METHODS FOR GEOGRAPHIC POSITIONING OF WATER WELLS

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INTRODUCTION

Groundwater modeling of aquifers (McDonald and Harbaugh 1985) dictates the accurate location of water wells in a three dimensional coordinate system. This location is required for the input of historical pumping data into the proper model grid cells and for the input of piezometric water elevations in observation wells that will be used for calibration purposes. The magnitude of the task of updating the locations of water wells is emphasized by plotting wells located within counties in Northeast Mississippi where there has been considerable study of the groundwater resources (Boswell 1977, 1978; Kernodle 1981; Zitta, et al. 1984, 1985, 1987). The plotted horizontal positions from the USGS well data base are shown in Figures 1, 2 and 3 for the Eutaw-McShan, Gordo, and Coker aquifers respectively in 13 counties whose boundaries were overlaid onto a previously existing 2.5 mile model grid (Zitta and Pang 1985, 1987).

The United States Geological Survey(USGS) well data base is the oldest and most complete, containing all wells drilled within the state, but the position of the wells in the data base was obtained from a variety of methods from field verification to data furnished by well drillers. The Mississippi Department of Health's (MSDH) data base contains all potable water wells. Recently the MSDH completed the task of tagging all potable wells under their authority with a code number and locating these wells on 1:100,000 maps. The Bureau (Office) of Land and Water Resources (BLWR) data base includes wells 6 inches or greater in diameter, which diameters are required to be included in the well permitting program. The BLWR located wells on 7.5 minute quad sheets using field and office methods. All three agencies have unique well identifiers in each data base plus geographic positions determined by methods of varying accuracy.

In Figures 4 & 5 the locations of the water wells are shown for the Starkville and West Point quad sheets, using the MSDH, USGS, BLWR, and the "MSU" positions identified by different symbols. The positions of the wells as plotted confirmed the need to develop an accurate, but inexpensive method to locate wells in the field. Comparison of the locations of water wells in the MSDH, USGS, and BLWR data bases indicated wide variations in position. Without a common identifier and with widely differing positions, it became very difficult to correlate the wells between the three data bases. The Mississippi Automated Resource Information System (MARIS) has been successful in correlating some of the wells between data bases and their data base was supplied to the researchers. Due to correlation and accuracy problems, it was decided to investigate the accuracy of different field methods for locating water wells within a common three-dimensional axis system and to suggest methods to perform this task.

To further emphasize the need to update the data bases, 25 wells within the Starkville quad are tabulated in Table 1. Compared to the "MSU" horizontal position determined by pacing-plotting-digitizing, the mean error of the MSDH data base is 570 feet with a standard deviation of 416 feet. The USGS well locations have a mean error of 505 feet with a standard deviation of 374 feet and the BLWR wells have a mean error of 479 feet with a standard deviation of 1064 feet. In Table 2, the wells within the data base on the West Point quad show a similar magnitude of error. These errors are greater than the 1 second in horizontal position deemed to be minimum in this study.

"MSU" AND SURVEYED FIELD LOCATION OF WATER WELLS

Twenty five major wells located on the USGS Starkville 7.5 minute quad sheet were selected as a test sample to evaluate the accuracy of data base well locations. In June 1991, the 25 wells were field located by pacing two perpendicular distances from landmarks that were identifiable on the quad sheet as well as the ground. The well locations were plotted as accurately as possible on the quad sheets. Using a hybrid PC program developed for the project, the NAD'27 coordinates of plotted well locations were determined with a digitizer. The elevation of each well was estimated to the nearest foot from its plotted position between adjacent contours on the map. This method came to be known as the "MSU" position. The horizontal and vertical position of the wells were expected to have an accuracy of 100 and 10 feet respectively. Digitizing the same points several times

indicated that the digitizer was able to reproduce the horizontal position of plotted wells to about 5 feet of accuracy. The accuracy of the elevation of the well would obviously be highly dependent on the accuracy of the plotted point.

After comparing the "MSU" positions with the plotted data base positions, it was decided to evaluate the accuracy of the "MSU" positions. Eighteen of the 25 wells were positioned by conventional surveying methods producing an expected 3-dimensional accuracy of one foot. Only 40-50 man-hours were required for this task because an extensive control net had been established by the "MSU" surveying classes over the past twenty-plus years. This net was submitted to, checked, and adjusted by the National Geodetic Survey (NGS) and included in the National Geodetic Reference System (NGRS) as Second Order Class I (1:50,000) accuracy.

GPS SINGLE UNIT AND MULTIPLE UNIT LOCATION OF WELLS

A hand held GPS unit (Magellan NAV 1000 Pro) was borrowed from the remote sensing laboratory to test its suitability for well location. A total of fifteen wells and control points were positioned using the 3-D mode. A more extensive test was run in December 1991 and January 1992 using two Magellan NAV 1000 Pro units borrowed from the Department of Chemical Engineering. One of these units, operating in the 3-D mode, was used on a total of about 40 control points and wells. Short occupation times were used collecting a minimum of 16 fixes. Since the elevation of all these points was known, another test was run with the single unit operating in the 2-D mode.

To cancel the effect of selective availability (SA), two GPS units along with radio communication were used on a total of 18 different control points and wells. As the elevation of these points was known, the units were operated in the 2-D double-differencing mode. The number of fixes was set for 100 on the 7 wells and 36 for the control points.

RESULTS AND DISCUSSION

Results of the analysis of water well locations for the Starkville and West Point quad maps are given graphically in Figures 5 and 6. Table 1 shows the results from the accurately surveyed positions compared with the errors in the "MSU" paced- plotted-digitized positions. The June 1991 "MSU" position showed a maximum horizontal and vertical error as 91 and 6 feet respectively with means of 25 and 2.3 feet. Comparing the "MSU" positions with the accurately surveyed positions proved that the "MSU" positions were within the expected horizontal and vertical accuracy of 100 and 10 feet respectively. To double-check the reliability of field pacing methods, all wells were revisited six months later in December 1991. New distances were paced without photographs, plotted on a new map, and positioned with a different digitizer. The second test produced similar results with a maximum and mean error of 88 and 34 feet respectively. Elevations were not redetermined from the second test.

In Tables 2 and 3, the "MSU" position is compared to the MSDH, USGS, and the BLWR positions in the data bases for the Starkville and West Point quads. Identification numbers are given in the first three columns, followed by the latitude and longitude of the field verified "MSU" position determined by pacing-plotting-digitizing. For the Starkville quad, the mean errors in the MSDH, USGS and BLWR data bases are 570, 505, and 479 feet respectively. The standard deviations are 416, 374, and 1064 feet. The error in each of the data bases is in relation to the "MSU" position. For the West Point quad, the mean errors in the MSDH, USGS and BLWR data bases are 1017, 846, and 395 feet respectively. The standard deviations are 2081, 1243, and 261 feet. The error in each of the data bases is in relation to the "MSU" position. The last column in Tables 2 and 3 is a brief description of the owner of the well. It is the opinion of the authors that wells can be field located by simple pacing-plotting-digitizing within ±100 feet on 7.5 minute quad maps and this accuracy should be expected in each data base. With this accuracy in well location, there should be no question as to the identification of each well within each data base.

Results from the MARIS effort indicated good correlation of wells within the three data bases for the wells which were identified as the same in each data base. Because of the errors in position in each data base, the latitude and longitude of the wells need to be accurately located in the field and accepted as the correct location by the three agencies.

In Table 4 the water well locations determined by the "MSU" method are compared to the GPS method using a single hand held unit. This first test was made during a time when selective availability (SA) was not on and good horizontal results were obtained, but the elevation errors were much greater than the 1 foot desired. Only one observation exceeded the one second horizontal accuracy required.

In Table 5 the water well locations determined by the "MSU" method are compared to the GPS method using a single hand held unit but in 3-D mode where the elevation is determined by the GPS unit. Again the error in elevation was larger than acceptable, but most

of the horizontal positions were within the acceptable range of 30 meters. The average error of 39 observations was 24 meters with a standard error of 12 meters. These results were obtained while selective availability (SA) was on. The results from a 2-D test are shown in Table 6. Little improvement was gained as the average error of 78 observations was 30 meters with a standard error of 20 meters.

The results from the test using two GPS units are shown in Table 7. The average position error was reduced to 7 meters with a standard error of 5 meters. The additional person, equipment, and coordination makes the method undesirable and should be limited to only those projects that require the higher accuracy. If a common shared base station was available, then this method could be used to increase the accuracy where needed. Since these tests were run, Magellan has upgraded their GPS units to track 5 satellites simultaneously instead of sequencing through them one at a time. This should reduce the occupation time and also improve the accuracy.

CONCLUSIONS

The experience gained from this project leads the authors to make these recommendations:

1. All Mississippi agencies with well data bases should utilize a common identifier to allow wells to be correlated easily. It is recommended that the identifier be similar to DDLLDDDDD with the first two digits being the county code number (01-82), the next two letters used to classify the type of well, and the last five digits to be consecutively assigned as entered in the data base.

2. All agencies should use the same horizontal position assigned by one or by an independent agency. Any refinements or corrections made should be distributed and all data bases revised. Revisions should only be made where increased accuracy is assured and verified.

3. Positions given in latitude and longitude should have an expected accuracy of one second (one second equals approximate 100 feet in latitude or 85 feet in longitude). This accuracy can be maintained either by field pacing-plotting-digitizing the well location on a 7.5 minute quad sheet or by careful use of a GPS unit. Elevations are best determined to the nearest one-half contour interval from interpolation on 7.5 minute quad maps. In no case can the elevation be accurately determined from hand held GPS units.

REFERENCES

Boswell, E.H. 1977. The Eutaw-McShan aquifer in Mississippi. U.S. Geological Survey, Water Resources Investigations 76-134. Open-File Report. Jackson, MS.

Boswell, E.H. 1978. The Tuscaloosa aquifer in Mississippi. U.S. Geological Survey, Water Resources Investigations 78-98. Open-File Report. Jackson, MS.

Kernodle, John M. 1981. Two-Dimensional groundwater flow model of the cretaceous aquifer system of Lee County and vicinity, Mississippi. U.S. Geological Survey, Water-Resources Investigations 81-70. Jackson, MS.

Magellan Systems Corporation. 1991. Magellan GPS NAV 1000 PRO, User Guide, Magellan Systems Corporation. Monrovia, CA.

Magellan Systems Corporation. 1991. Magellan Systems Post-Processing Software, User Guide, Magellan Systems Corporation. Monrovia, CA.

McDonald, Michael G. and Aarlen W. Harbaugh. 1985. A modular three-dimensional finite-difference ground-water flow model. U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 6, Chapter A1, (Scientific Publications Co.). Washington, D.C.

Zitta, V.L., R.L. Frnka, and Tak-Kai Pang. 1984. Mathematical models for water resources policy and management with application to the Eutaw-McShan Aquifer. Water Resources Research Institute, Mississippi State University. September.

Zitta, V.L. and Tak-Kai Pang. 1985. Water resources policy and management: an application of mathematical models. Proceedings Mississippi Water Resources Conference, Water Resources Research Institute. Mississippi State University.

Zitta, V.L. and Tak-Kai Pang. 1986. Application of a layered groundwater model to critical areas in Northeast Mississippi. Water Resources Research Institute. Mississippi State University. July. (Final Report). Paper by same title in Proceedings Mississippi Water Resources Conference, March 1987.

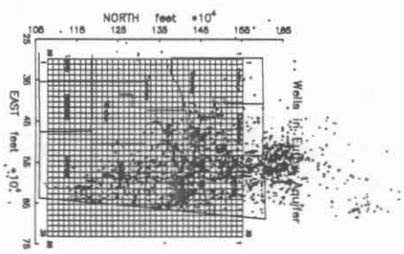

Figure 1. Numerical Grid Overlaid by County Boundaries and Well Locations-Eutaw-McShan Aquifer0

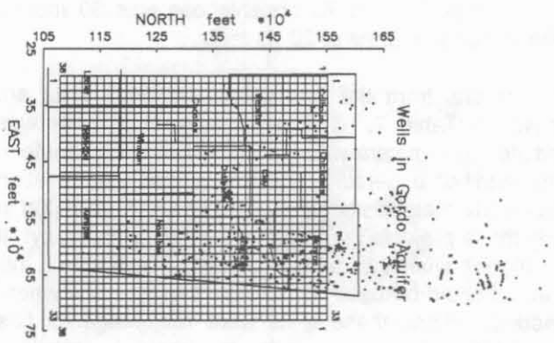

Figure 2. Numerical Grid Overlaid by County Boundaries and Well Locations - Gordo Aquifer

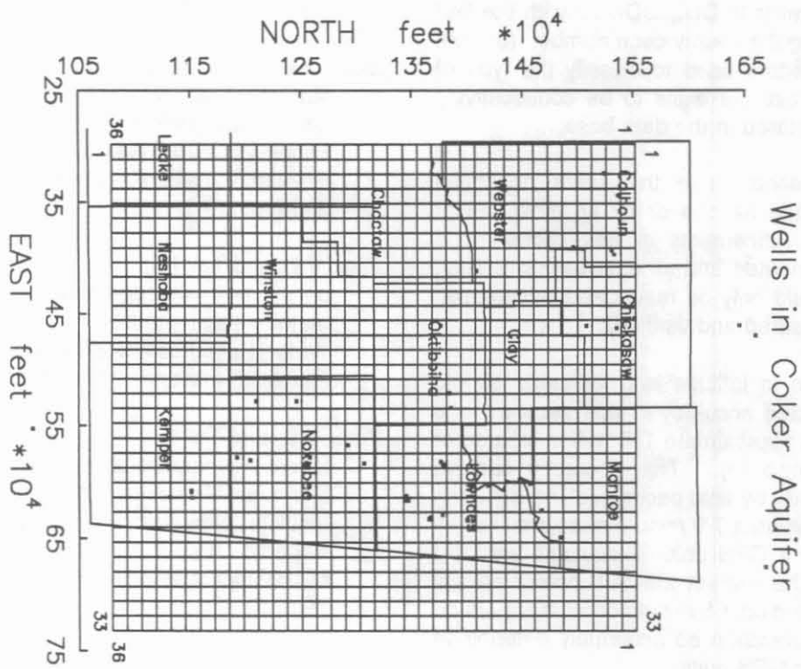

Figure 3.Numerical Grid Overlaid by County Boundaries and Well Locations - Coker Aquifer

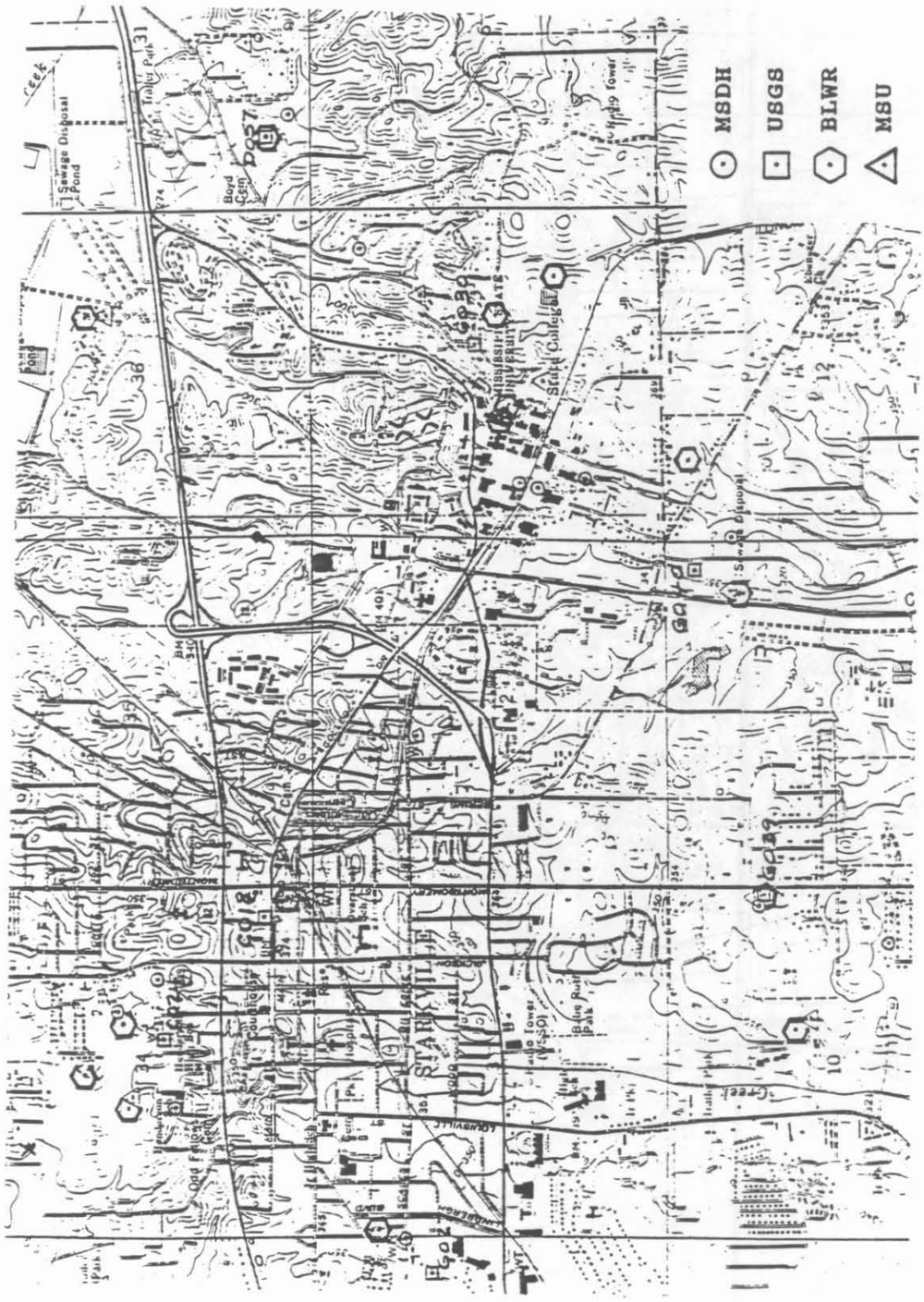

Figure 4. Well Locations, 7.5 Minute Quad Map for Starkville

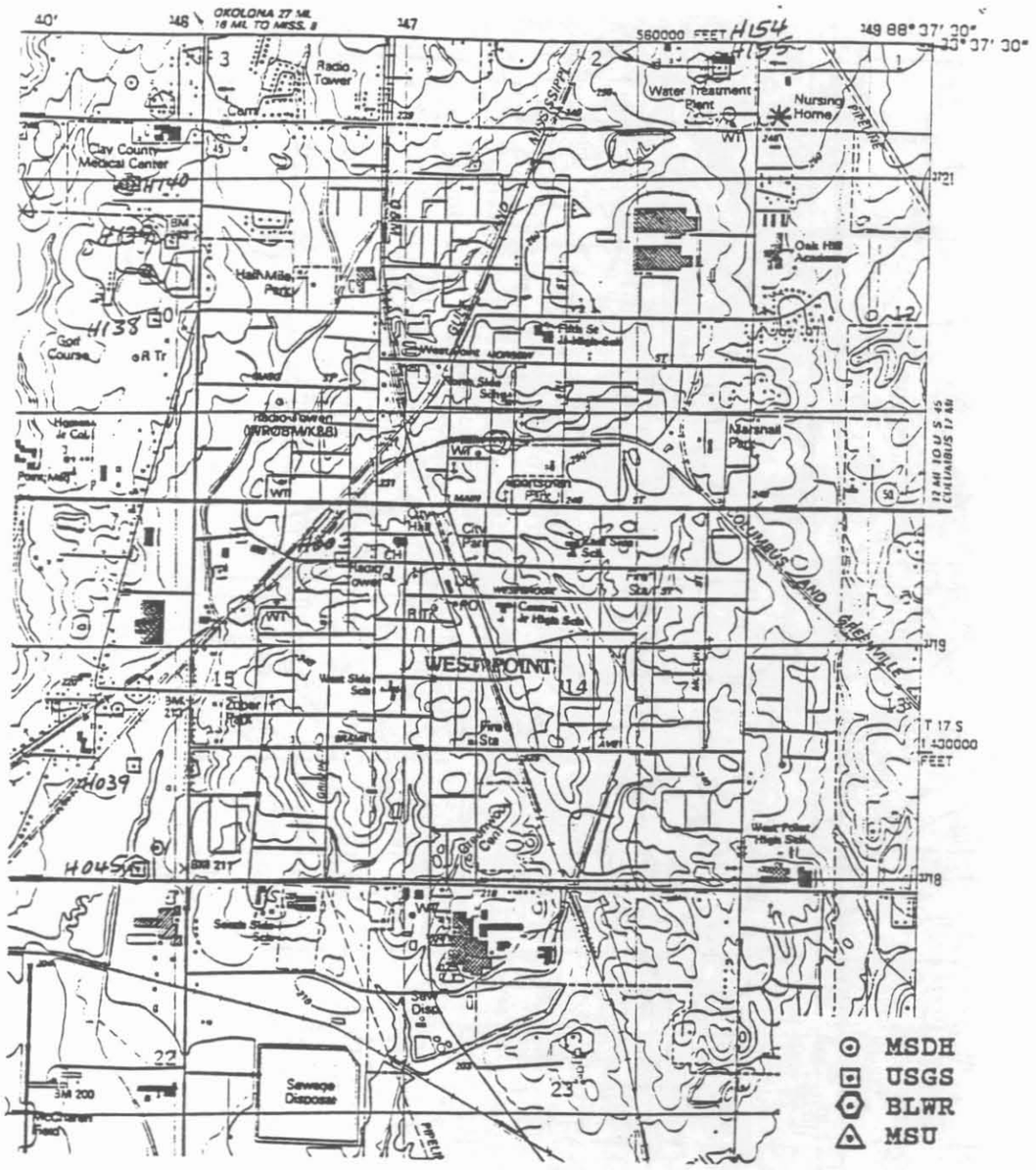

Figure 5. Well Locations, 7.5 Minute Quad Map for West Point

TABLE 1. WATER WELL POSITION FROM QUAD SHEETS

WELL ID		NAD'27 COORDINATES(FT) X	Y	Z	ERROR(FT) X	Y	POS	
Turkey Creek	(1)	517542	1369331	377				
	(2)	517568	1369322	372	+26	-9	28	-5
	(3)	517579	1369360		+37	+29	47	
Oktoc WA #1		521923	1348655	329				
		521942	1348669	325	+19	+14	24	-4
		521896	1348739		-27	+84	88	
MSU S Farm (S)		513632	1366565	309				
		513647	1366587	309	+15	+22	27	0
		513631	1366578		-1	+13	13	
MSU S Farm (N)		513214	1368374	318				
		513241	1368393	312	+27	+19	33	-6
		513227	1368380		+13	+6	14	
Cla Vil WA #1		524062	1385941	266				
		524078	1385851	265	+16	-90	91	-1
		524096	1385908		+34	-33	47	
Cla Vil WA #2		519921	1381603	332				
		519924	1381573	333	+3	-30	30	+1
		519966	1381569		+45	-34	56	
MSU North Farm		515756	1383774	278				
		515771	1383765	279	+15	-9	17	+1
		515781	1383737		+26	-37	45	
Hi-Tech Cable		497518	1372524	325				
		497513	1372520	324	-5	-4	6	-1
		497528	1372575		+10	+51	52	
City Curry St		504919	1382964	375				
		504918	1382956	374	-1	-8	8	-1
		504940	1382948		+21	-16	26	
City Henderson		503890	1383342	343				
		503904	1383327	345	+14	-15	21	+2
		503871	1383362		-19	+20	28	
City Parkdale		504316	1384070	340				
		504312	1384037	340	-4	-33	33	0
		504337	1384051		+21	-19	28	
Borden Milk		506955	1380491	381				
		506932	1380502	380	-23	+11	25	-1
		506956	1380519		+1	+28	28	
City Mont St		506899	1373623	350				
		506903	1373617	353	+4	-6	7	+3
		506921	1373602		+22	-21	30	
City Acad Rd		505065	1372720	325				
		505059	1372707	320	-6	-13	14	-5
		505059	1372728		-6	+8	10	
MSU WWT Plant		511543	1374018	342				
		511550	1374017	342	+7	-1	7	0
		511543	1374047		0	+29	29	
MSU Bandfield		514762	1376946	395				
		514757	1376958	392	-5	+12	13	-3
		514762	1376935		0	-11	11	
MSU East		514366	1377475	382				
		514418	1377494	380	+52	+19	55	-2
		514392	1377468		+26	-7	27	
MSU West		514201	1377597	379				
		514213	1377588	373	+12	-9	15	-6
		514229	1377606		+28	+9	29	

(1) Position from July 1991 field survey with 1-foot accuracy
(2) Position from June 1991 pacing-plotting-digitizing quad sheet/photos
(3) Position from Dec 1991 pacing-plotting-digitizing quad sheet/no photos

Table 2. Comparison of Well Locations; MSDH, USGS, BLWR and MSU Water Wells on Starkville 7.5′ Quad

MSDH ID	USGS ID	BLWR ID	MSU[1] POS	MSDH[2] POS	ERROR ft	USGS[2] POS	ERROR ft	BLWR[2] POS	ERROR ft	LOCAL ID
0601	D042	01607	332835	332834	100	332833	200	352833	200	CLA VIL WA #1
			884516	884521	425	884515	85	884515	85	
1201	G020	00829	332713	332711	200			332714	100	MSU EAST
			884710	884724	1190			884713	250	
1202	G018	00830	332714	332708	605			332713	100	MSU WEST
			884712	884725	1105			884710	170	
1203	G033	00831	332707	332701	605			332706	100	MSU BANDFIELD
			884706	884723	1445			884647	1600	
1204	G040	00832	332638	332638	0	332644	605	332637	100	MSU WW PLANT
			884744	884734	850	884740	340	884744	0	
1401	H016	01583	332227	332225	200	332231	405	332228	100	OKTOC WA #1
			884542	884538	340	884545	255	884541	85	
2001	G027	01335	332730	332729	100	332725	505	332733	300	CITY SCALES ST
			884940	884940	0	884946	510	884938	170	
2002	C021	01336	332807	332807	0	332812	505	332812	500	CITY CURRY ST
			884902	884853	765	883948	9mi	884901	85	
2003	C024	01337	332811	332804	705	332806	505	332811	0	CITY HENDERSON
			884914	884916	170	884904	850	884916	170	
2004	C027	01338	332817	332813	405			332818	100	CITY PARKDALE
			884909	884859	850			884910	85	
2005	G039	01339	332635	332634	100	332633	200	332633	200	CITY S. MONT.
			884839	884840	85	884838	85	884838	85	
2006		12215	332625	332614	1110			332628	300	CITY ACAD. RD
			884900	884847	1105			884902	170	
2201	G031		332358	332359	100	332400	200			T WAR WA #1
			885043	885046	255	885050	595			
2401	H017	01053	332552	332604	1210	332545	705	332552	0	TURKEY CR WA
			884633	884630	255	884625	680	884632	85	
3501	G011	01584	332232	332225	705	332238	605	332235	300	OKTOC WA #2
			884750	884737	1105	884750	0	884749	85	
3601	G030	00879	332727	332736	910	332718	910	332715	1200	UNIV HTS WA
			884651	884642	765	884659	680	884654	250	
4001	G012		332317	332311	605	332317	0			T WAR WA #2
			885043	885038	425	885041	170			
4301	D057	01606	332753	332747	605	332750	305	332750	300	CLA VIL WA #2
			884605	884618	1105	884622	1445	884622	1450	
3801	C018	00731	332742			332750	810	332747	500	BORDEN MILK
			884838			884842	340	884839	85	
	G034		332620			332615	505			BLUEFIELD WA #1
			885147			885200	1105			
	G037		332504			332509	505			BLUEFIELD WA #2
			885217			885235	1530			
		00716	332525					332554	2900	MSU S.FARM S
			884719					889726	DUD	
		00718	332543					332645	6200	MSU S.FARM N
			884724					884720	340	
		00717	332815					332818	300	MSU N.FARM
			884654					884654	0	
		00902	332624					332623	100	HI-TEC CABLE
			885029					287030	DUD	
			Mean (ft)		570		505		479	
			Std. Dev. (ft)		416		374		1064	

[1] Determined by pacing-plotting-digitizing on 7.5′ quad.
[2] Positions from data base furnished by agency.

Table 3. Comparison of Well Locations; MSDH, USGS, BLWR and MSU Water Wells on West Point 7.5′ Quad

MSDH ID	USGS ID	BLWR ID	MSU[1] POS	MSDH[2] POS	ERROR ft	USGS[2] POS	ERROR ft	BLWR[2] POS	ERROR ft	LOCAL ID
0801	H039	01325	333556	333556	0	333548	800	333559	300	WEST POINT #4
			883947	883945	170	883942	425	883942	425	
0802	H045	01326	333533	333537	400	333534	100	333534	100	WEST POINT #5
			883942	883938	340	883941	85	883941	85	
0803	H138	01328	333656	333657	100	333650	600	333703	700	WEST POINT #7
			883941	883942	85	883940	85	883940	85	
0804	H139	01329	333721	333723	200	333701	2000	333720	100	WEST POINT #8
			883941	883945	340	883937	340	883939	170	
0805	H140	01330	333758	333804	600	333709	5000	333807	900	WEST POINT #9
			883937	883944	600	883944	600	883944	600	
0806	H154	01331	333720	333724	400	333726	600	333726	600	WEST POINT #11
			883809	883808	85	883805	340	883805	340	
0807	H155	01333	333719	333720	100	333726	700	333726	700	WEST POINT #10
			883803	883803	0	883805	170	883808	420	
1201			333532	333634	6300					BRYAN NORTH
			883849	883841	680					
			333525							BRYAN WEST
			883849							
1202			333521	333634	7400					BRYAN SHALLOW
			883848	883842	510					
			333520							BRYAN SOUTH
			883847							
			Mean (ft)		1017		846		395	
			Std. Dev. (ft)		2081		1243		261	

[1] Determined by pacing-plotting-digitizing on 7.5′ quad.
[2] Positions from data base furnished by agency.

TABLE 4. WATER WELLS AND CONTROL POINTS ON STARKVILLE 7.5′ QUAD

WELL ID	MSU POS[1] LAT/LONG/ELEV	GPS POS[2] LAT/LONG/ELEV	ERROR SEC/SEC/FT
CITY ACAD RD	33 26 26	33 26 25	-1
	88 49 00	88 49 00	0
	325	549	+224
CITY S. MONT	33 26 35	33 26 34	-1
	88 48 39	88 48 39	0
	350	494	+144
7404	33 25 57	33 25 56	-1
	88 47 50	88 47 49	-1
	349	483	+134
7412	33 25 20	33 25 20	0
	88 47 51	88 47 51	0
	347	446	+99
MSU S. FARM S	33 25 25	33 25 24	-1
	88 47 19	88 47 19	0
	309	405	+96
MSU S. FARM N	33 25 43	33 25 43	0
	88 47 24	88 47 24	0
	318	364	+46
MSU WW PLANT	33 26 39	33 26 37	-2
	88 47 44	88 47 45	+1
	342	359	+17
MSU BANDFIELD	33 27 07	33 27 06	-1
	88 47 06	88 47 06	0
	395	404	+9
CLA VIL WA #2	33 27 54	33 27 53	-1
	88 46 05	88 46 05	0
	332	379	+47
CLA VIL WA #1	33 28 36	33 28 36	0
	88 45 16	88 45 17	+1
	266	189	-77
MSU N. FARM	33 28 15	33 28 15	0
	88 46 54	88 46 55	+1
	278	138	+140
CITY HENDERSON	33 28 11	33 28 11	0
	88 49 14	88 49 14	0
	343	294	-49
TURKEY CR WA	33 25 52	33 25 51	-1
	88 46 33	88 46 33	0
	377	391	+14
OKTOC WA #1	33 22 28	33 22 28	0
	88 45 41	88 45 41	0
	329	371	+42
BURT	33 22 55	33 22 54	-1
	88 45 57	88 45 57	0
	347	163	-184

[1] Horizontal position determined by pacing-plotting-digitizing on 7.5′ quad. Vertical position determined by interpolation between contours on 7.5′ quad.
[2] GPS positions from single hand held unit.

TABLE 5. SINGLE GPS UNIT OPERATING IN 3-D MODE

STA-WELL DATE	FIXED/OBSERVED POSITION DEG-MIN LAT	LON	SECONDS LAT	LON	ALT (M)	GPS POSITIONAL RESULTS ERROR(METERS) LAT	LON	POS	ALT	FIX NO.	PDOP
D 58	3328	8843	37.79	05.59	84						
12-16-91PM			37.11	05.44	56	-11	-15	19	-28	17	3.2
D 59	3328	8843	38.22	34.51	83						
12-16-91PM			37.17	34.90	120	-28	+3	28	+37	18	3.6
MAYHAW AZ	3328	8840	39.92	32.93	73						
12-16-91PM			39.88	32.62	141	-1	-8	8	+68		3.3
STATE AZ	3327	8848	19.57	05.94	116						
12-12-91PM			20.09	05.42	129	+16	-14	21	+13	32	
12-16-91AM			20.52	06.96	167	+29	+27	40	+51	17	3.4
1-10-92S1			20.13	06.05	77	+17	-3	17	-41	41	3.3
1-10-92S2			19.06	06.46	120	-16	-13	21	+2	43	5.0
6928	3328	8846	08.05	37.55	85						
12-16-91PM			08.03	36.97	-30	-1	-15	15	-115	22	4.7
7603	3325	8847	10.95	16.58	103						
12-12-91PM			09.89	16.96	14	-33	+10	34	-89	1	3.9
12-16-91AM			10.18	16.69	62	-24	-3	24	-43	17	2.5
8301	3328	8840	38.28	51.12	80						
12-16-91PM			38.94	51.16	98	+20	+1	20	+18		3.3
8401	3328	8845	20.74	40.09	87						
12-16-91PM			19.84	41.25	218	-23	+2	23	+131	18	4.7
8405	3328	8844	37.54	04.97	83						
12-16-91PM			36.78	04.97	45	-22	+3	22	-38	18	4.1
8406	3328	8842	37.80	38.22	88						
12-16-91PM			36.92	38.07	61	-11	-13	17	-27	17	2.8
8407	3328	8842	38.11	16.94	85						
12-16-91PM			37.72	17.56	135	+19	-1	19	+50	17	2.4
8408	3328	8841	37.79	44.94	77						
12-16-91PM			37.45	45.47	149	-1	+8	8	+72	17	2.4
8409	3328	8839	44.71	30.74	67						
12-16-91PM			43.72	32.20	56	-31	+38	49	-11		3.9
8413	3328	8844	37.32	29.68	79						
12-16-91PM			35.07	30.93	214	-32	-10	34	+135	19	4.4
BF WA #1	3326	8851	?????	?????	91						
12-19-91AM			22.11	47.32	57				-34	17	3.9
BF WA #2	3325	8852	?????	?????	88						
12-19-91AM			05.14	16.68	57				-31	17	4.5
BORDEN	3327	8848	43.02	38.10	116						
12-19-91AM			43.35	37.67	143	+10	-11	15	+27	20	3.4
CITY AC RD	3326	8849	26.14	00.42	99						
12-17-91AM			27.31	00.07	194	+36	-9	37	+95	19	3.4
CITY CURRY	3328	8849	07.49	02.13	114						
12-17-91PM			07.89	02.32	108	+12	+5	13	-6	24	3.7
CITY HE SC	3328	8849	11.23	14.27	105						
12-17-91PM			10.47	14.21	187	-24	-2	24	+82	18	3.3
CITY MO ST	3326	8848	35.07	38.78	107						
12-17-91AM			34.72	40.48	134	-11	+44	46	+27	17	3.3
CITY PD SD	3328	8849	18.43	09.24	104						
12-17-91PM			18.49	09.58	204	+2	+9	9	+100	21	2.8
CITY SC ST	3327	8849	?????	?????	?						
12-19-91AM			32.69	42.16	53					17	3.3
CV WA #1	3328	8845	36.85	16.12	81						
12-18-91AM			36.63	16.23	97	-7	+3	7	+16	17	6.9
CV WA #2	3327	8846	53.96	05.04	101						
12-18-91AM			53.33	04.85	74	-20	-5	20	-27	18	3.4

TABLE 5(CON'T). SINGLE GPS UNIT OPERATING IN 3-D MODE

STA-WELL DATE	FIXED/OBSERVED POSITION DEG-MIN LAT	LON	SECONDS LAT	LON	ALT (M)	GPS POSITIONAL RESULTS ERROR(METERS) LAT	LON	POS	ALT	FIX NO.	PDOP
HI-TECH	3326	8850	24.20	29.49	99						
12-19-91AM			22.83	29.86	110	-42	+10	44	+11	17	3.5
MSU BAND	3327	8847	07.92	05.96	120						
12-17-91PM			07.84	06.20	168	-2	+6	7	+48	25	4.6
MSU EAST	3327	8847	13.15	10.64	116						
12-17-91PM			12.71	11.58	278	-14	+24	28	+162	23	4.5
MSU NF	3328	8846	15.47	54.19	85						
12-17-91PM			15.95	54.38	114	+15	+5	16	+29	20	2.6
MSU SFN	3325	8847	43.11	24.28	97						
12-16-91AM			42.49	25.46	89	-19	+31	36	-8	16	3.4
12-17-91AM			43.89	23.38	134	+24	-23	33	+37	16	3.4
MSU SFS	3325	8847	25.21	19.35	94						
12-16-91AM			25.39	19.47	124	+6	+3	7	+30	18	3.4
12-17-91AM			25.23	18.71	133	+1	-17	17	+39	17	3.4
MSU WEST	3327	8847	14.36	12.58	116						
12-17-91PM			13.74	12.69	192	-19	+3	19	+76	18	4.3
MSU WWTP	3326	8847	38.96	43.97	104						
12-16-91AM			37.87	44.44	4	-34	+12	36	-100	17	3.4
12-17-91AM			39.15	43.23	171	+6	-19	20	+67	16	2.5
OK WA #1	3322	8845	27.97	41.68	100						
12-18-91AM			29.66	41.14	96	+52	-14	54	-4	17	3.4
OK WA #2	3322	8847	?????	?????	98						
12-18-91AM			33.68	50.22	119				+21	17	3.3
TC WA	3325	8846	52.56	33.20	115						
12-18-91AM			51.98	33.45	105	-18	+6	19	-10	16	3.4
TW WA #1	3323	8850	?????	?????	87						
12-19-91AM			58.29	43.05	228				+141	17	3.6
TW WA #2	3323	8850	?????	?????	85						
12-19-91AM			18.36	43.05	76				-9	18	3.5
UNIV HTS	3327	8846	?????	?????	101						
12-18-91AM			25.90	49.56	152				+41	16	4.9

TABLE 6. SINGLE UNIT OPERATING IN 2-D MODE

STA-WELL DATE	FIXED/OBSERVED POSITION DEG-MIN LAT	LON	SECONDS LAT	LON	ALT (M)	GPS POSITIONAL RESULTS ERROR(METERS) LAT	LON	POS	FIX NO.	PDOP
D 58	3328	8843	37.79	05.59	84					
12-19-91PM			39.09	04.62		+40	-25	47	17	3.3
1-11-92M			37.24	04.06		-17	+39	43	50	2.0
D 59	3328	8843	38.22	34.51	83					
12-19-91PM			38.31	33.98		+3	+14	14	17	1.6
MAYHAW	3328	8840	40.20	17.31	88					
12-19-91PM			39.77	16.83		-13	+12	18	17	1.9
MAYHAW AZ	3328	8840	39.92	32.93	73					
12-19-91PM			39.88	31.54		-1	+36	36	17	2.0
1-11-92O			40.84	32.24		+29	+18	34	49	1.8
STATE AZ	3327	8848	19.57	05.94	116					
1-10-92S3			20.31	05.65		+23	+7	24	47	2.0
1-20-92A			20.19	05.95		+19	0	19	103	1.6
B			18.58	06.57		-31	-16	35	115	1.5
C			19.00	05.88		-18	+2	18	102	2.0
D			19.58	05.51		0	+11	11	103	1.6
E			20.22	05.60		+20	+9	22	120	1.4
F			19.65	05.58		+2	+9	9	104	1.3
G			19.79	05.56		+7	+10	12	102	1.4
H			19.84	06.02		+8	-2	8	104	1.4
I			19.98	05.86		+13	+2	13	136	1.3
J			19.34	05.87		-7	+2	7	102	1.3
6917	3327	8847	18.93	40.09	111					
12-21-91AM			18.93	40.48		0	-9	9	18	1.5
12-21-91PM			19.19	40.45		+9	-10	13	17	1.3
6928	3328	8846	08.05	37.55	85					
12-19-91PM			08.86	38.15		+25	+16	30	16	1.5
1-11-92K			07.79	36.21		-8	+35	36	41	1.5
7101	3328	8847	04.98	34.28	107					
12-21-91AM			04.67	34.77		-10	-13	16	16	1.6
12-21-91PM			05.88	35.10		+28	-21	35	17	1.3
1-11-92J			05.92	33.72		+29	+14	32	42	1.7
8301	3328	8840	38.28	51.12	80					
12-19-91PM			38.91	51.43		+19	-8	21	17	2.2
8401	3328	8845	20.74	40.09	87					
12-19-91PM			21.22	40.45		+43	-21	48	16	1.4
1-11-92D			20.08	40.09		-20	0	20	40	2.0
E			20.95	40.58		+7	-13	15	50	1.8
F			20.11	40.02		-19	+2	19	47	1.6
G			21.60	39.53		+27	+14	30	40	2.6
H			22.44	38.86		+53	+32	62	41	2.2
I			19.33	41.12		-44	-27	52	40	1.9
J			21.81	39.72		+33	+10	34	40	1.9
K			20.60	38.70		-4	+36	36	41	1.5
L			20.14	41.05		-18	-25	31	39	2.4
M			20.56	38.31		-5	+46	46	39	2.0
N			21.61	39.96		+27	+3	27	39	1.8
O			21.58	39.28		+26	+21	33	38	1.8
PP			18.71	39.94		-63	+4	63	72	1.7
8403	3327	8847	42.08	41.42	117					
12-21-91AM			42.09	41.83		+1	-11	11	18	1.5
12-21-91PM			42.38	40.35		+9	+28	29	17	1.3
8405	3328	8844	37.54	04.97	83					
12-19-91PM			37.85	05.44		+9	-12	15	17	1.6
1-11-92L			36.89	06.13		-20	-30	36	40	2.4

TABLE 6(CON'T). SINGLE UNIT OPERATING IN 2-D MODE

STA-WELL DATE	FIXED/OBSERVED POSITION DEG-MIN LAT	LON	SECONDS LAT	LON	ALT (M)	GPS POSITIONAL RESULTS ERROR(METERS) LAT	LON	POS	FIX NO.	PDOP
8406	3328	8842	37.80	38.22	88					
12-19-91PM			39.50	36.92		+52	+34	62	17	2.9
8407	3328	8842	38.11	16.94	85					
12-19-91PM			37.58	17.27		-16	-8	18	17	2.6
8408	3328	8841	37.79	44.94	77					
12-19-91PM			36.74	46.03		-32	-28	43	17	2.4
1-11-92N			38.66	44.81		+27	+3	27	41	1.8
8409	3328	8839	44.71	30.74	67					
12-19-91PM			42.11	31.54		-80	-21	83	17	1.8
1-11-92P			42.52	30.72		-68	0	68	48	1.7
8601	3327	8848	56.94	32.00	114					
12-21-91AM			56.66	32.36		-8	-11	14	17	1.7
12-21-91PM			57.08	32.40		+4	-10	11	16	1.3
1-11-92I			55.59	32.45		-42	-12	44	42	1.9
8603	3327	8849	56.86	23.80	105					
12-21-91AM			57.28	24.86		+13	-28	31	17	1.8
12-21-91PM			56.82	24.90		-1	-28	28	16	1.3
8605	3327	8849	49.64	56.37	98					
12-21-91AM			49.52	54.62		-9	+41	42	18	2.1
12-21-91PM			50.51	57.72		+26	-34	43	17	1.4
1-11-92H			51.01	55.48		+42	+23	48	45	2.2
8607	3327	8850	42.99	43.13	94					
12-21-91AM			43.51	43.47		+16	-9	18	17	2.0
12-21-91PM			38.92	43.37		-126	-6	126	18	1.4
1-11-92G			44.00	42.45		+31	+17	35	58	2.6
8612	3326	8850	44.61	42.39	101					
12-21-91AM			43.45	42.93		-36	-14	39	16	2.0
12-21-91PM			44.28	42.76		-8	-4	9	27	1.4
1-11-92F			44.19	42.41		-13	-1	13	38	1.6
8613	3326	8850	30.63	42.53	101					
12-21-91AM			31.57	43.90		+30	-35	46	18	2.2
12-21-91PM			30.73	42.46		+3	+2	4	16	1.5
1-11-92E			30.70	42.95		+2	-11	11	41	1.8
8614	3326	8850	11.36	41.64	99					
12-21-91AM			12.83	41.75		+45	-4	45	18	2.7
12-21-91PM			12.30	42.98		+28	-34	44	17	1.5
1-11-92D			10.54	41.83		-25	-5	25	45	2.0
BORDEN	3327	8848	43.02	38.10	116					
1-20-92G			43.44	37.99		+13	+3	13	163	1.4
CITY AC RD	3326	8849	26.14	00.42	99					
1-20-92B			25.11	01.12		-32	-18	37	134	2.8
CITY CURRY	3328	8849	07.49	02.13	114					
1-20-92E			08.18	01.79		+21	+9	23	109	1.4
CITY HE SC	3328	8849	11.23	14.27	105					
1-20-92G			11.15	13.85		-2	+11	11	35	1.3
CITY MO ST	3326	8848	35.07	38.78	107					
1-20-92A			35.16	38.46		+3	+8	9	181	1.6
CITY SC ST	3327	8849	?????	?????	??					
1-20-92D			30.72	39.94		?	?	?	105	1.6
HI-TECH	3326	8850	24.20	29.49	99					
1-20-92C			23.90	29.29		-9	+5	10	101	2.0
MSU BAND	3327	8847	07.92	05.96	120					
1-20-92J			07.69	05.79		-7	+4	8	122	1.3
1-20-92K			06.54	05.53		-42	+11	43	2	1.3
MSU EAST	3327	8847	13.15	10.64	116					
1-20-92H			12.64	10.82		-16	-5	17	104	1.4

TABLE 7. TWO UNITS OPERATING IN 2-D DOUBLE DIFFERENCING MODE

STA-WELL DATE	FIXED/OBSERVED POSITION DEG-MIN LAT	LON	SECONDS LAT	LON	ALT (M)	GPS POSITIONAL RESULTS ERROR(METERS) LAT	LON	POS	FIX NO.	PDOP
D 58	3328	8843	37.79	05.59	84					
1-11-92M			37.66	05.69		-4	+3	5	39	2.0
MAYHAW AZ	3328	8840	39.92	32.93	73					
1-11-92O			40.03	32.87		+4	-2	4	38	1.8
6928	3328	8846	08.05	37.55	85					
1-11-92K			07.89	37.71		-5	+4	6	40	1.5
7101	3328	8847	04.98	34.28	107					
1-11-92J			04.71	34.29		-8	0	8	40	1.7
8405	3328	8844	37.54	04.97	83					
1-11-92L			37.48	05.16		-2	+5	5	39	2.4
8408	3328	8841	37.79	44.94	77					
1-11-92N			37.84	44.97		+2	+1	2	39	1.8
8601	3327	8848	56.94	32.00	114					
1-11-92I			57.16	31.56		+7	-11	13	40	1.9
8605	3327	8849	49.64	56.37	98					
1-11-92H			49.53	56.74		-4	+9	10	41	2.2
8607	3327	8850	42.99	43.13	94					
1-11-92G			43.31	42.85		+10	-7	12	39	2.6
8612	3326	8850	44.61	42.39	101					
1-11-92F			44.65	42.53		+1	+4	4	38	1.6
8613	3326	8850	30.63	42.53	101					
1-11-92E			30.63	42.50		0	-1	1	41	1.8
8614	3326	8850	11.36	41.64	99					
1-11-92D			11.13	41.85		-7	+5	9	40	2.0
BORDEN	3327	8848	43.02	38.10	116					
1-20-92G			43.06	38.26		+1	+4	4	102	1.4
CITY AC RD	3326	8849	26.14	00.42	99					
1-20-92B			25.53	00.96		-19	+14	24	100	2.8
CITY CURRY	3328	8849	07.49	02.13	114					
1-20-92E			07.62	02.15		+4	+1	4	104	1.4
CITY MO ST	3326	8848	35.07	38.78	107					
1-20-92A			35.06	38.72		0	-2	2	103	1.6
CITY SC ST	3327	8849	?????	?????	???					
1-20-92D			30.71	40.29		?	?	?	103	1.6
HI-TECH	3326	8850	24.20	29.49	99					
1-20-92C			24.46	29.24		+8	-6	10	101	2.0
MSU BAND	3327	8847	07.92	05.96	120					
1-20-92J			07.79	05.79		-4	-4	6	102	1.3
MSU EAST	3327	8847	13.15	10.64	116					
1-20-92H			?????	?????					0	