.2	9.5
# 4	180.9	60.61%	60.6	4.8
# 10	216.6	52.83%	52.8	2.0
# 20	237.2	48.34%	48.3	0.85
# 40	257.4	43.95%	43.9	0.43
# 60	269.9	41.22%	41.2	0.25
# 100	292.9	36.22%	36.2	0.15
# 200	330.9	27.94%	27.9	0.075

GRADATION CURVE

Boring DH-6, sample at 35 to 36.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-6	Wet soil & dish	1087
Sample	bag	Dry soil & dish	1054.8
Depth	35-36.5 feet	Dish	214.1

Moisture Content = 3.8

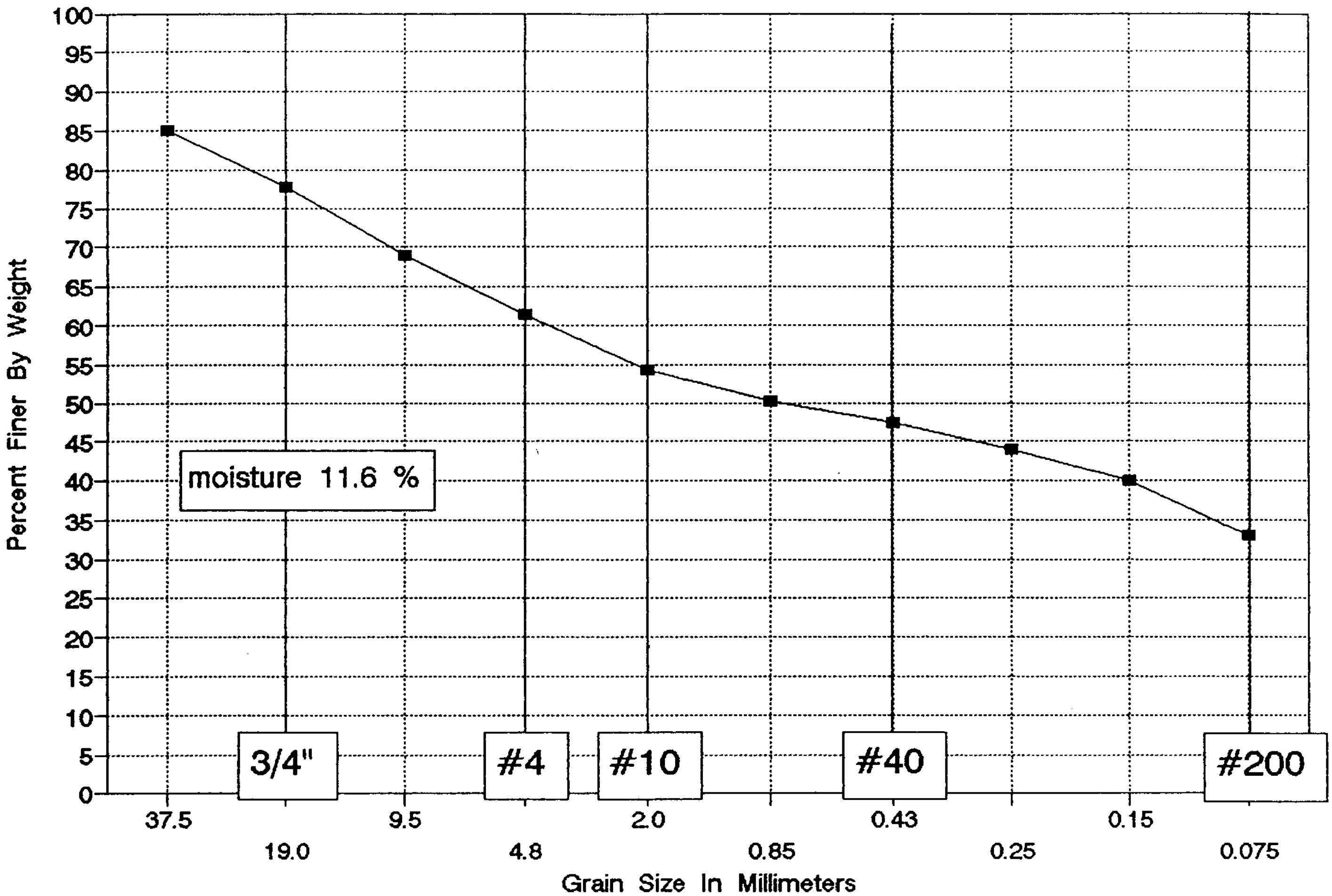
SIEVE ANALYSIS

Dry weight of total sample= 840.7

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	188.5	77.58%	77.6	37.5
3/4 inch	247.1	70.61%	70.6	19.0
3/8 inch	333.9	60.28%	60.3	9.5
# 4	414.7	50.67%	50.7	4.8
# 10	479.7	42.94%	42.9	2.0
# 20	529.9	36.97%	37.0	0.85
# 40	658.9	21.62%	21.6	0.43
# 60	745.3	11.35%	11.3	0.25
# 100	778	7.46%	7.5	0.15
# 200	795.3	5.40%	5.4	0.075

GRADATION CURVE

Boring DH-7, sample at 15 to 16.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-7	Wet soil & dish	859.4
Sample	bag	Dry soil & dish	792.4
Depth	15-16.5 feet	Dish	216.3

Moisture Content = 11.6

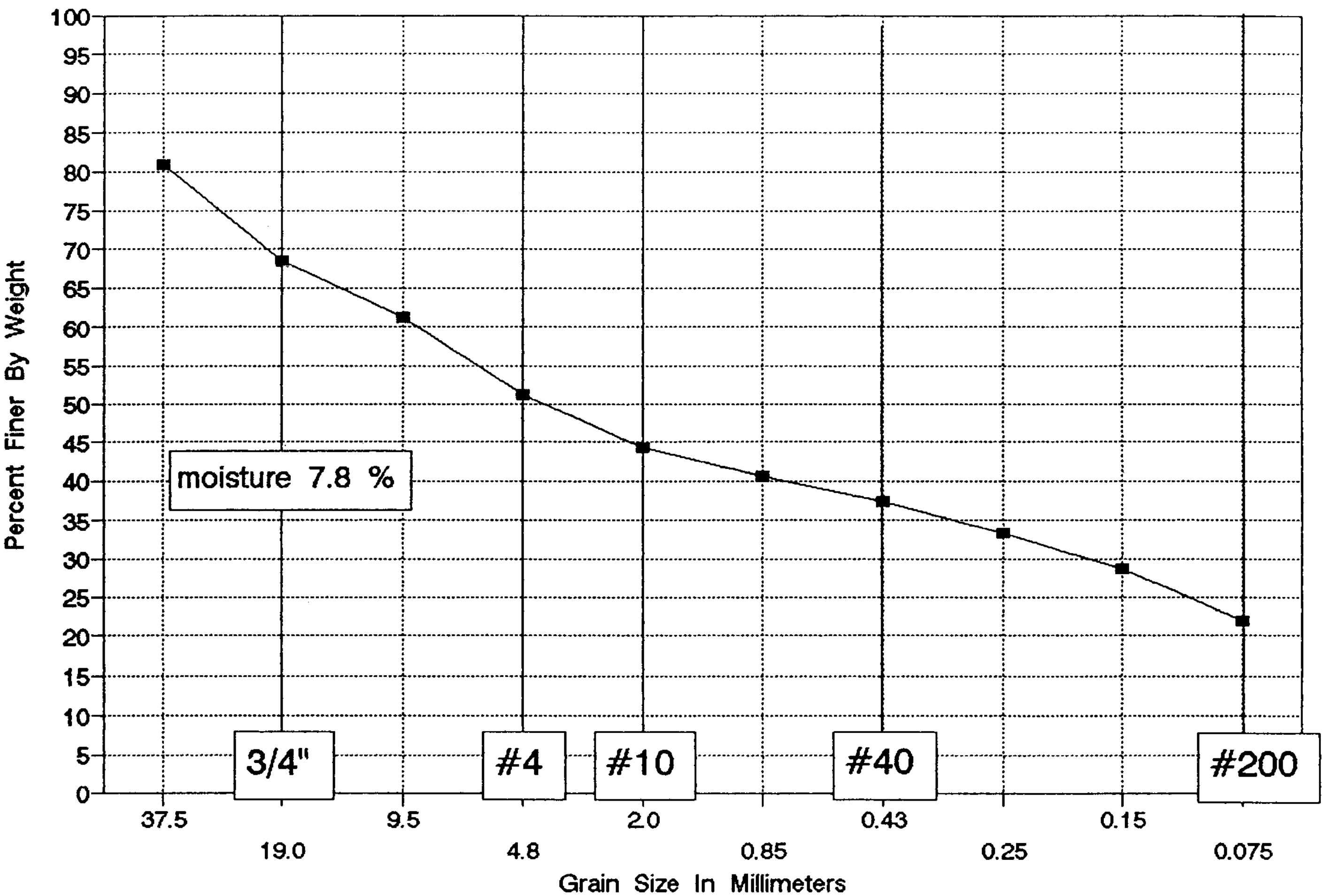
SIEVE ANALYSIS

Dry weight of total sample= 576.1

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	86.7	84.95%	85.0	37.5
3/4 inch	128.7	77.66%	77.7	19.0
3/8 inch	179.2	68.89%	68.9	9.5
# 4	221.9	61.48%	61.5	4.8
# 10	263.9	54.19%	54.2	2.0
# 20	286.9	50.20%	50.2	0.85
# 40	303	47.40%	47.4	0.43
# 60	322.9	43.95%	44.0	0.25
# 100	345.7	39.99%	40.0	0.15
# 200	386.1	32.98%	33.0	0.075

GRADATION CURVE

Boring DH-7, sample at 45 to 46.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-7	Wet soil & dish	980.4
Sample	bag	Dry soil & dish	925
Depth	45-46.5 feet	Dish	215.4

Moisture Content = 7.8

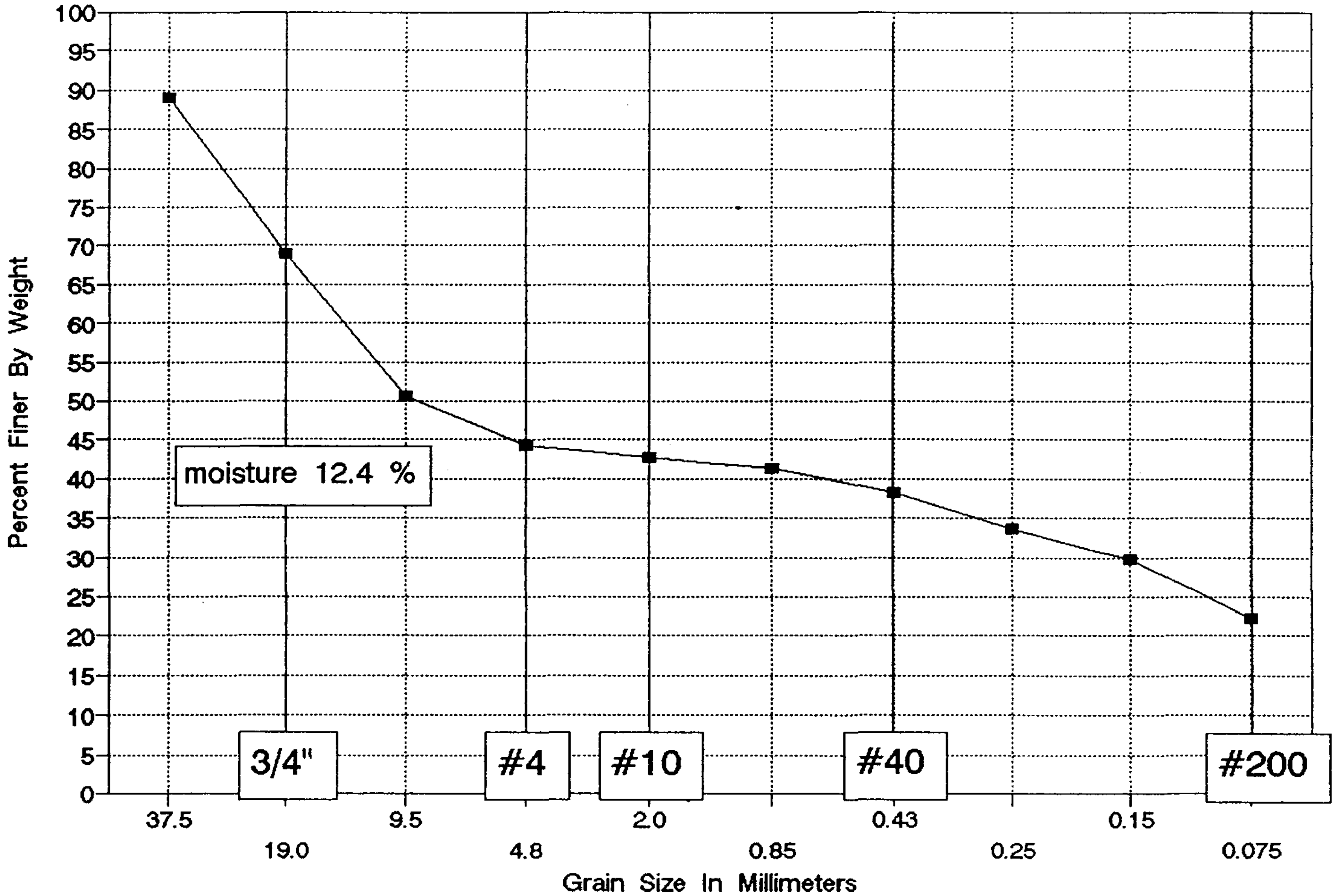
SIEVE ANALYSIS

Dry weight of total sample= 709.6

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	135.1	80.96%	81.0	37.5
3/4 inch	222.8	68.60%	68.6	19.0
3/8 inch	275.2	61.22%	61.2	9.5
# 4	346.8	51.13%	51.1	4.8
# 10	395.2	44.31%	44.3	2.0
# 20	422.3	40.49%	40.5	0.85
# 40	443.7	37.47%	37.5	0.43
# 60	473.3	33.30%	33.3	0.25
# 100	506.7	28.59%	28.6	0.15
# 200	553.9	21.94%	21.9	0.075

GRADATION CURVE

Boring DH-7, sample at 65 to 66.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-7	Wet soil & dish	1076.2
Sample	bag	Dry soil & dish	982.2
Depth	65-66.5 feet	Dish	222.5

Moisture Content = 12.4

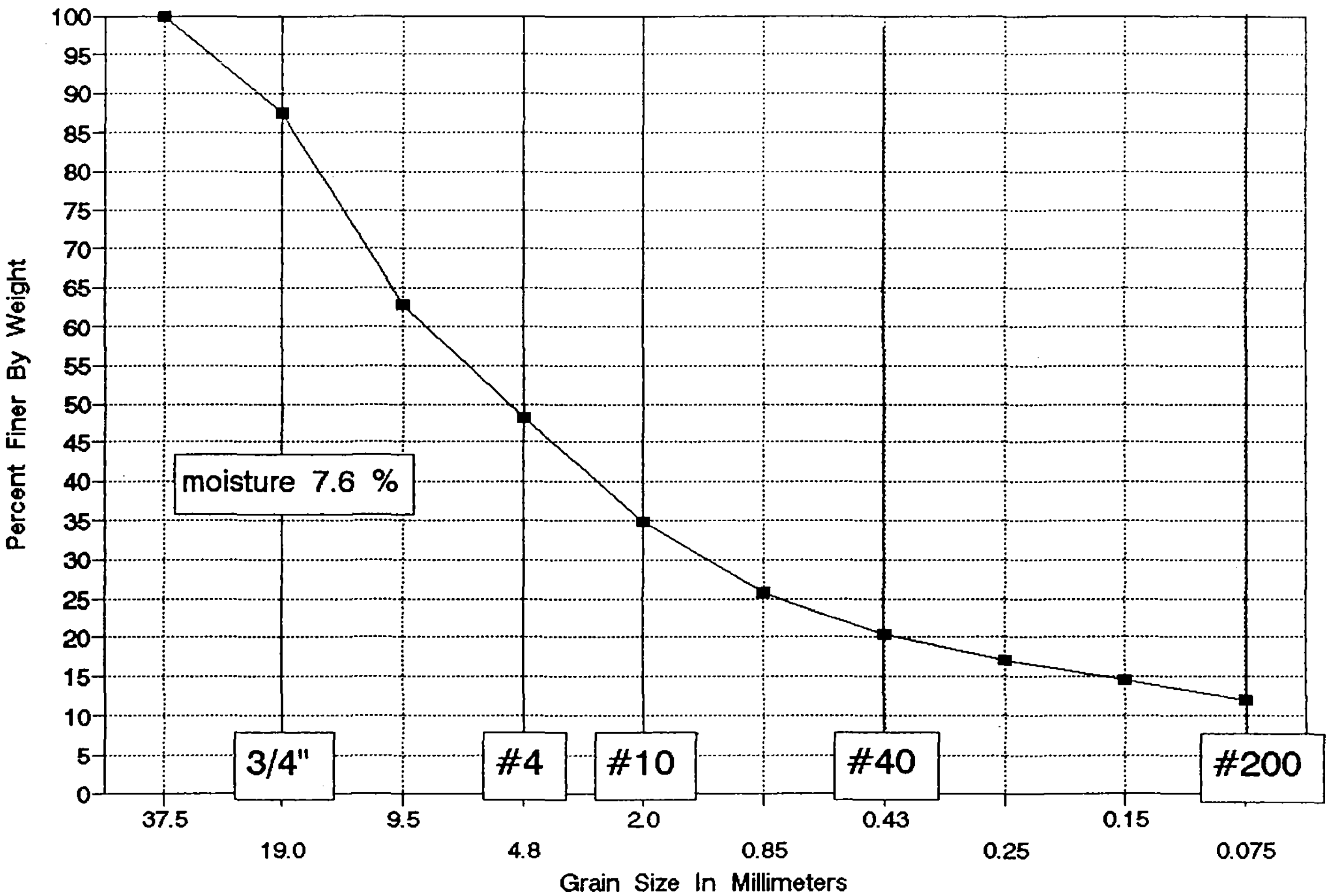
SIEVE ANALYSIS

Dry weight of total sample= 759.7

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	82.7	89.11%	89.1	37.5
3/4 inch	235.7	68.97%	69.0	19.0
3/8 inch	376.2	50.48%	50.5	9.5
# 4	422.5	44.39%	44.4	4.8
# 10	434	42.87%	42.9	2.0
# 20	445.5	41.36%	41.4	0.85
# 40	468.5	38.33%	38.3	0.43
# 60	503.8	33.68%	33.7	0.25
# 100	534.2	29.68%	29.7	0.15
# 200	589.8	22.36%	22.4	0.075

GRADATION CURVE

Boring DH-7, sample at 90 to 90.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-7	Wet soil & dish	975.1
Sample	bag	Dry soil & dish	921.6
Depth	90-90.5 feet	Dish	219.6

Moisture Content = 7.6

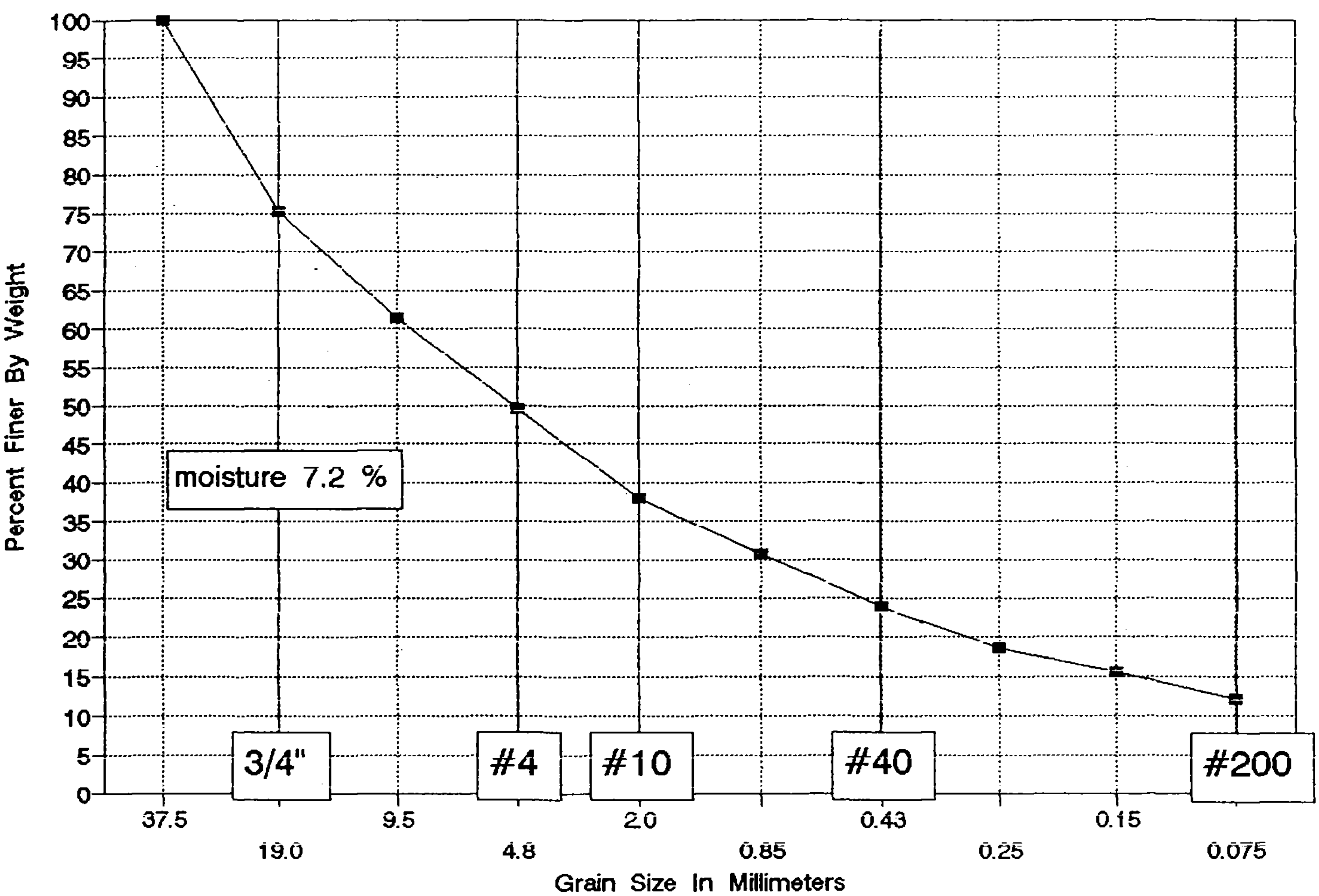
SIEVE ANALYSIS

Dry weight of total sample= 702

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	0	100.00%	100.0	37.5
3/4 inch	89	87.32%	87.3	19.0
3/8 inch	261.5	62.75%	62.7	9.5
# 4	363.4	48.23%	48.2	4.8
# 10	457.1	34.89%	34.9	2.0
# 20	522.3	25.60%	25.6	0.85
# 40	558.1	20.50%	20.5	0.43
# 60	582.3	17.05%	17.1	0.25
# 100	599.9	14.54%	14.5	0.15
# 200	617.6	12.02%	12.0	0.075

GRADATION CURVE

Boring DH-8, sample at 19 to 20.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-8	Wet soil & dish	1151.7
Sample	bag	Dry soil & dish	1088.8
Depth	19-20.5 feet	Dish	210.6

Moisture Content = 7.2

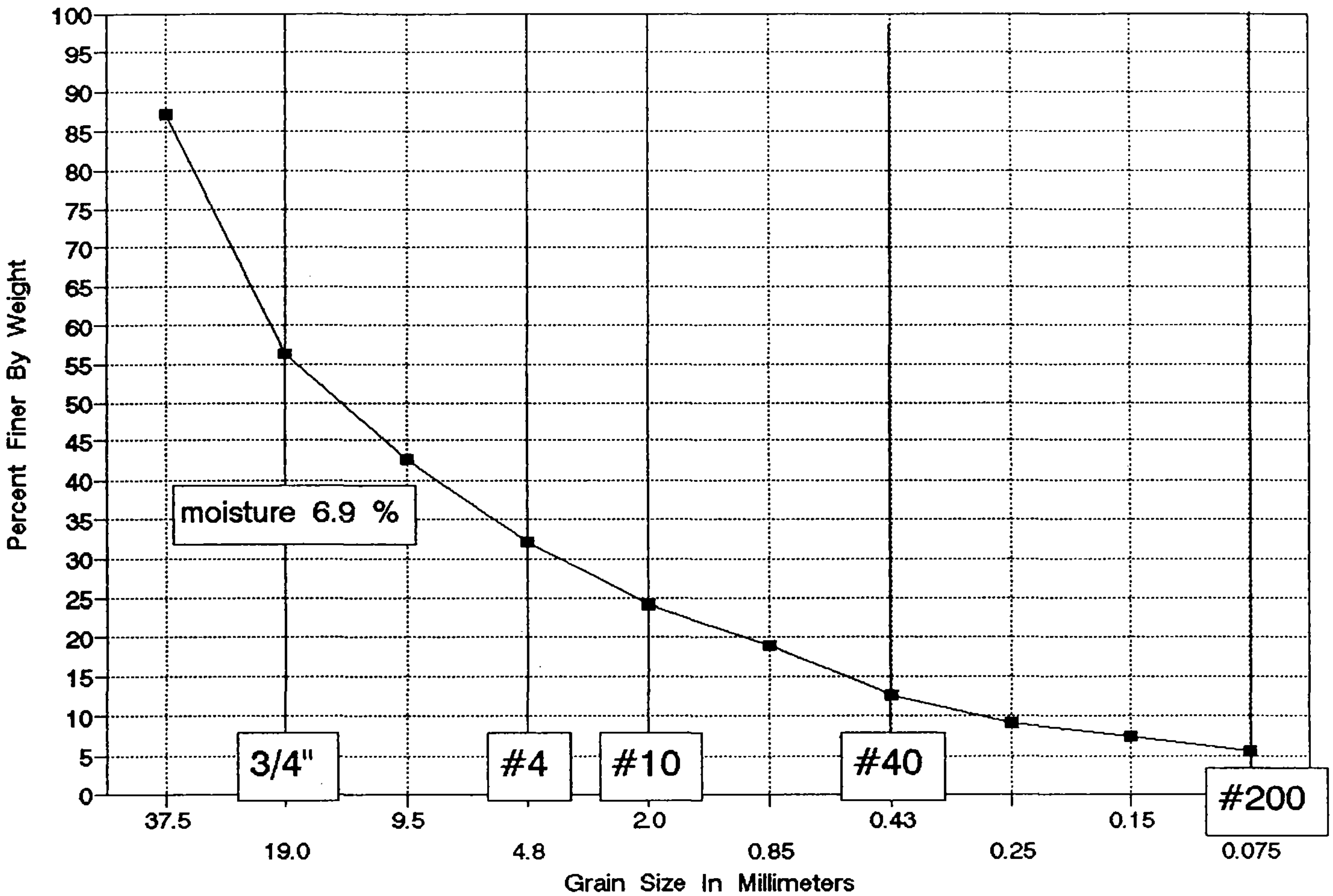
SIEVE ANALYSIS

Dry weight of total sample= 878.2

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	0	100.00%	100.0	37.5
3/4 inch	217.5	75.23%	75.2	19.0
3/8 inch	337.8	61.53%	61.5	9.5
# 4	443.8	49.46%	49.5	4.8
# 10	545	37.94%	37.9	2.0
# 20	607.9	30.78%	30.8	0.85
# 40	669.5	23.76%	23.8	0.43
# 60	712.8	18.83%	18.8	0.25
# 100	741.1	15.61%	15.6	0.15
# 200	771.6	12.14%	12.1	0.075

GRADATION CURVE

Boring DH-8, sample at 44 to 45.5 feet



State of Utah
Department of Natural Resources
DIVISION OF WATER RESOURCES

Woodruff Creek Dam

Boring	DH-8	Wet soil & dish	1317.9
Sample	bag	Dry soil & dish	1246.2
Depth	44-45.5 feet	Dish	211.6

Moisture Content = 6.9

SIEVE ANALYSIS

Dry weight of total sample= 1034.6

Sieve #	weight retained	Finer	% Finer	mm
1.5 inch	131.4	87.30%	87.3	37.5
3/4 inch	452.8	56.23%	56.2	19.0
3/8 inch	593.7	42.62%	42.6	9.5
# 4	703.9	31.96%	32.0	4.8
# 10	783.7	24.25%	24.3	2.0
# 20	838.1	18.99%	19.0	0.85
# 40	903.4	12.68%	12.7	0.43
# 60	941.3	9.02%	9.0	0.25
# 100	958.5	7.36%	7.4	0.15
# 200	976.9	5.58%	5.6	0.075

APPENDIX C

RESULTS OF DOWNHOLE SHEAR WAVE SURVEY

LGS GEOPHYSICS INC.

RESULTS OF DOWNHOLE SHEAR WAVE SURVEY
AT WOODRUFF CREEK DAM, WOODRUFF, UTAH

Prepared For: Utah Division of Water Resources,
Salt Lake City, Utah

Prepared By: LGS Geophysics Inc.
Salt Lake City, Utah

July 5, 1994

LGS GEOPHYSICS INC.
engineering, environmental, mining geophysics

July 5, 1994

Utah Division of Water Resources
1636 W. North Temple, Suite 310
Salt Lake City, Ut 84116-3156

Attn: Bill Leeflang, P.E.

Subject: Results of Geophysical Downhole Shear Wave Survey at Woodruff Creek Dam, Woodruff, Utah.

Gentlemen:

Presented in this report are the results of our down hole shear wave survey conducted within drill hole D-7, located at the crest of the above dam. The drill hole was surveyed at five foot depth increments to 79 ft., the approximate total depth of the hole. The purpose of the survey was to determine the seismic compressional and shear wave velocities, at five foot intervals, of the subsoils encountered by the drill hole. The seismic velocities thus measured form the basis for determining the elastic moduli of the subsoils investigated under dynamic, low strain (X 10-E5 in./in.) and high loading rate conditions.

Field Investigations:

Field investigations were completed in June, 1994. The drill hole had been cased with 2 in. ID, PVC casing and backfilled with grout in preparation for conducting the survey. The downhole measurements were conducted using two orthogonal geophone units, spaced five feet apart, with each unit containing a vertical, a transverse and a radially oriented geophone. The field procedure consisted of placing the two units into the cased hole and recording the arrival of the various components of a surface generated seismic wave or signal as they arrived, successively, at the upper and lower packages. The first test location consisted of the upper package

1104 Ashton Ave. Salt Lake City Utah 84106 • (801) 466 • 1784

placed at 0 ft. (ground surface) within the drill hole and the lower package at 5 ft. within the hole. A horizontally polarized seismic signal was then generated near the hole collar, using the horizontal traction method (weighted plank). The arrival time for this signal was indicated by the two geophone packages and subsequently amplified and recorded by the seismograph. The direction of the energy impact was then reversed to confirm the onset of the shear wave arrival. The geophones were then lowered five ft. and the process repeated. This procedure was followed for each successive five foot depth increment to the hole bottom.

Equipment:

A signal enhancement seismograph was used in the data collection. The enhancement feature allowed the use of a series of light hammer blows in generating the seismic signal, rather than a single heavy blow, thus minimizing the potential for unwanted signals and also aids minimizing any delay inherent in the timing switch mechanism. The seismic signals were unfiltered to minimize signal distortion. A signal voltage sampling rate of 50,000 measurements per second was used in the analog to digital convertor step to allow a high degree of accuracy (± 0.1 milliseconds) in determining the arrival times of the seismic signals of interest. The impedence values of the seismograph and geophones were within 5% to allow accurate recording of the particle velocities at the low strain levels measured. The frequency response of the vertical and the radial and transversely mounted, horizontal geophones within each of the geophone packages was 8 Hz.

Data Reduction, Comments

The compressional seismic wave was indicated as the first arrival by the vertical geophone within each of the two geophone packages; the horizontal (shear) component from the same hammer impact was indicated by the transverse/radial geophones within the packages. The shear wave arrivals were corroborated by a reversed response of the transverse/radial geophones on reversal of the direction of impact of the seismic source. Using two geophone packages, separated by a five ft. interval, enabled the measurement of interval times as well as the total travel time to the geophones from the source. Use ofinterval times in the calculations avoids the possibility of potential measurement error due to any delay inherent in the timing system and essentially eliminating the affect of different travel time paths of the seismic energy as a source of error. Corrections were made in the depth increments in determining the seismic velocities to compensate for the offset of the seismic source from the hole collar. The seismic source was located three feet from the hole collar and oriented parallel to the dam axis.

The Shear modulus (G) was computed by the relationship given below, using the shear wave velocity (Vs) measured for each depth increment and the in situ density (d) of the material.

$$G = d(Vs)^2$$

[d=soil moist unit weight (135 lbs./ft.^{3})/gravity constant(32.2 ft./sec.^{2})]

The ratio of the compressional and shear wave velocities (Vp/Vs) obtained for each depth increment was then calculated for use in determining Poissons' ratio (p) by the following relationship:

$$p = (Vp/Vs)^2-2/2(Vp/Vs)^2-2$$

Youngs' modulus was then determined for each depth increment, using the Shear modulus and Poissons' ratio for the same increment, by the following relationship:

$$E = 2G(1+p)$$

Results

The results of the calculations together with the seismic velocities measured are presented on Table I.

We have appreciated providing this service to you. Please contact us if there are any questions on the above or if we may be of further service to you.

LGS GEOPHYSICS INC.

LaMonte Sorenson
Principal

TABLE I

RESULTS OF DOWNHOLE SHEAR WAVE SURVEY IN
DRILL HOLE D-7, WOODRUFF CREEK DAM, WOODRUFF, UTAH

DEPTH (ft.)	Vp (ft./sec.)	Vs (ft./sec.)	p	G (lb./ft.^{2})	E (lb./ft.^{2})
0- 5	1667	677	.40	1.92 x 10E6	5.38 x 10E6
5-10	2043	1044	.32	4.57 "	12.06 "
10-15	2450	1256	.32	6.61 "	17.45 "
15-20	2778	1250	.37	6.55 "	17.94 "
20-25	2632	1266	.35	6.72 "	18.13 "
25-30	2800	1266	.33	6.72 "	17.87 "
30-35	2632	1282	.34	6.89 "	18.45 "
35-40	2273	1136	.33	5.41 "	14.39 "
40-45	2439	1020	.39	4.36 "	12.12 "
45-50	2083	1042	.33	4.55 "	12.10 "
50-55	1923	1064	.32	4.74 "	12.52 "
55-60	1923	1020	.30	4.36 "	11.34 "
60-65	2381	1064	.38	4.74 "	13.08 "
65-70	2273	1163	.32	5.67 "	14.96 "
70-75	2632	1163	.38	5.56 "	15.64 "
75-79	2666	1027	.41	4.41 "	12.43 "

Vp = compressional wave velocity
Vs = shear wave velocity
p = Poissons' ratio
G = shear modulus
E = Young's modulus