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VIDEO TECHNIQUE FOR ZEBRA MUSSEL QUANTIFICATION IN THE WESTERN BASIN OF LAKE ERIE

by

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MANAGEMENT PERSPECTIVE

Title: Video technique for zebra mussel quantification in the western basin of Lake Erie

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Issue: Lakewide management plans for Lake Erie require that the impact of the zebra mussel (Dreissena polymorpha) and its variants be understood and dealt with. A recent trend toward colonization of offshore (soft substrate) areas raises concerns regarding the role of substrate type plays in limiting the spread of ZM. This publication address the important issue of accurate quantification of ZM colonies using remote techniques in western Lake Erie.

Current status: The overall study of relationships between zebra mussel colonization and substrate in offshore (soft sediment) areas of western Lake Erie began in 1994 and will continue until 1997. This step deals with the analysis of video-camera data from field surveys in 1994.

Next steps: These results will be combined with larger-scale survey images from side-scan surveys to produce an order-of-magnitude estimation of the ZM population in western Lake Erie. Such an estimate and the details of the spatial distribution pattern will be useful in characterizing the impact of ZM on offshore soft-sediment areas.

ABSTRACT

This report was prepared under contract by Hydrisar, Ltd. with the aim of developing an accurate means of quantifying the coverage of zebra mussels (Dreissena) using video images. Problems encountered include variation in horizontal scale due to changing camera distance, low visibility, variable size distribution of the mussels, and inability to distinguish dead from live mussels. Zebra mussel quantification from the video footage was carried out by a number of steps:

- Manually counting the number of alive and dead mussels in each of 105 video frames,
- Calculating the percentage of ground coverage by zebra mussels (both dead and alive) for each of the selected frames,
- Determining the altitude of the camera for each of the selected frames in order to determine the area of the lake floor coverage by the camera at the given altitude for the selected frames,
- Determining the number of zebra mussels per metre squared on the lake floor, based on the number of mussels counted and the area of lake-floor coverage by the camera.

Zebra mussel quantification proved to be very dependent on defining an accurate scale (Z value). The results from the 105 frames counted showed a fairly uniform distribution of zebra mussel populations throughout the sites filmed in the Western Basin of Lake Erie. It was found that the average coverage ranged from 1000-2000 mussels per metre squared on sediments, while on hard rock the populations rose to almost 5000 mussels / m^2. This figure represents only the surface layer and is therefore difficult to compare with quadrat sample counts based on the top 4 cm.

INTRODUCTION

Video footage of Western Lake Erie's bottom was collected from 12 stations during a research cruise aboard the RV Hydra during August 1994. The purpose of the footage was to record zebra mussel infestation on the lake floor and to act as a tool, along with sidescan sonar imagery, for quantifying zebra mussel populations in the lake.

The following report (1) explains the method used to quantify zebra mussel populations from the video footage and (2) lists the results of the zebra mussel quantification from the video footage collected in 1994.

OVERVIEW OF THE BASIC PROCESS

The video footage was collected using a Benthos underwater camera that was lowered over the side of the RV Hydra. The images collected by the camera were transmitted to a control system on the boat where they were recorded onto VHS.

At the University of Toronto, zebra mussel quantification from the video footage was carried out by a number of steps which included (1) manually counting the number of alive and dead mussels in each of 105 video frames, (2) calculating the percentage of ground coverage by zebra mussels (both dead and alive) for each of the selected frames, (3) determining the altitude of the camera for each of the selected frames, (4) determining the area of the lake floor coverage by the camera at the given altitude for the selected frames, and (5) determining the number of zebra mussels per metre squared on the lake floor, based on the number of mussels counted and the area of lake-floor coverage by the camera.

The results from each frame were tabulated and totalled. The results are presented at the end of this report (Appendix A).

THE STEP-BY-STEP QUANTIFICATION PROCESS

Video Frame Selection

It was decided that approximately 100 frames would be counted from the two hours worth of video footage collected. The basic criteria used in selecting video frames to count were (1) The footage had to be of quality good enough to yield a reasonably accurate count (see section 2.1.2 on counting), (2) the lens of the Benthos camera had to be aimed directly downward at the lake floor. This angle (90°) was essential since frames in which the lens was not pointed perpendicular to the lake floor had distorted dimensions. This distortion allowed for potential errors in altitude and area coverage calculations, as will be discussed later in the report. (3) Frames which contained footage that appeared in previously counted frames were not counted. These exclusions were made to avoid counting the same zebra mussels multiple times. Finally, (4), an attempt was made to select a wide variety of frames (ranging from extremely high to extremely low mussel population) to reflect the diversity of the zebra mussel distributions.

Video quality permitting, a count was done every 10-20 frames. The frame number displayed by the counter on the VCR was recorded for each count to reference it, where frame 0 represents the first frame of the tape. Note that the counts were done using two different tape formats: VHS and 8mm (see equipment table).

Manual Counting

Once a frame was selected it was paused and counted. Two separate counts were conducted for each frame. The first was for alive zebra mussels and the second was for dead ones. Alive mussels were differentiated from dead mussels by colour. It was decided that black (dark) shells represented alive mussels and white shells represented dead mussels (note that only white shells of significant size were counted since in some frames the dead shells were fragmented).

Quantification was done by manually counting one zebra mussel at a time until all the mussels in the selected frame had been accounted for. As a consistency check, each count was conducted at least twice. In some regions of the selected frames, where the images were slightly blurred, approximation was required to determine mussel totals. This approximation is reflected in the range value accompanying each count. For example, the following mussel counts were obtained from the first frame counted at station #3.

Station #	Frame #	A-Mus	Range	D-Mus	Range	T-Mus	Range
3	23	210	195-225	95	90-120	305	285-345

Here 210 alive mussels were counted. However, because of unclear mussel definition in the frame, the number of alive mussels could range from 195-225 (approximately). Therefore, the purpose of the range value is simply to express the relative "exactness" of the count. Similarly, 95 dead mussels were counted; however, the "exact" number of dead mussels could range anywhere from 90 to 120. Relatively speaking, a very accurate count would have a range of +5/-5. However, at high camera altitudes, or in extremely populated areas, a count with a +5/-5 range is nearly impossible because of the size of the mussels in the frame and/or the vast number of mussels in the frame. Therefore, ranges as high as +40/-40 were not uncommon at high altitudes or in extremely populated areas.

Note that the total mussel values are just the sum of the alive and dead mussel values.

Determining Percent Coverage

In addition to the mussel counts described above, the percentage of frame covered by both alive and dead mussels was determined. The values for alive percent coverage and dead percent coverage were determined by visual approximation. The total percent coverage value was obtained by adding the percent coverages of the alive and dead mussels.

The reason for determining the percent coverage was to give an idea of the relative population densities of the mussel beds, since, for example, it is hard to visualize what a density of 1714 mussels per metre squared "looks like". It is important to note the altitude of the camera when considering the percentage coverage, since at low altitudes it is possible to have high percentage coverages and low mussel counts. The reverse can also hold true at high camera altitudes.

Determining the Camera Altitude

Knowing the altitude of the camera is useful since it can help correlate values such as mussel populations and percentage coverages (see above paragraph).

The basis for the determination of the camera altitude (and camera area coverage -- see next section) is the use of a constant, Z, that represents the average length (long dimension) of the zebra mussels being counted. For this quantification study, a Z value of 1cm was used. This value was determined from two sources. The first source was a mussel-covered rock collected during the 1994 survey. The average mussel length (Z value) on the sample was 1cm. The second source was the video footage itself. In some frames of the footage, where the camera was resting on the lake floor, the camera lens was rotated so that the hoop, (support frame) of the camera could be seen. It was observed that the average mussel length in these frames was the same as the diameter of the hoop which has a diameter of 1cm.

With the determined Z value, the width of the frame was calculated by measuring how many averaged-size mussels (averaged-size from that particular frame) fitted across the screen multiplied by the Z value, since at different camera altitudes the mussels appeared to be of different lengths.

Sample Calculation: Station #3, Frame #23

Number of mussels that fit across the width of the frame = X = 49, Z = 1cm

Therefore, screen width = (49)(1) = 49cm

Once the screen width was calculated, the camera altitude was determined from a graph of camera altitude vs frame width (see graph in Appendix B), plotted from Benthos camera specifications.

DETERMINING THE CAMERA-AREA COVERAGE

Determining the area of lake floor that the camera covered at a given altitude was the key step in determining the "mussels per metre squared" values.

The process used to determine the area coverage made use of the Z value described in the above section. Quite simply, the area was calculated by multiplying the frame width by the frame height (see section 3.3, Calculating Area Coverage). It was determined that for both monitors used during the mussel counts (see list of equipment) the ratio of screen width to screen height was 1.35:1. Therefore, the area coverage was calculated using the following relationship (see Appendix B for derivation):

$$A = (ZX)^2/1.35$$

Where A is the area covered by the camera, Z is the Z value described in section 2.1.4 which is equal to 1cm, and X is the number of averaged-size mussels that fit across the width of the screen. Note that although area is a function of the camera altitude, the camera altitude plays no part in the above area equation. Again, see section 3.3, Calculating Area Coverage.

Sample Calculation: Station #3, Frame #23

$A = (ZX)^2/1.35$

$A = [(0.01)(49)]^2/1.35$

$A = 0.178m^2$

Determining Mussel Populations Per Metre Squared

Once the area coverage was calculated for each frame, it was possible to derive a value that represents the mussels per metre squared. It is important to note that the value assumes that the area which makes up the metre squared, is identical to the area covered by the frame. The importance of this value is that it allows for comparison between values obtained from different frames that may have covered different areas.

To calculate the mussels per metre squared, the number of counted mussels was divided by the calculated area. This calculation was done separately for the alive mussels and dead mussels. (Note the value for the total mussels is the sum of the alive and dead mussels.)

Sample Calculation: Station #3, Frame #23

Alive Mussels = 210

Area = $0.178 m^2$

Therefore,

Alive Mussels per metre squared (A/m^2) = 210/0.178 = 1180 mussels/m^2.

Notes

During the mussel counts an effort was made not only to include frames with average coverage, but also to take into account frames of abnormally high or low population density. The reason was to reflect the diversity of mussel coverage along the lake floor. Counts of frames in which abnormally high or low population densities were encountered were noted by placing an * in the last column of the mussel count result tables (Appendix A). Simple inspection of the values pertaining to the specific * frame will reveal whether the population was abnormally high or low. In some cases an * was placed where the number of alive mussels may have been average, but the number of dead mussels high or low (or vice versa). In addition to the use of an * in the notes column of the result tables, an @ sign was used to signify that the camera was resting on the lake floor for that particular frame.

Equipment Table

Station #	Equipment used for counts	Number of frames counted
3	Zenith VR 1861-1 VCR with an Electrohome Sherbrooke #18-C30414-21 monitor (VHS format)	29
6	Sony EV-A300U Video-8 tape player with a Panasonic BT-H1350-Y monitor (8mm format)	16
7	Sony EV-A300U Video-8 tape player with a Panasonic BT-H1350-Y monitor (8mm format)	25
8	Sony EV-A300U Video-8 tape player with a Panasonic BT-H1350-Y monitor (8mm format)	8
12	Zenith VR 1861-1 VCR with an Electrohome Sherbrooke #18-C30414-21 monitor (VHS format)	15
13	Zenith VR 1861-1 VCR with an Electrohome Sherbrooke #18-C30414-21 monitor (VHS format)	12
14	Zenith VR 1861-1 VCR with an Electrohome Sherbrooke #18-C30414-21 monitor (VHS format)	7
Totals		112

Note that the video frame reference numbers do not coincide between the two tape formats (i.e., VHS frame #1400 is not the same as 8mm frame #1400).

DISCUSSION OF ERRORS

Selecting the Z Value

The greatest possible source of error in this study was the selection of an incorrect Z value. Zebra mussels have been known to range in size up to 4cm long. The Z value is the key component of the camera ground-coverage calculation which is directly related to the value obtained for the number of mussels per metre squared. Although measurements were made to ensure that an accurate Z value was used, the following example illustrates the direct relationship between the Z value and the subsequent results of a mussel count.

Using a Z value = 2cm for the Station #3, Frame # 23 count, the following results were obtained:

Alt (m)	SA (m^2)	A-Mus	D-Mus	T-Mus	A/m^2	D/m^2	T/m^2
1.08	0.711	210	95	305	295	134	429

Note that the actual results obtained for a Z value of 1cm were:

Alt (m)	SA (m^2)	A-Mus	D-Mus	T-Mus	A/m^2	D/m^2	T/m^2
0.54	0.178	210	95	305	1180	534	1714

Therefore, it can be seen that a Z value which differs by a factor of two causes the results of the count to differ by a factor of four. Similarly a Z factor which differs by a factor of 3, causes the count to differ by a factor of nine (i.e., the relationship is exponential).

Although everything possible was done to ensure an accurate Z value, the following table shows percent errors for the entire count based on possible differences between the applied Z value and the actual Z value.

Z_{actual} - $Z_{applied}$ (cm)	T/m^2	% difference
-0.75	30640	1500
-0.5	7660	300
-0.25	3404	78
0	1915	0
0.25	1226	36
0.5	851	56
0.75	625	67
1.0	479	75

In the above example the applied Z value equaled 1cm. Note that the 4th row of data (Zactual - Zapplied = 0) is the data that appears in the Totals result chart.

Allowing for Field of View Distortion

For a frame to be counted it was essential that the lens of the camera be aimed directly downward at the lake floor. Recorded Benthos images in which the camera was not pointed directly downward had a distorted field of view which made it impossible to accurately calculate the area coverage for the particular frame. However, there was no way of monitoring when the camera was aimed exactly downward. Therefore some of the area calculations may have been slightly off because of field of view distortions created by the camera. At low camera altitudes distortion played a very insignificant role. However at higher altitudes (>1.0m) the effects of distortion became more significant (note that the majority of frames counted in this study were at altitudes < 1.0m). The magnitude of these distortions was not calculated during this study; however, they should be kept in mind when interpreting the data.

Calculating Area Coverage

The area covered by the camera in each frame was calculated by multiplying the width of the frame by the height of the frame (see section 2.1.5). The results obtained were in no way erroneous. However, an alternate method was available which made use of the Benthos camera specifications. The specifications related camera altitude to camera area coverage. However, it was found that at very low camera altitudes (<1.0m) the specifications failed because of their asymptotic nature near the origin (see graph in Appendix B). Calculations were carried out using the area given by the specifications and assuming a Z value = 1cm. The results yielded numbers in the range of 100,000 mussels per metre squared in densely populated areas. From inspection alone it can be seen that surface numbers of this size are virtually impossible. For example, assume one mussel took up an area of 0.5 cm^2 (1 x 0.5 cm). In 1m^2 the maximum number of mussels covering the surface would be no more than 20,000.

Therefore, the Benthos camera specifications for area coverage were not used in this study.

DISCUSSION

Counting zebra mussels manually from video footage proved to be a very time-consuming process. However, the results showed significant consistencies. For example, all the frames counted (except frames 1340-1452 in station #7) produced an average in the range of 1000-2000 mussels per metre squared. It is interesting to note that most of these counts were of mussel populations that had formed on the lake-floor sediments. As expected, the mussel populations were significantly higher in regions of hard substrate, such as rock. Station #7 results showed that in the moraine region of the footage (frames 1340-1452), the mussel population was near 5000 mussels per metre squared.

Another interesting observation was the extremely low number of dead mussels at stations 12, 13, and 14. However, it should be noted that in the footage of these stations, there appeared to be a fairly significant amount of sediment transport (the water column was very cloudy). Therefore, the low dead mussel counts may have been a result of the dead mussels being buried quickly.

With buried mussels in mind, it is extremely important to note that the results of this study represent zebra mussel lake-floor coverage viewed from an aerial position (i.e., two dimensional view point). Mussels embedded under other mussels, under sediments, and/or under the rocks could not be accounted for in this study. Therefore the results of this study should be interpreted as a minimum lake-floor-coverage.

112 frames in total were studied during the quantification. Seven of the 112 frames were used only to get percent-coverage values, since the altitude of the camera and clarity of the individual mussels in each of the frames were too poor to conduct manual counts. The remaining 105 frames were manually counted.

Although the 1994 data set lists 16 stations, video footage was collected at only stations 3,5,6,7,8,10,11,12,13,14,15, and 16. The remainder of the stations were sediment sampling stations. Of the above video-footage stations, only stations 3,6,7,8,12,13, and 14 produced data that was countable. The other stations were either completely mussel free, or water column turbulence was so great during filming that usable images were not produced. See Appendix C for maps showing the location of each station.

The key to an accurate study done in a manner similar to this one is having precise Z values. Determining such a value is difficult since zebra mussels can vary greatly in size over a small area. Therefore, future studies of this kind should make use of as many 'scaling' devices (devices attached to the camera to help measure the average mussel size) as possible to ensure the Z values are accurate.

CONCLUSIONS

In conclusion, manually counting zebra mussels as a way of quantifying populations proved to be very dependent on defining an accurate scale (Z value).

The results from the 105 frames counted showed a fairly uniform distribution of zebra mussel populations throughout the sites filmed in the Western Basin of Lake Erie. It was found that the average coverage ranged from 1000-2000 mussels per metre squared on sediments, while on hard rock the populations rose to almost 5000 mussels per metre squared.

APPENDIX A

Legend: 1994 Lake Erie Zebra Mussel Survey Data Set

Station # - site of video footage
Frame # - frame counter number on tape player
Alt (m) - camera altitude in metres
SA (m^2) - area of camera's field of view calculated from frame
A-Mus - alive mussels counted in frame
Range - possible range of alive mussels in frame
D-Mus - dead mussels counted in frame
Range - possible range of dead mussels in frame
T-Mus - total mussels counted in frame (alive + dead)
Range - possible range of total mussels in frame
%-A - percentage of frame covered by alive mussels
%-D - percentage of frame covered by dead mussels
%-T - percentage of frame covered by all mussels (alive + dead)
A/m^2 - number of alive mussels per metre squared
D/m^2 - number of dead mussels per metre squared
T/m^2 - number of total mussels (alive + dead) per metre squared
Notes - additional comments: * - extreme frame (very high or very low mussel population)
@ - camera frame resting on lake floor

1994 Lake Erie Zebra Mussel Survey - Pelee, Station #3

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
3	23	0.54	0.178	210	195-225	95	90-120	305	285-345	25	8	33	1180	534	1714	
3	35	0.35	0.076	350	320-400	100	90-110	450	410-510	84	8	92	4605	1316	5921	*
3	42	0.61	0.224	480	460-530	160	150-170	640	610-700	60	10	70	2143	714	2857	*
3	55	0.48	0.137	430	410-500	170	160-180	600	570-680	75	5	80	3139	1241	4380	*
3	70	0.68	0.276	660	630-720	165	155-175	825	785-895	55	5	60	2391	598	2989	
3	87	0.55	0.185	470	450-530	210	190-240	680	640-770	57	8	65	2541	1135	3676	
3	115	0.73	0.323	520	500-560	175	165-190	695	665-750	47	8	55	1610	542	2152	
3	154	0.32	0.062	105	95-115	38	35-44	143	130-159	20	5	25	1694	613	2307	
3	172	0.28	0.046	150	135-165	53	48-58	203	183-223	60	10	70	3261	1152	4413	*
3	192	0.4	0.096	265	255-285	50	45-55	315	300-340	8	42	50	2760	521	3281	
3	209	0.31	0.058	100	90-110	35	30-40	135	120-150	22	8	30	1724	604	2328	
3	218	0.31	0.058	145	135-165	56	48-64	201	183-229	43	12	55	2500	966	3466	
3	231	0.28	0.046	180	170-200	70	60-80	250	230-280	45	10	55	3913	1522	5435	*
3	238	0.31	0.058	200	190-220	67	62-75	267	252-295	60	10	70	3448	1155	4603	
3	302	0.31	0.058	64	60-70	50	45-60	114	105-130	10	8	18	1104	862	1966	
3	307	0.25	0.039	70	65-75	24	20-28	94	85-103	17	8	25	1795	615	2410	
3	314	0.26	0.043	55	50-60	34	30-40	89	80-100	12	13	25	1279	791	2070	
3	320	0.23	0.033	50	45-55	13	11-15	63	56-70	17	8	25	1515	394	1909	@
3	325	0.23	0.033	10	8-12	19	16-22	29	24-34	3	5	8	303	576	879	*@
3	348	0.23	0.033	43	40-46	13	10-16	56	50-62	13	2	15	1303	394	1697	@
3	437	0.9	0.486	575	559-625	90	80-110	665	630-735	35	5	40	1183	185	1368	
3	444	0.9	0.486	250	230-280	140	125-160	390	355-440	13	7	20	514	288	802	*
3	506	0.58	0.2	30	25-35	97	87-107	127	112-142	2	5	7	150	485	635	*
3	533	0.57	0.193	190	175-205	30	25-35	220	200-240	35	5	40	985	155	1140	
3	549	0.39	0.091	80	75-85	40	35-45	120	110-130	15	5	20	879	440	1319	
3	584	0.37	0.081	52	45-54	70	60-80	122	105-139	5	8	13	642	864	1506	*
3	677	0.48	0.137	160	145-185	36	30-42	196	175-227	25	5	30	1168	263	1431	
3	747	0.88	0.462	370	350-410	77	67-87	447	417-497	15	5	20	801	167	968	
3	767	0.88	0.462	250	230-380	75	65-85	325	295-365	13	5	18	541	162	703	
Totals	**23-767**			**6514**		**2252**		**8766**					**51071**	**19254**	**70325**	
Mean				**225**		**78**		**303**		**31**	**8**	**39**	**1761**	**664**	**2425**	

1994 Lake Erie Zebra Mussel Survey - Pippe B, Station #6

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
6	922	0.92	0.51	100	95-110	57	50-57	157	145-16	5	2	7	196	112	308	
6	942	0.92	0.51	95	90-100	62	58-65	157	148-16	5	1	6	186	122	308	
6	966	0.39	0.091	40	38-45	24	22-26	64	60-71	6	3	9	440	264	704	
6	983	0.4	0.096	15	14-18	33	30-35	48	44-55	4	4	8	156	344	500	*
6	1000	0.32	0.062	65	55-75	25	22-29	90	77-104	12	3	15	1048	403	1451	
6	1004	0.32	0.062	35	30-40	70	65-70	105	95-115	7	6	13	565	1129	1694	
6	1011	0.31	0.058	9	8-10	18	17-19	27	25-29	1	2	3	155	310	465	*
6	1014	0.31	0.058	125	120-135	40	36-44	165	156-17	15	5	20	2155	690	2845	
6	1022	0.24	0.036	350	330-380	42	40-45	392	370-42	75	5	80	9722	1167	10889	*
6	1033	0.43	0.113	75	70-80	21	19-23	96	89-103	12	2	14	664	186	850	
6	1047	0.24	0.036	130	120-140	75	70-80	205	190-22	42	8	50	3611	2083	5694	*
6	1064	0.31	0.058	35	32-40	28	26-30	63	58-70	7	3	10	603	483	1086	
6	1073	0.31	0.058	8	7-9	11	10-12	19	17-21	1	1	2	138	190	328	*
6	1081	0.23	0.033	17	14-20	14	13-15	31	27-35	16	9	25	515	424	939	@
6	1104	0.24	0.036	37	35-40	28	26-30	65	61-70	7	3	10	1028	778	1806	
6	1116	0.24	0.036	120	110-130	59	56-62	179	166-19	25	15	40	3333	1639	4972	*
Totals	**922-1116**			**1256**		**607**		**1863**					**24515**	**10324**	**34839**	
Mean				**79**		**38**		**117**		**15**	**5**	**20**	**1532**	**645**	**2177**	

1994 Lake Erie Zebra Mussel Survey - Pippe B, Station #7

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
7	1172	0.47	0.131	50	500-800	195	180-210	245	225-265	3	10	13	382	1489	1871	
7	1179	0.35	0.076	425	87-97	195	50-60	480	410-510	75	5	80	5592	2566	8158	*
7	1181	0.35	0.076	92	360-450	55	175-215	287	267-307	35	15	50	1211	724	1935	
7	1190	0.27	0.046	10	0-10	175	170-180	185	170-195	0	10	10	217	3804	4021	*
7	1206	1.01	0.613							20	10	30				
7	1238	1	0.6	0	0-50	160	155-200	160	155-250	0	5	5	0	267	267	*
7	1261	1.01	0.613	0	0-50	175	170-210	175	170-260	0	5	5	0	292	292	*
7	1317	0.52	0.164	0	0-10	74	70-8074	74	70-90	0	4	4	0	451	451	
7	1318	0.42	0.107	180	160-200	78	70-86	258	230-286	15	5	20	1682	729	2411	*
7	1322	0.43	0.113	0	0-10	80	75-85	80	75-95	0	5	5	0	708	708	*
7	1333	0.42	0.107	0	0-10	78	73-83	78	73-93	0	5	5	0	729	729	*
7	1340	0.23	0.033	105	100-115	40	38-42	145	138-157	60	10	70	3182	1212	4394	@
7	1349	0.23	0.033	140	130-150	36	34-38	176	164-188	65	5	70	4242	1091	5333	@
7	1356	0.25	0.039	105	95-115	42	38-46	147	133-161	45	10	55	2692	1077	3769	
7	1363	0.5	0.15	650	600-800	100	90-110	750	690-910	53	7	60	4333	667	5000	
7	1368	0.52	0.164	450	400-600	60	57-63	510	457-663	50	7	57	2744	366	3110	
7	1374	0.25	0.039	135	125-145	65	60-70	200	185-215	50	10	60	3461	1667	5128	
7	1380	0.23	0.033	160	150-190	69	63-75	229	213-265	65	30	95	4848	2090	6938	*@
7	1394	0.41	0.101	300	280-340	65	60-70	365	340-410	60	5	65	2970	644	3614	
7	1397	0.34	0.071	310	290-340	108	105-111	418	395-450	63	7	70	4366	1521	5887	
7	1401	0.26	0.043	72	67-79	106	102-110	178	169-189	12	8	20	1674	2465	4139	*
7	1408	0.25	0.039	190	180-210	112	108-118	302	288-328	40	25	65	4872	2872	7744	
7	1411	0.23	0.033	100	95-105	91	86-96	191	181-211	60	25	85	3030	2758	5788	@
7	1439	0.5	0.15	250	240-270	106	100-112	356	340-382	55	10	65	1667	707	2374	
7	1452	1.46	1.33							55	10	65				
Sub Totals	**1172-1333**			**757**		**1265**		**2022**					**9084**	**11759**	**20843**	
Mean				**76**		**127**		**203**		**14**	**7**	**21**	**908**	**1176**	**2084**	
Sub Totals	**1340-1452**			**2967**		**1000**		**3967**					**44081**	**19137**	**63218**	
Mean				**228**		**77**		**305**		**52**	**12**	**64**	**3391**	**1472**	**4863**	
Totals	**1172-1452**			**3724**		**2265**		**5989**					**53165**	**30896**	**84061**	
Mean				**162**		**98**		**260**		**35**	**10**	**45**	**2312**	**1343**	**3655**	

1994 Lake Erie Zebra Mussel Survey - Pippe B, Station #8

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
8	1520	0.99	0.587							60	5	65				*
8	1532	0.99	0.587							23	2	25				
8	1550	0.99	0.587							10	2	12				*
8	1566	0.99	0.587							23	2	25				
8	1597	0.58	0.2	260	230-300	37	34-40	297	264-340	22	3	25	1300	185	1485	
8	1600	0.6	0.216	230	210-255	28	24-32	258	234-287	24	1	25	1065	130	1195	
8	1624	0.23	0.033	23	21-25	9	7-11	32	28-36	7	1	8	697	273	970	*@
8	1631	0.99	0.587							55	5	60				*
Totals	**1520-1631**			**513**		**74**		**587**					**3062**	**588**	**3650**	
Mean				**171**		**25**		**196**		**28**	**3**	**31**	**1021**	**196**	**1217**	

1994 Lake Erie Zebra Mussel Survey - Erie A, Station #12

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
12	3791	0.37	0.081	20	17-23	3	1-5	23	18-28	3	1	4	247	37	284	*
12	3800	0.28	0.046	80	75-85	2	0-4	82	75-89	19	1	20	1739	44	1783	
12	3806	0.29	0.05	75	70-80	0	0-4	75	70-84	25	0	25	1500	0	1500	
12	3812	0.26	0.043	75	70-80	0	0-3	75	70-84	30	0	30	1744	0	1744	
12	3819	0.29	0.05	52	48-60	0	0-5	52	48-65	20	0	20	1040	0	1040	
12	3824	0.41	0.101	130	120-140	5	2-10	135	122-155	20	2	22	1287	50	1337	
12	3832	0.44	0.119	97	90-105	8	6-10	105	96-115	9	1	10	815	67	882	
12	3848	0.33	0.067	62	56-70	4	2-6	66	58-76	14	1	15	925	60	985	
12	3866	0.38	0.086	90	80-100	9	6-12	99	86-112	18	2	20	1047	105	1152	
12	3878	0.49	0.143	14	10-16	1	0-3	15	10-19	3	1	4	98	7	105	*
12	3892	0.49	0.143	7	5-12	0	0-4	7	5-16	2	0	2	49	0	49	*
12	3898	0.49	0.143	13	11-16	2	1-5	15	12-21	3	1	4	91	14	105	*
12	3904	0.32	0.062	40	35-45	2	1-4	42	36-49	8	2	10	645	32	677	
12	3926	0.34	0.071	80	75-85	2	1-5	82	76-90	24	1	25	1127	28	1155	
12	3940	0.49	0.143	25	22-28	5	3-8	30	25-36	3	1	4	168	35	203	*
Totals	**3791-3940**			**860**		**43**		**903**					**12522**	**479**	**13001**	
Mean				**57**		**3**		**60**		**13**	**1**	**14**	**835**	**32**	**867**	

1994 Lake Erie Zebra Mussel Survey - Erie A, Station #13

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
13	3971	0.25	0.039	105	95-115	3	0-8	108	95-123	49	1	50	2692	77	2769	
13	3985	0.3	0.054	65	50-80	0	0-5	65	50-85	35	0	35	1148	0	1148	
13	3996	0.32	0.062	45	40-50	5	2-8	50	42-58	19	1	20	726	81	807	
13	4000	0.35	0.076	85	75-100	6	4-8	91	79-108	28	2	30	1118	79	1197	
13	4005	0.34	0.071	100	90-115	6	4-9	106	194-124	33	2	35	1408	85	1493	
13	4022	0.34	0.071	75	65-85	2	1-5	77	66-90	39	1	40	1056	28	1084	
13	4027	0.29	0.05	95	80-105	14	10-18	109	90-123	31	4	35	1900	280	2180	
13	4036	0.31	0.058	95	85-110	6	4-10	101	89-120	38	2	40	1638	103	1741	
13	4076	0.4	0.096	80	70-95	10	8-14	90	78-109	22	2	25	833	104	937	
13	4088	0.25	0.039	105	100-120	0	0-5	105	100-125	55	0	55	2692	0	2692	
13	4096	0.28	0.046	60	50-70	0	0-5	60	50-75	15	0	15	1304	0	1304	
13	4104	0.31	0.058	100	90-115	6	4-9	106	94-124	38	2	40	1724	103	1827	
Totals	**3971-4104**			**1010**		**58**		**1068**		**402**	**17**	**420**	**18239**	**940**	**19179**	
Mean				**84**		**5**		**89**		**34**	**1**	**35**	**1520**	**78**	**1598**	

1994 Lake Erie Zebra Mussel Survey - Erie A, Station #14

Station #	Frame #	Alt (m)	SA (m^2)	A-Mus	Range	D-Mus	Range	T-Mus	Range	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2	Notes
14	4203	0.37	0.081	85	80-105	9	6-12	94	86-117	20	2	22	1049	111	1160	
14	4215	0.43	0.113	200	170-220	18	13-23	218	183-253	53	2	55	1770	159	1929	
14	4223	0.41	0.101	150	130-170	29	24-34	179	154-204	50	5	55	1485	287	1772	
14	4245	0.41	0.101	9	7-11	13	10-16	22	17-27	1	1	2	89	129	218	*
14	4269	0.32	0.062	95	80-105	5	3-7	100	83-112	44	1	45	1532	81	1613	
14	4278	0.35	0.076	105	90-120	6	3-9	111	93-129	24	1	25	1382	79	1461	
14	4284	0.38	0.086	156	140-170	25	20-30	181	160-200	50	5	55	1814	291	2105	
Totals	**4203-4284**			**800**		**105**		**905**		**242**	**17**	**259**	**9121**	**1137**	**10258**	
Mean				**114**		**15**		**129**		**35**	**2**	**37**	**1303**	**162**	**1465**	

1994 Lake Erie Zebra Mussel Survey - Totals

Station #	A- Mus Total	A-Mus Mean	D-Mus Total	D-Mus Mean	T-Mus Total	T-Mus Mean	%-A	%-D	%-T	A/m^2	D/m^2	T/m^2
3	6514	225	2252	78	8766	303	31	8	39	1761	664	2425
6	1256	79	607	38	1863	117	15	5	20	1532	645	2177
7	3724	162	2265	98	5989	260	35	10	45	2312	1343	3655
8	513	171	74	25	587	196	28	3	31	1021	196	1217
12	860	57	43	3	903	60	13	1	14	835	32	867
13	1010	84	58	5	1068	89	34	1	35	1520	78	1598
14	800	114	105	15	905	129	35	2	37	1303	162	1465
Totals	**14677**	**892**	**5404**	**262**	**20081**	**1154**	**191**	**30**	**221**	**10284**	**3120**	**13404**
Mean	**2097**	**127**	**772**	**37**	**2869**	**164**	**27**	**4**	**31**	**1469**	**446**	**1915**

APPENDIX B

Derivation of the Camera-area Coverage Equation (Section 2.1.5)

$A = WH$

where W = the width of the frame, and H = the height of the frame.

Note that $W = 1.35H$

Therefore,

$A = W^2/1.35$

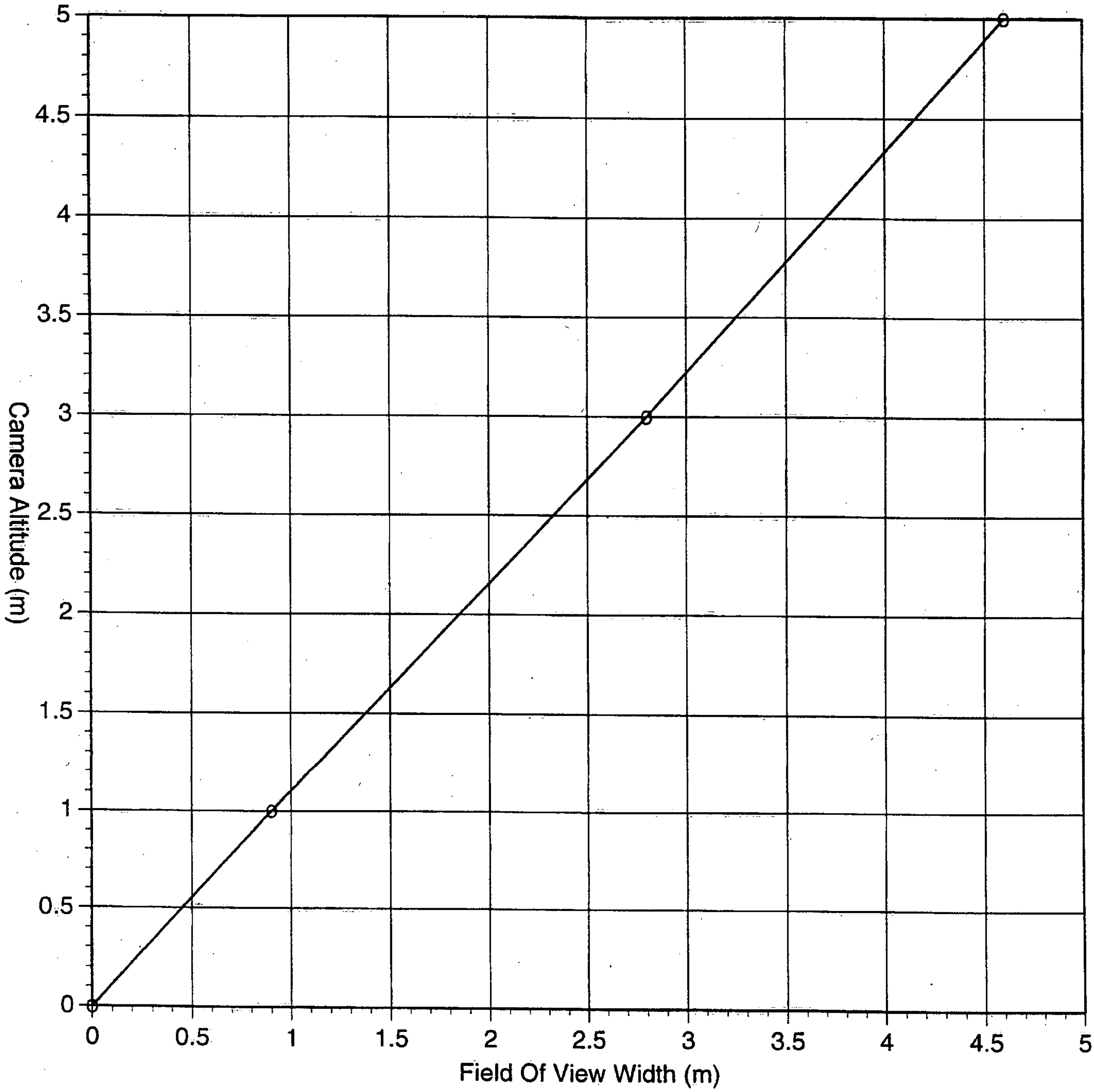
However,

$W = ZX$, where Z is the Z value, and X is the number of averaged size mussels that fit across the frame (section 2.1.4)

Therefore,

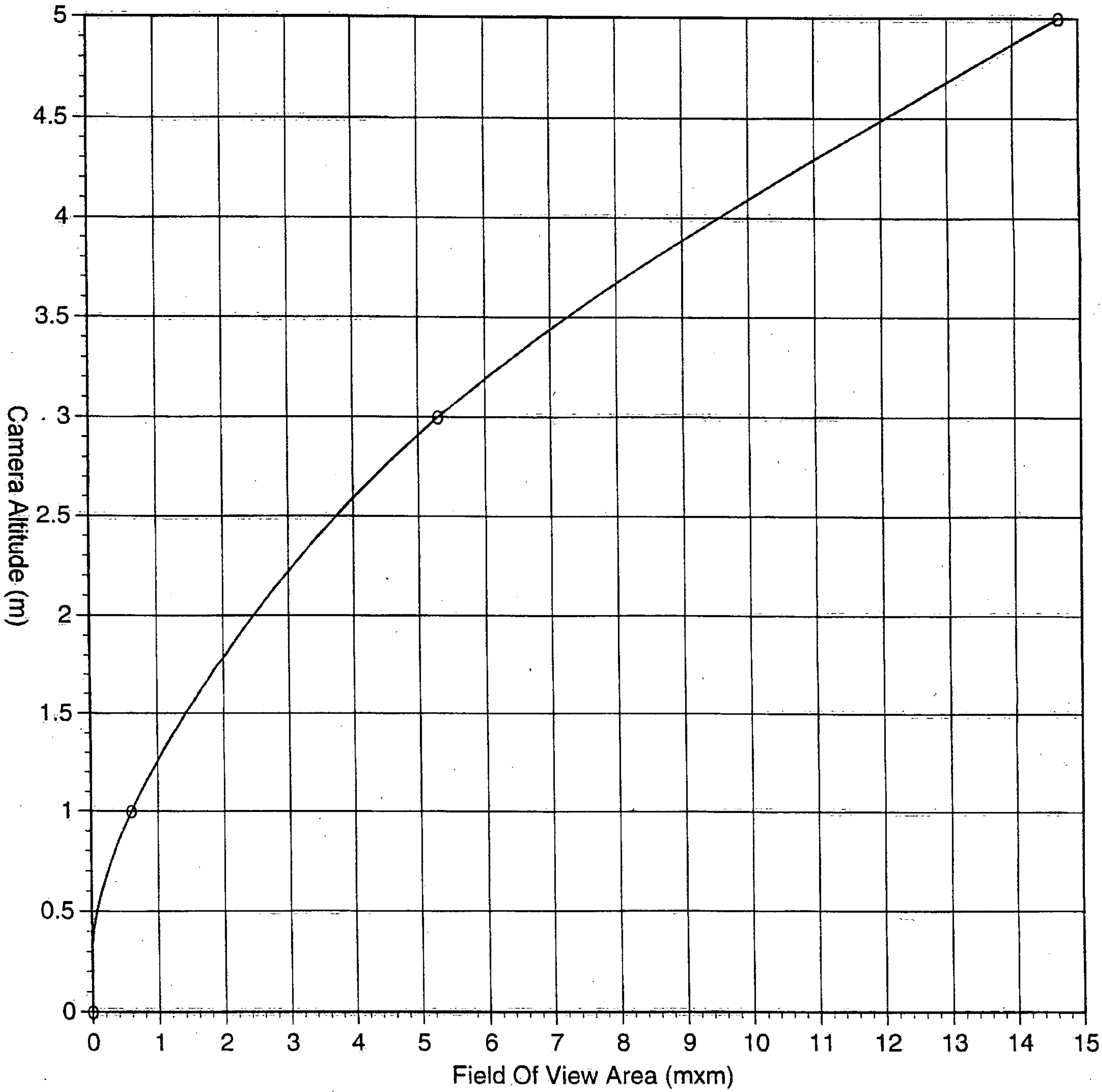
$$\mathbf{A = (ZX)^2/1.35}$$

Camera Altitude vs. Field Of View Width For The Benthos Model 378 Camera*



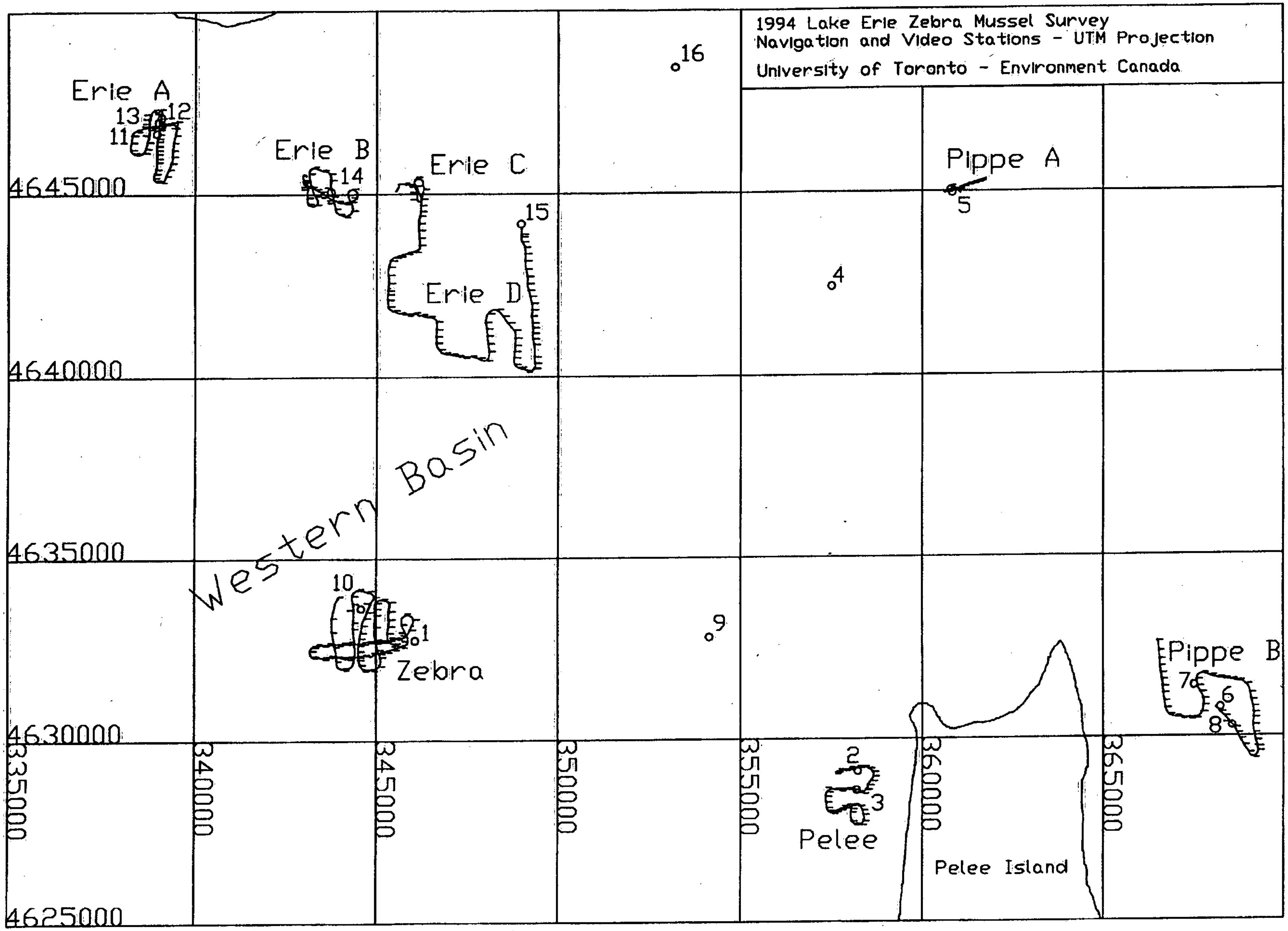
* standard 28 mm lens

Camera Altitude vs. Field Of View Area For The Benthos Model 378 Camera*



* standard 28 mm lens

APPENDIX C


1994 Lake Erie Zebra Mussel Survey
Navigation and Video Stations - UTM Projection
University of Toronto - Environment Canada
Erie A
Erie B
Erie C
Erie D
Pippe A
Pippe B
Western Basin
Zebra
Pelee
Pelee Island
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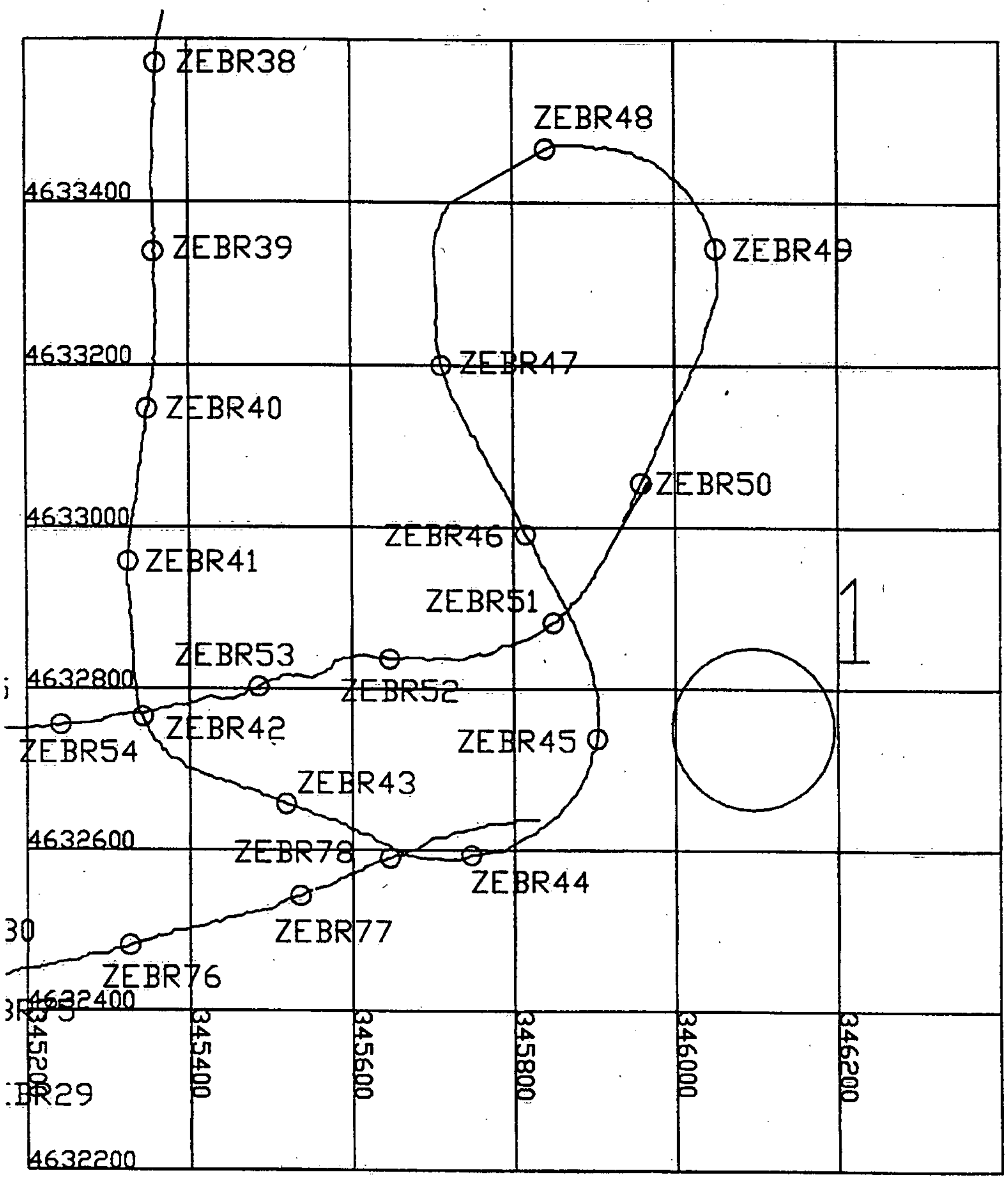

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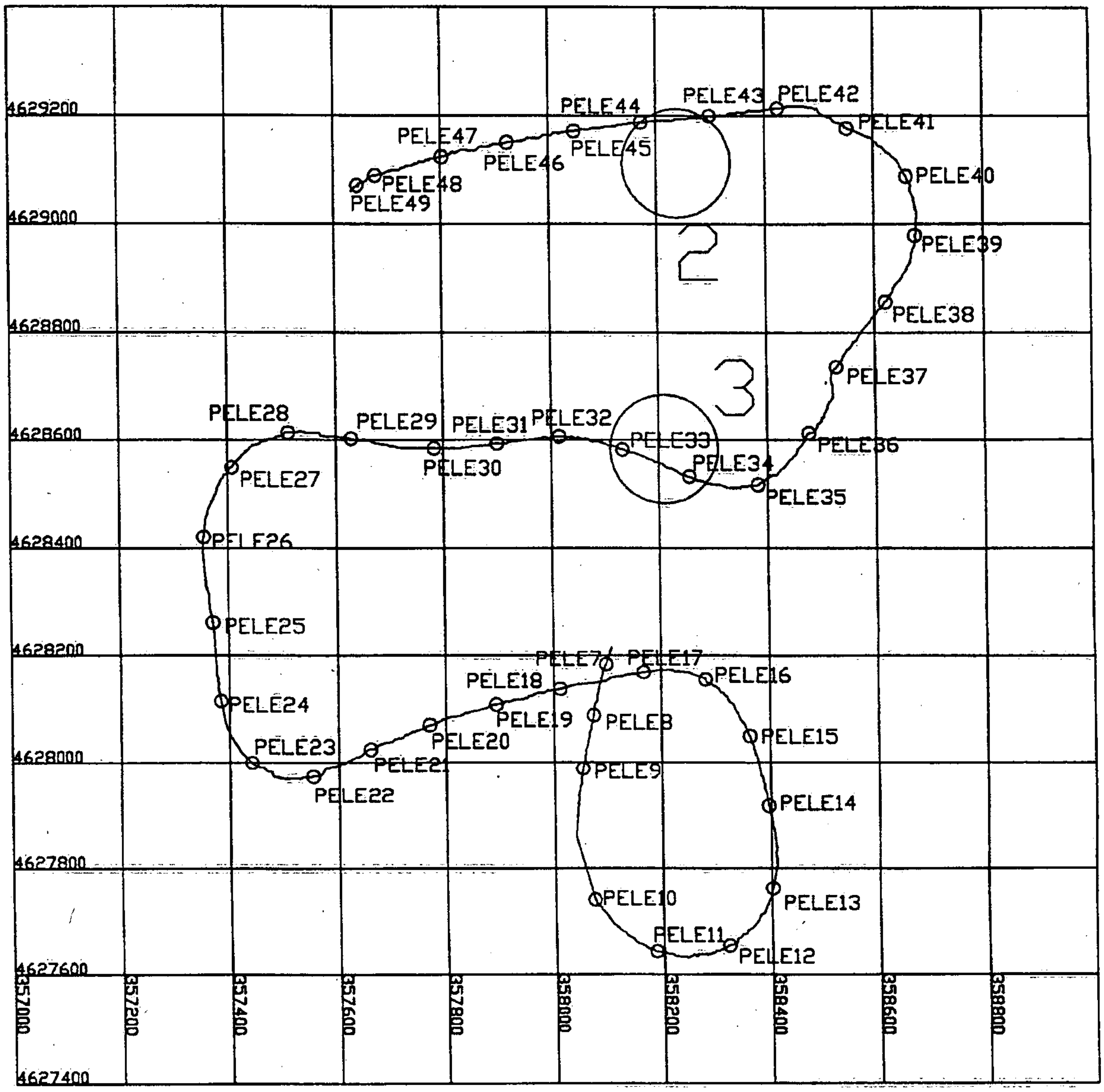

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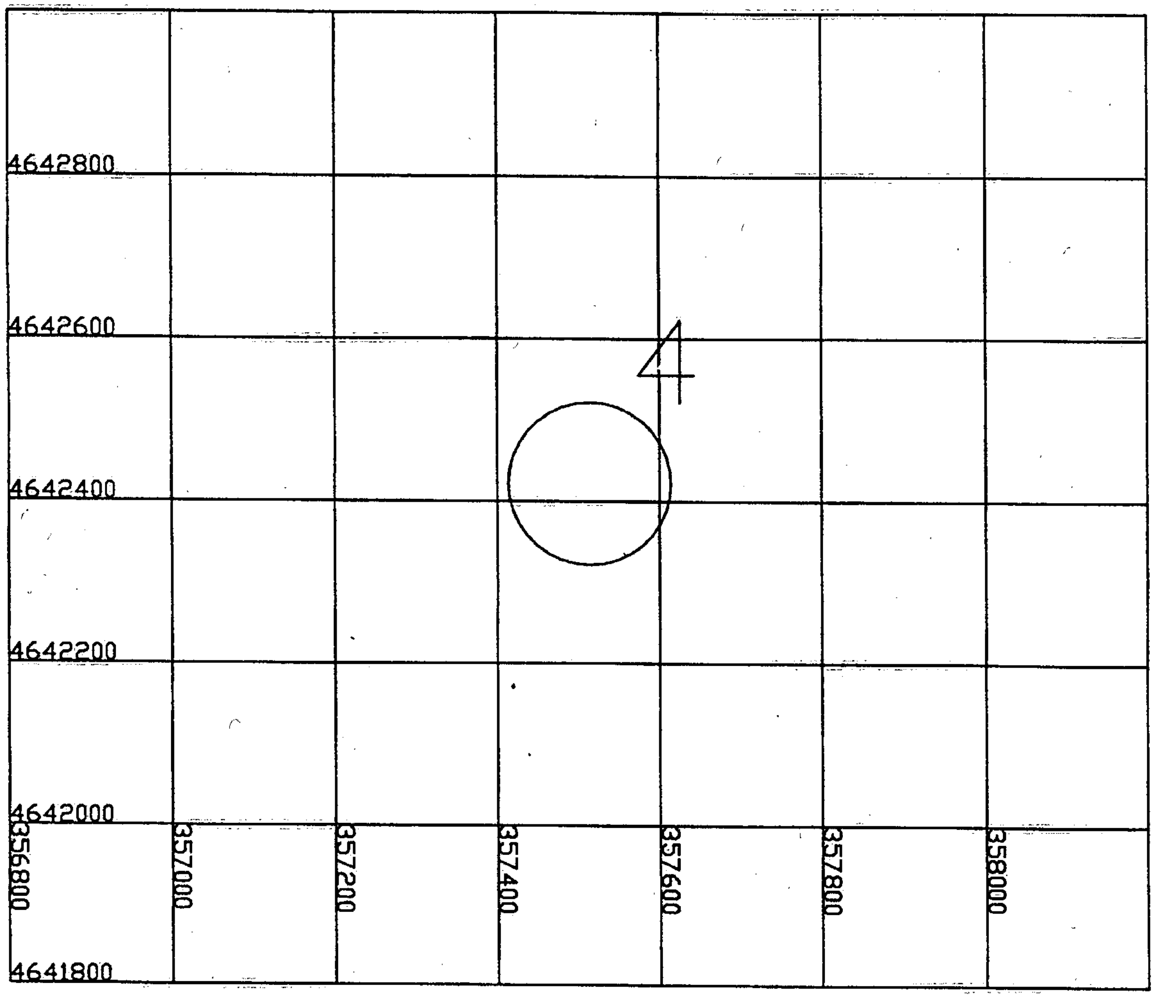
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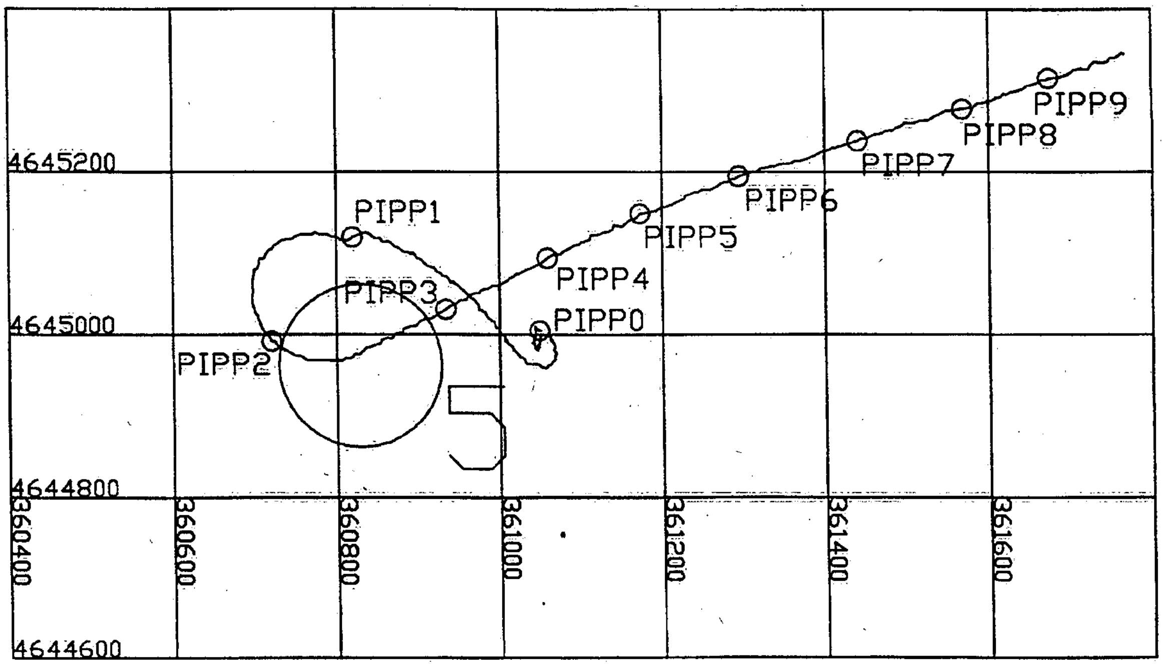

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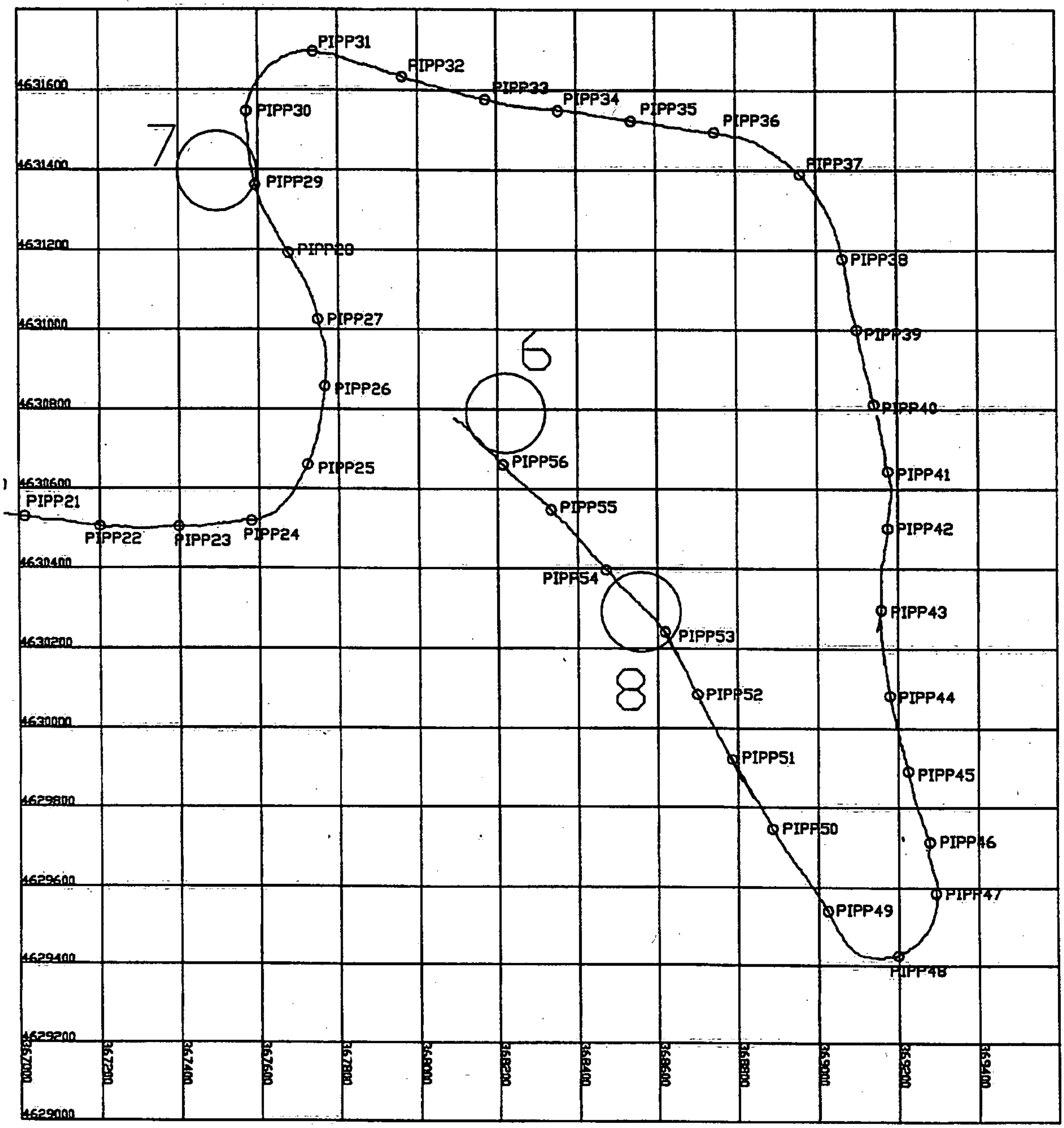

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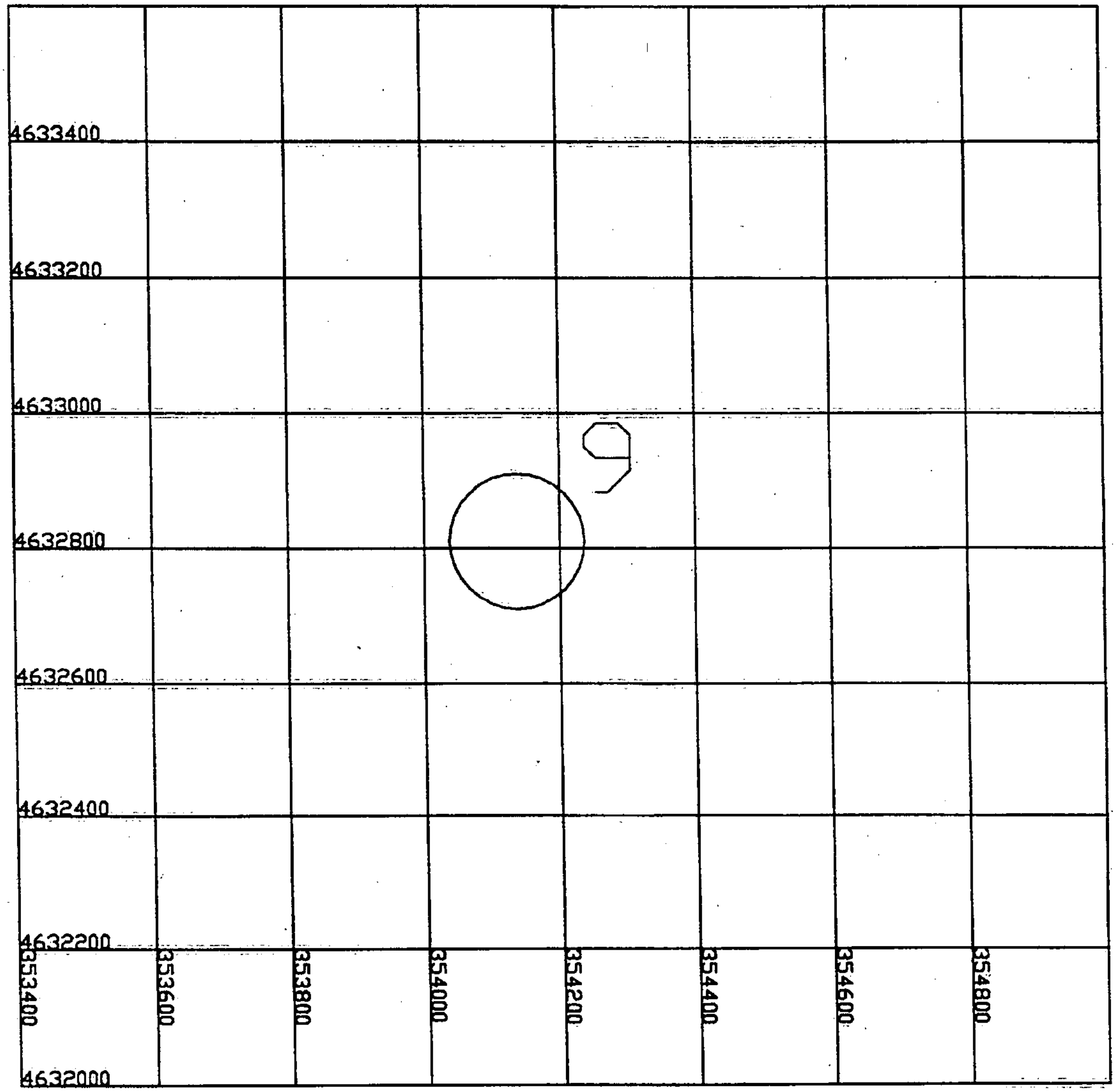

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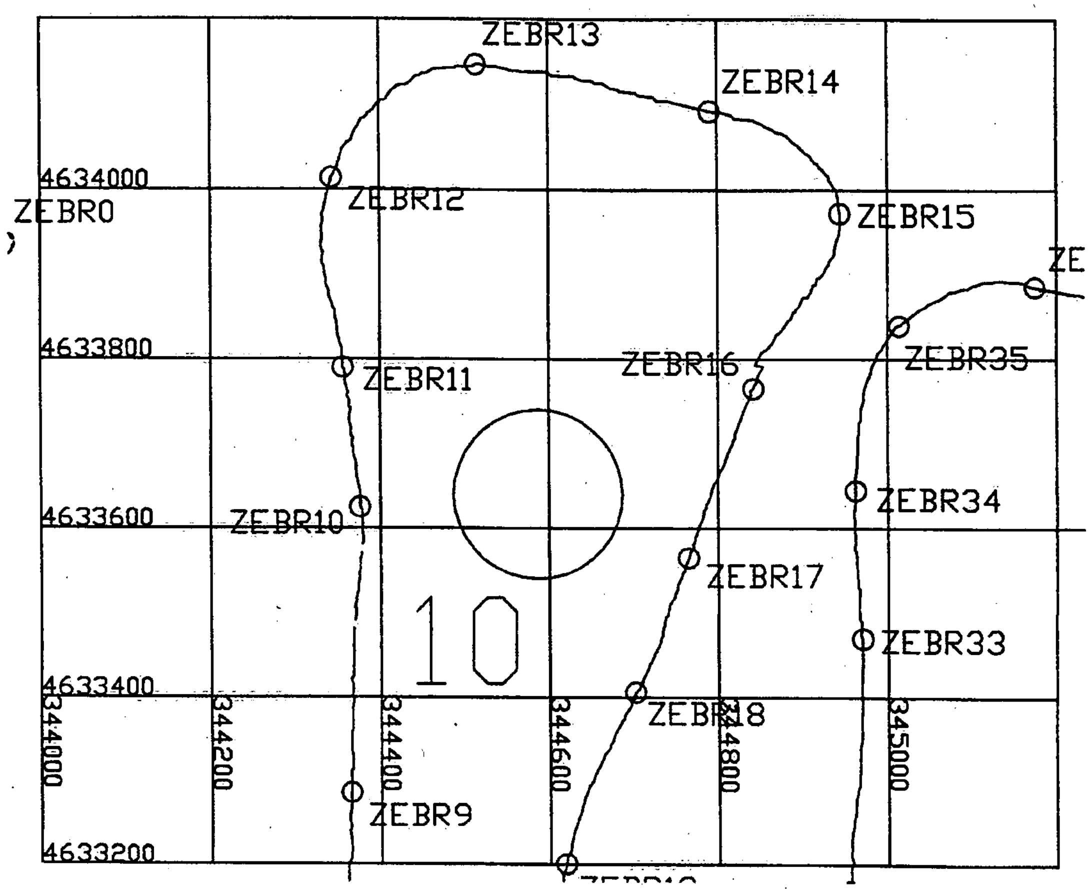

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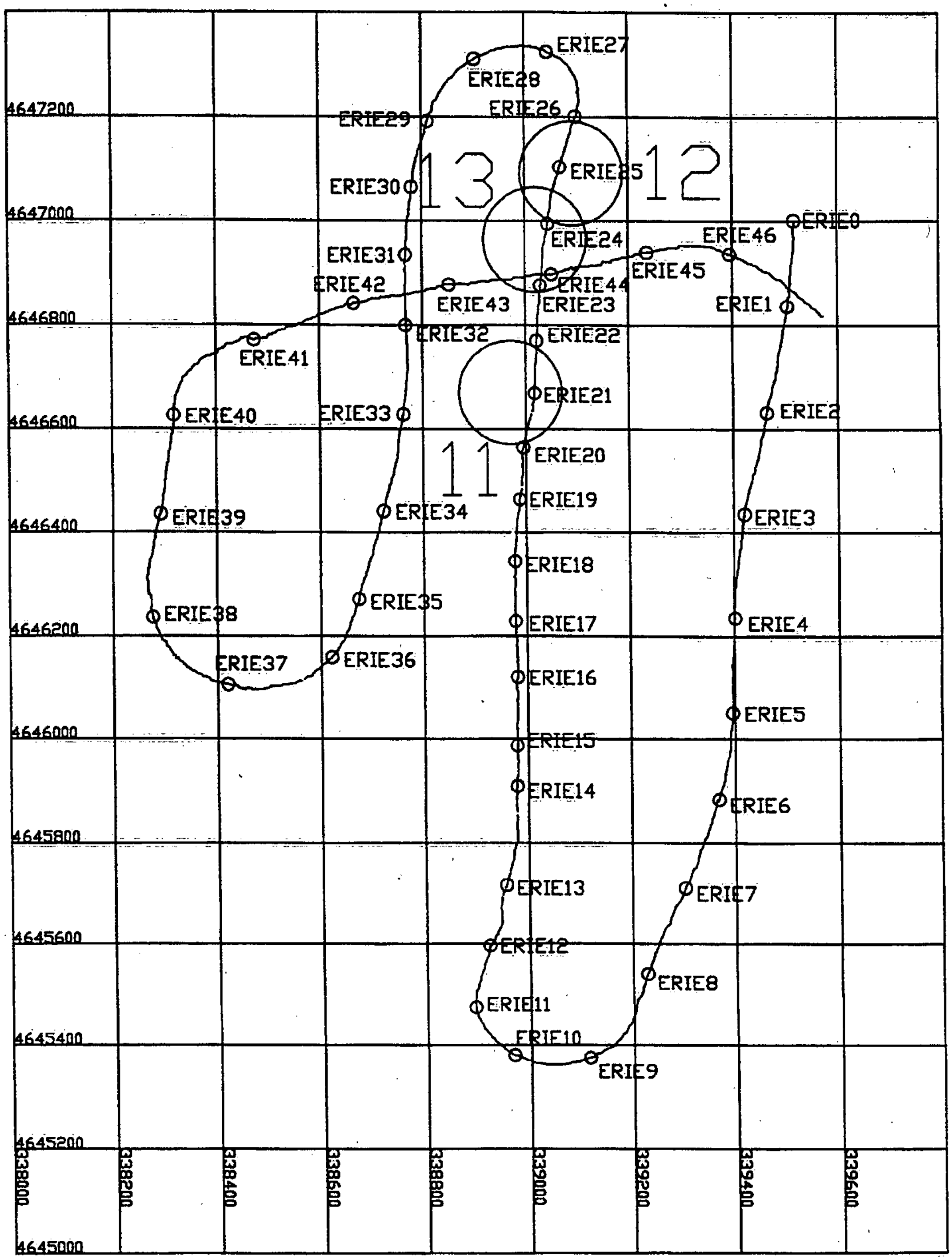

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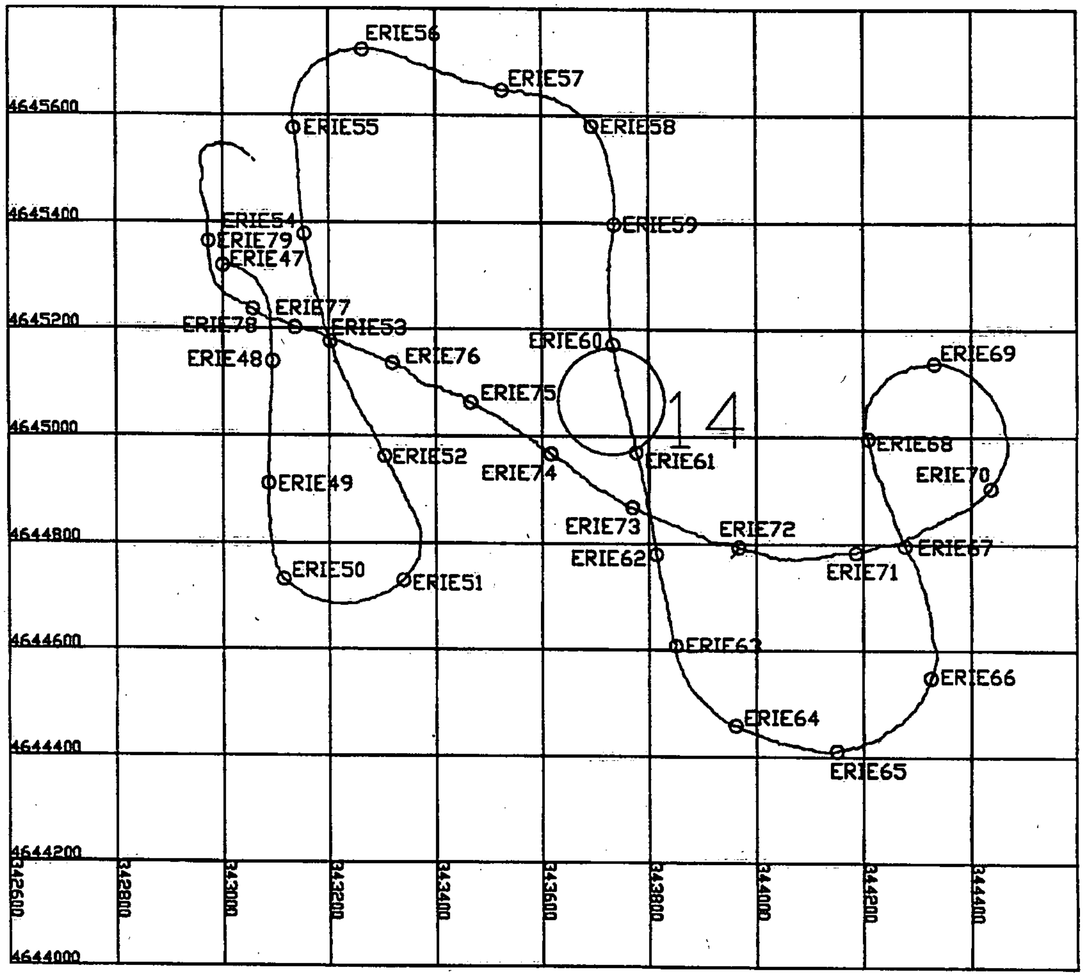
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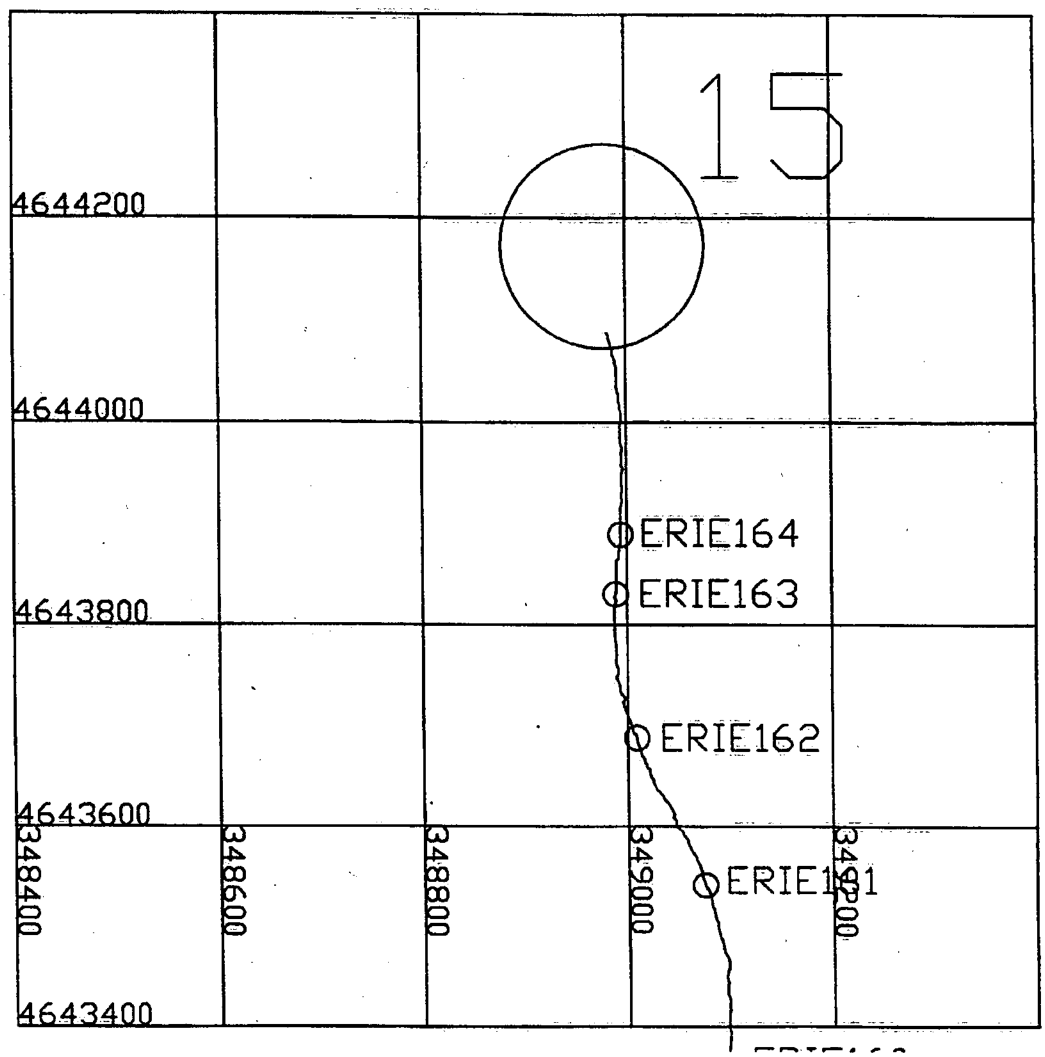
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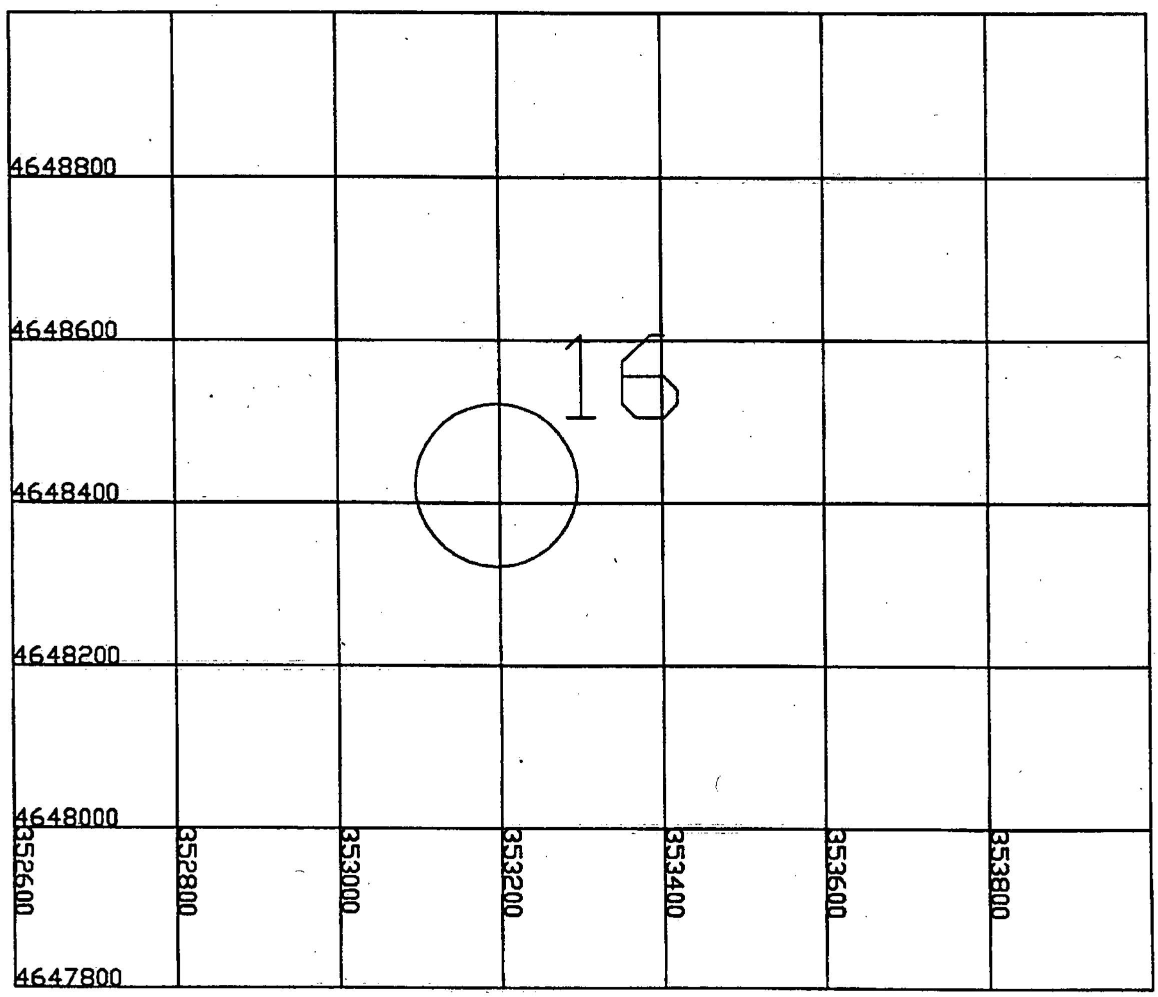
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