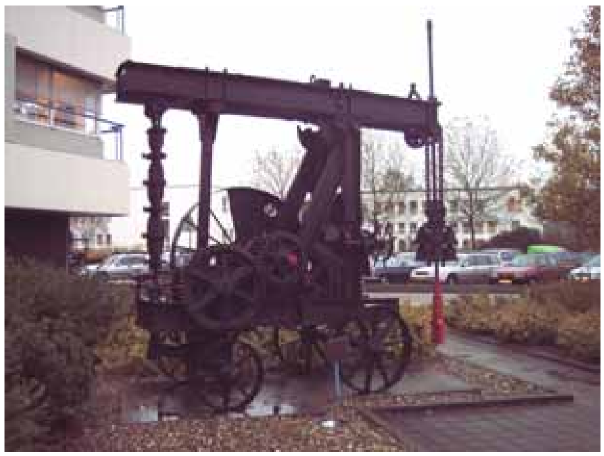
CAVERN CLUSTER UPDATE:
HENGELO BRINEFIELD

Topical Report RSI-1866



prepared for

Akzo Nobel Chemicals bv
Boortorenwed 20, P.O. Box 25
7550 GC Henfelo Ov
Netherlands

February 2006

CONSULTING & SERVICES

CAVERN CLUSTER UPDATE:
HENGELO BRINEFIELD

Topical Report RSI-1866

by

5.1.2.e

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February 2006

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1.0 INTRODUCTION

Over the past 2 years, RESPEC has evaluated aspects of the stability of closely spaced caverns (cavern clusters) and the measured surface subsidence at Akzo Nobel's Hengelo brinefield. Two reports have been prepared relative to cavern clusters: Van Sambeek [2004] and Van Sambeek [2005]. This report updates the analysis in those reports by examining the effect of changing the cavern geometries from their current to their planned (ultimate) cavern size.

Because this report primarily updates our analyses, the report does not repeat background information on the Hengelo brinefield nor provide detailed descriptions of the technical methods used; the reader should refer to the reports referenced above to obtain such background information. The reanalysis of the cavern clusters no longer separates the clusters with inactive wells from the clusters with active wells; all clusters are reevaluated as one group.

2.0 CAVERN CLUSTER ANALYSIS

In the Hengelo brinefield, the term "cavern cluster" is used to describe a group of closely spaced caverns arranged in a way that more-or-less isolates a salt pillar between three or four caverns. The stresses in this "pillar" are calculated using equations presented in Van Sambeek [2004]. The potential for dilatancy (strength-reducing volumetric deformation) in the pillar is assessed using these calculated stresses and the BGR criterion for salt damage [Eickemeier and Heusermann, 2004]. As described by Van Sambeek [2004; 2005], the stability of the pillar depends on the height of the pillar relative to its diameter, or H:D ratio. Using the calculated stresses and the damage criterion, an allowable pillar height (defined as the allowable cavern heights) was calculated for each inactive- and active-cavern cluster.

Since the Van Sambeek reports of 2004 and 2005, the maximum diameter (sonar) outlines of several inactive caverns have been updated and the future, or projected, outline of active cavern clusters is now available. In that regard, the allowable heights for all 21 previously defined cavern clusters were checked and updated, when appropriate, to include these new cavern outlines. The calculation sheets showing the geometry of each cluster are attached as Appendix A. The calculation information and calculated average stresses and allowable pillar height are presented in Table 1.

Table 1. Geometrical Parameters and Calculated Allowable Cluster Pillar Heights (Previous and Updated for Changes in Cavern Boundaries) (Page 1 of 3)

	Cluster	Cavern Series #1	Cavern Series #2	Cavern Series #3	W (m)	Wo (m)	Beta (deg)	Hmax old (m)	Hmax new (m)
	1	239	248	270					
Average Height (m)		29	30	24	80	162	237	20.3	n/c
Avg Sub Rate (mm/yr)		–0.2	–0.3	–0.1					
	2	201	305	308					
Average Height (m)		15	15	24	117	297	204	34.6	30.5
Avg Sub Rate (mm/yr)		–0.1	–0.1	–0.2					
	3	237	248	251					
Average Height (m)		22	27	27	92	229	222	27.2	23.1
Avg Sub Rate (mm/yr)		0.1	–0.1	0.0					
	4	182	198	352					
Average Height (m)		15	21	24	101	228	211	30.1	26.6
Avg Sub Rate (mm/yr)		–0.2	–0.1	0.0					
	5	314	317	325					
Average Height (m)		15	13	19	111	300	227	37.9	27
Avg Sub Rate (mm/yr)		–0.2	–0.3	–0.3					
	6	237	248	265					
Average Height (m)		22	27	27	133	232	204	37.7	38.1
Avg Sub Rate (mm/yr)		0.1	–0.1	0.0					
	7	275	278	287					
Average Height (m)		16	15	15	126	209	189	36.7	37.6
Avg Sub Rate (mm/yr)		–0.5	–0.5	–0.2					
	8	275	278	290					
Average Height (m)		16	15	15	129	263	190	43.6	36.3
Avg Sub Rate (mm/yr)		–0.5	–0.5	–0.2					
	9	225	314	331					
Average Height (m)		29	29	15	96	223	239	30.4	23.5
Avg Sub Rate (mm/yr)		–0.3	–0.3	–0.2					
	10	207	259	262					
Average Height (m)		15	15	n/a	109	203	191	31.9	n/c
Avg Sub Rate (mm/yr)		0.0	–0.3	–0.5					
	11	393	396	402					
Average Height (m)		10	10	10	118	270	179	37.8	33.2
Avg Sub Rate (mm/yr)		–0.1	0.0	0.0					
	12	402	405	414					
Average Height (m)		10	10	10	117	249	149	33.7	35.2
Avg Sub Rate (mm/yr)		–0.9	–1.3	–1.3					
	13A	209	253	211					
Average Height (m)		26	18	24	88	185	215	23.4	n/c
Avg Sub Rate (mm/yr)		–0.3	–0.3	–0.5					

Table 1. Geometrical Parameters and Calculated Allowable Cluster Pillar Heights (Previous and Updated for Changes in Cavern Boundaries) (Page 2 of 3)

	Cluster	Cavern Series #1	Cavern Series #2	Cavern Series #3	W (m)	Wo (m)	Beta (deg)	Hmax old (m)	Hmax new (m)
	13B	253	256	211					
Average Height (m)		20	19	14	98	166	264	25.6	n/c
Avg Sub Rate (mm/yr)		–0.9	–1.0	–0.6					
	13C	256	215	211					
Average Height (m)		17	22	25	74	159	247	18.2	n/c
Avg Sub Rate (mm/yr)		0.0	0.1	0.0					
	14A	102	104	140					
Average Height (m)		11	10	5	116	216	196	33.1	n/c
Avg Sub Rate (mm/yr)		–2.7	–2.1	–2.2					
	14B	104	122	180					
Average Height (m)		5	15	24	132	228	209	37.7	n/c
Avg Sub Rate (mm/yr)		–2.2	–1.1	–0.4					
	14C	180	140	104					
Average Height (m)		23	26	37	115	205	189	33.6	n/c
Avg Sub Rate (mm/yr)		–1.2	–1.2	–1.1					
	14D	122	170	180					
Average Height (m)		24	22	23	113	216	205	31.5	n/c
Avg Sub Rate (mm/yr)		–0.4	–0.5	–0.4					
	15	110	112	116					
Average Height (m)		32	15	10	105	176	169	32.1	n/c
Avg Sub Rate (mm/yr)		–0.9	–0.2	–0.3					
	16	118	120	128					
Average Height (m)		40	35	31	126	226	190	36.7	n/c
Avg Sub Rate (mm/yr)		–0.2	–0.2	–0.2					
	17	118	223	225					
Average Height (m)		40	40	33	137	240	205	39.2	n/c
Avg Sub Rate (mm/yr)		–0.2	–0.1	0.0					
	18	78	80	112					
Average Height (m)		9	21	43	148	221	193	45.5	n/c
Avg Sub Rate (mm/yr)		–0.2	–0.7	–0.5					
	19A	144	156	159					
Average Height (m)		41	39	35	103	249	235	31	25.2
Avg Sub Rate (mm/yr)		–0.6	–0.6	–0.2					
	19B	142	144	159					
Average Height (m)		14	25	41	68	224	256	19.7	14.7
Avg Sub Rate (mm/yr)		–0.8	–0.6	–0.6					
	19C	132	142	159					
Average Height (m)		39	27	14	47	164	345	10.5	7.8
Avg Sub Rate (mm/yr)		–1.3	–0.8	–0.8					

Table 1. Geometrical Parameters and Calculated Allowable Cluster Pillar Heights (Previous and Updated for Changes in Cavern Boundaries) (Page 3 of 3)

	Cluster	Cavern Series #1	Cavern Series #2	Cavern Series #3	W (m)	Wo (m)	Beta (deg)	Hmax old (m)	Hmax new (m)
	19D	96	98	132					
Average Height (m)		21	11	0	119	233	188	37.5	34
Avg Sub Rate (mm/yr)		–1.2	–1.1	–1.0					
	20	57	88	90					
Average Height (m)		27	21	9	109	191	191	31.9	n/c
Avg Sub Rate (mm/yr)		–1.3	–1.2	–1.0					
	21	239	248	448					
Average Height (m)		29	30	24	38	119	216	31.5	n/c
Avg Sub Rate (mm/yr)		–0.2	–0.3	–0.1					

Cluster 12 has a notable change in the updated allowable cavern height in that the new height is greater than the former allowable height (35.2 versus 33.7 meters). Van Sambeek [2004] attempted to project the future outline of all three caverns involved. In this analysis, the projected outline for Cavern 405 was provided by Akzo Nobel and Caverns 402 and 414 were fixed in size. These changes in the outline provide a larger cluster pillar (117 versus 111 meters) but about the same exposure angle (149 versus 150 degrees); hence, the allowable cavern height increased relative to the earlier calculation.

Clusters 6 and 7 also have updated allowable cavern heights that are slightly greater than the former allowable cavern heights. These two small increases in allowable cavern height relate to refinements in obtaining the geometrical details (pillar diameter, tributary diameter, and exposure angles). Similar small changes in the allowable height might also have occurred in other cavern clusters because of refinements; however, those small changes are masked by much larger changes caused by incorporating the future projected cavern outlines.

3.0 CONCLUSIONS

The 21 cavern clusters were reanalyzed to account for known changes in cavern geometry and for enlargement of active caverns to their ultimate size. The reanalysis determined new maximum heights for several of the caverns. The allowable maximum cavern heights are listed in Table 1 for each cluster.

4.0 REFERENCES

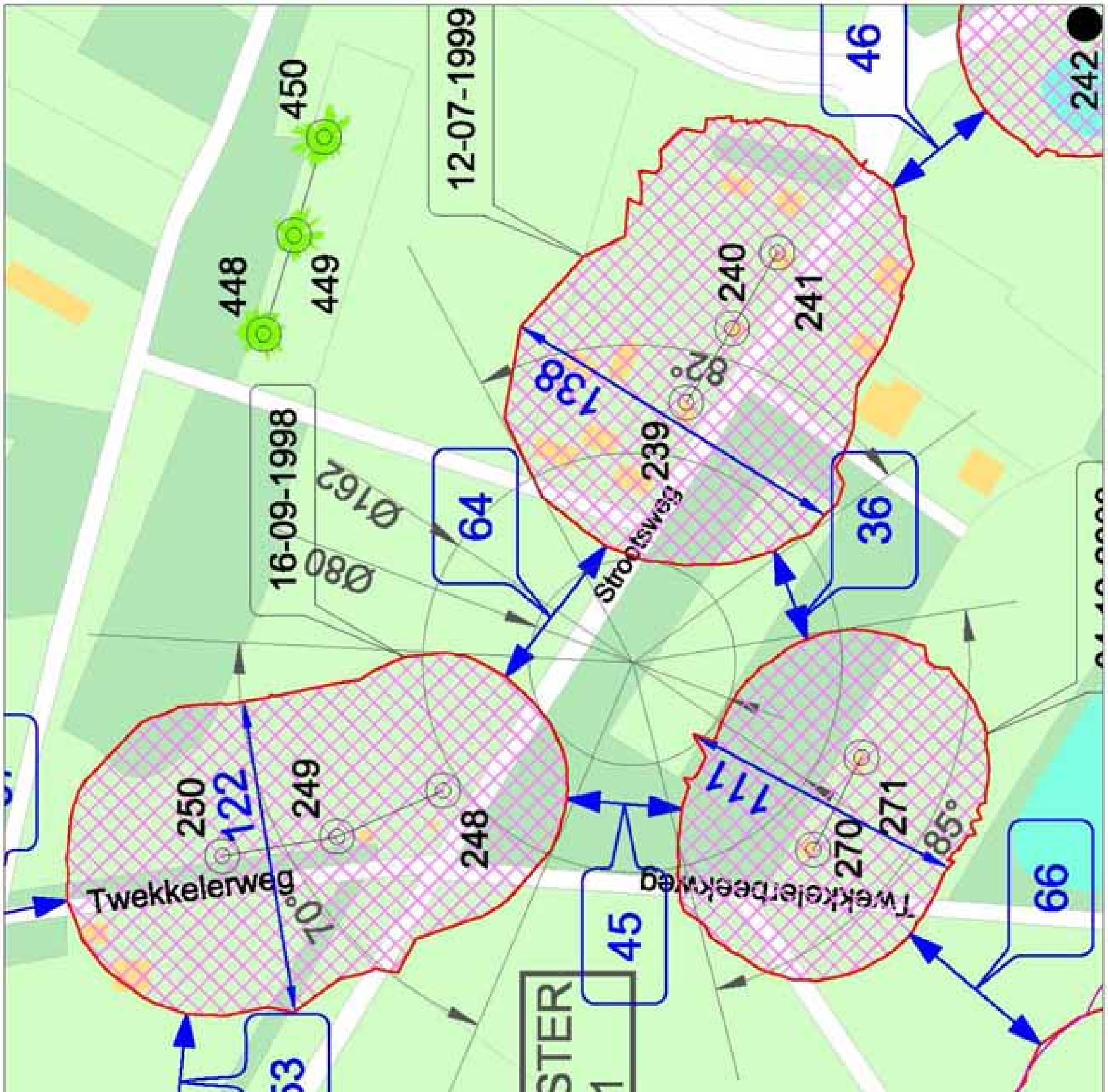
Eickemeier, R. and S. Heusermann, 2004. *Standsicherheitsberechnungen zu den Kavernen-Clustern 209-211-215-253-256 und 245-281-287,* Tagebuch-Nr.10527/04, prepared for Akzo Nobel Salt bv, Hengelo, Niederlande, by Bundesanstalt Für Geowissenschaften Und Rohstoffe (BGR), Hannover, Germany, November.

Van Sambeek, L. L., 2004. *Cluster Analysis of Active Caverns: Akzo Nobel – Hengelo Brinefield*, RSI-1774, prepared for Akzo Nobel Chemical, Hengelo, Netherlands, by RESPEC, Rapid City, SD, USA, April.

Van Sambeek, L. L., 2005. *Stability Analysis of Inactive Caverns: Hengelo Brinefield*, RSI-1793, prepared for Akzo Nobel Chemical, Hengelo, Netherlands, by RESPEC, Rapid City, SD, USA, January.

APPENDIX A

INDIVIDUAL CAVERN CLUSTERS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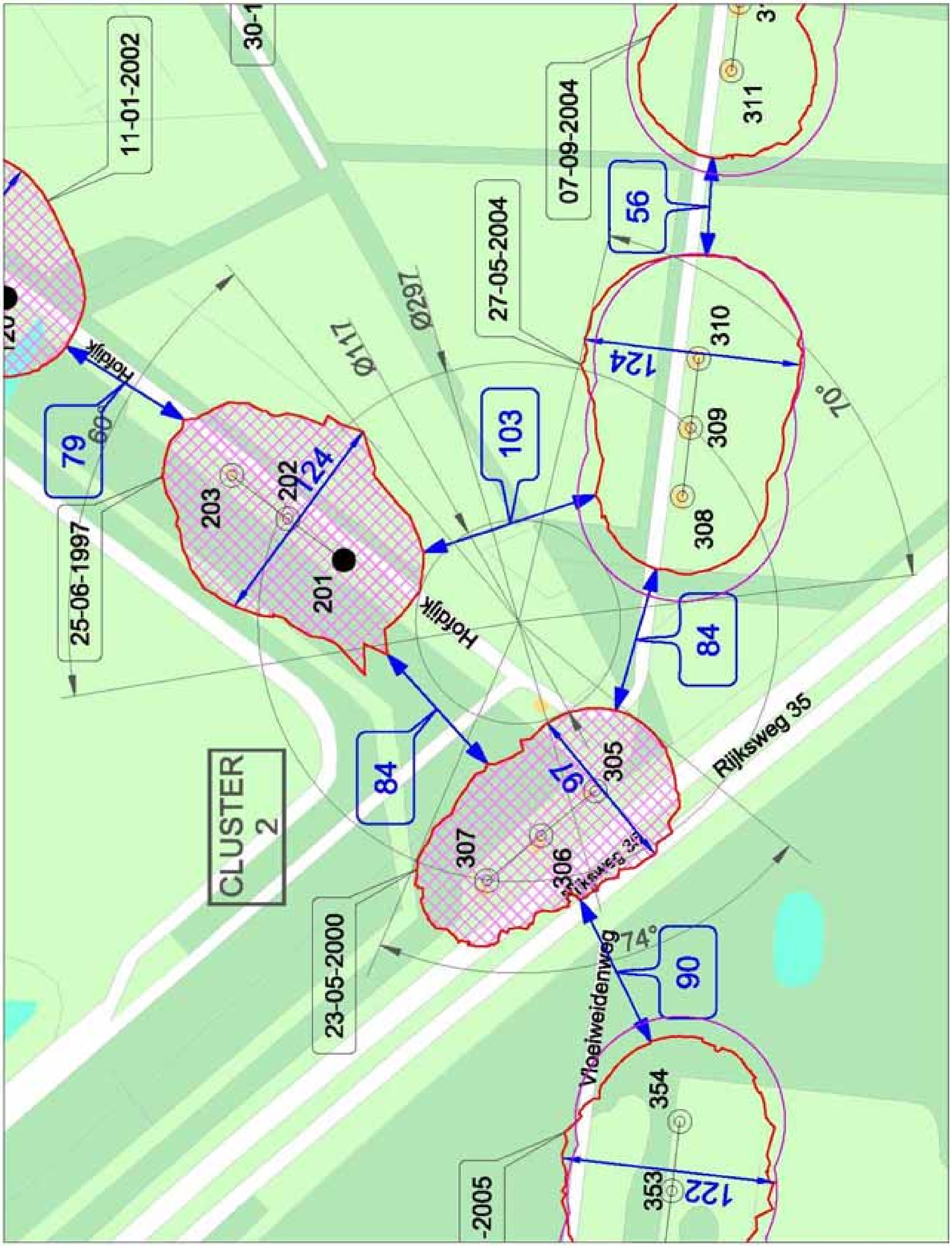
46
242
450
448
449
240
241
138
82°
239
16-09-1998
Ø162
Ø80
64
36
Strootsweg
250
122
249
248
Twekkelerweg
70°
111
271
270
85°
Twekkelerbeekweg
66
45
53
CLUSTER
1
238
237
265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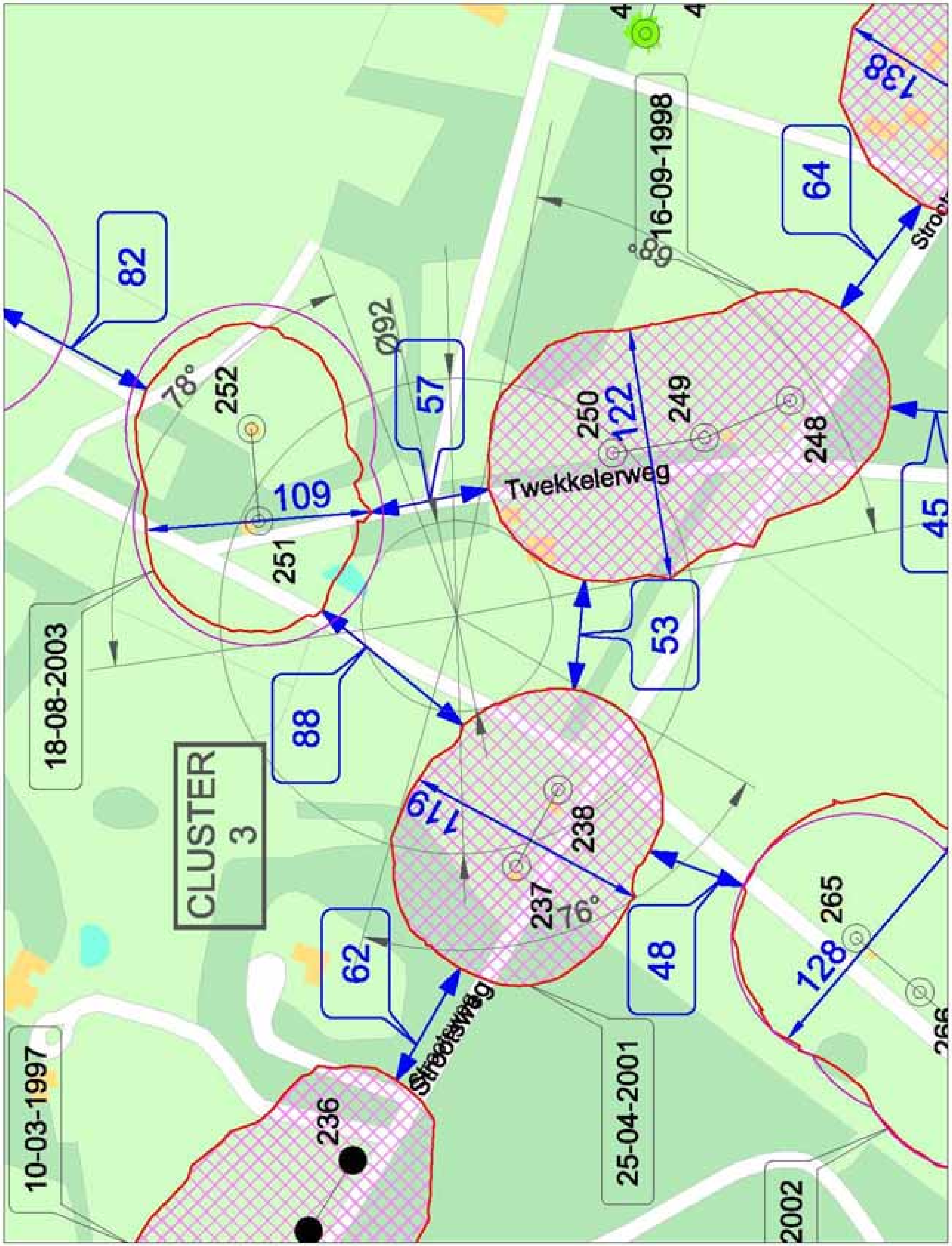
11-01-2002
25-06-1997
23-05-2000
27-05-2004
07-09-2004
-2005
30-1
Hofdijk
Rijksweg 35
Vloeiweidenweg
Ø117
Ø297
79
124
103
84
84
56
124
97
90
122
70°
74°
201
202
203
305
306
307
308
309
310
311
353
354



CLUSTER
3
18-08-2003
16-09-1998
10-03-1997
25-04-2001
2002
Twekkelerweg
Strootsweg
82
109
57
122
64
138
45
53
88
119
62
48
128
78°
76°
Ø92
252
251
250
249
248
238
237
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265
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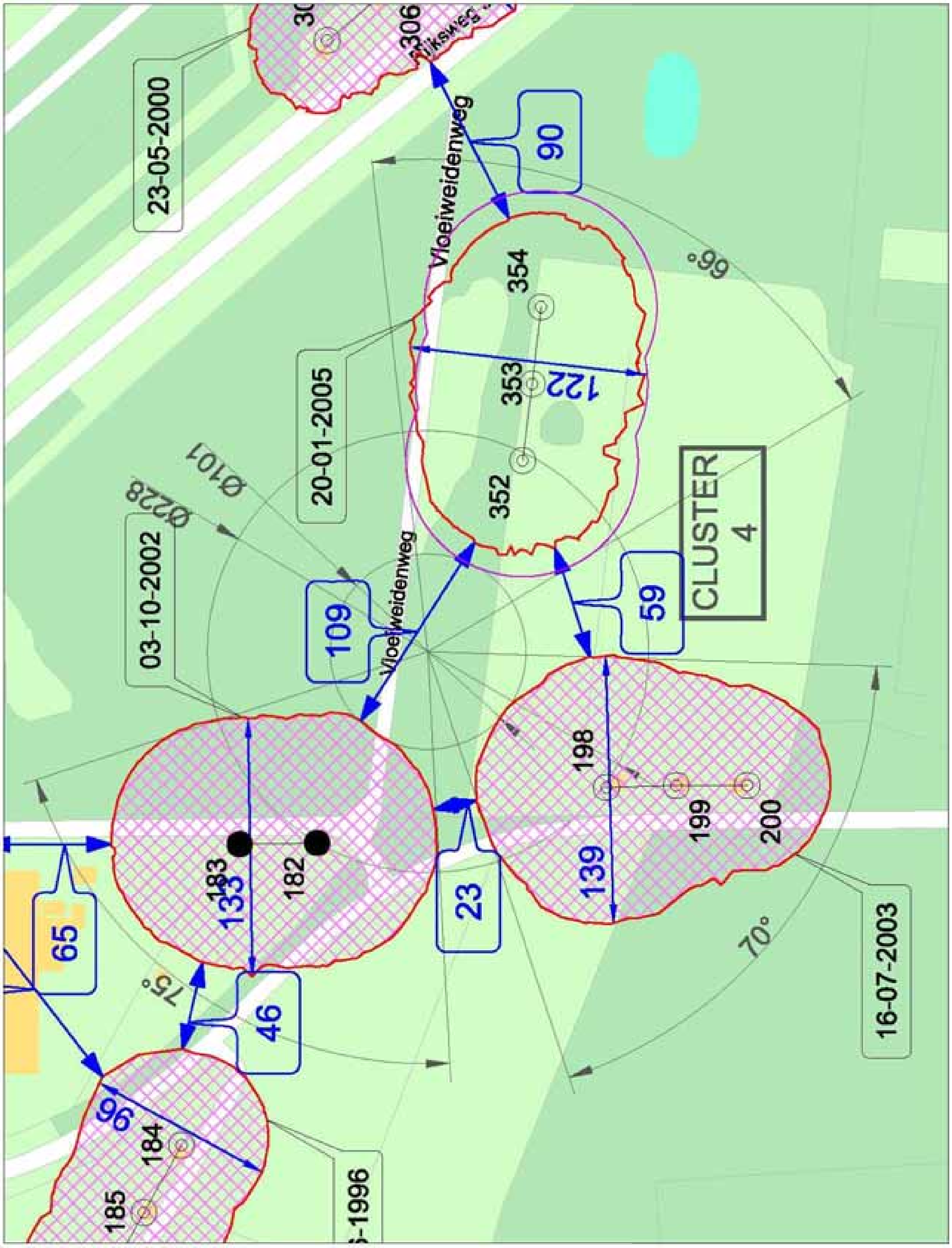

23-05-2000
20-01-2005
03-10-2002
16-07-2003
-1996
Vloeiweidenweg
Vloeiweidenweg
CLUSTER
4
Ø228
Ø101
90
109
59
122
133
139
23
46
65
96
66°
70°
75°
352
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354
198
199
200
183
182
184
185
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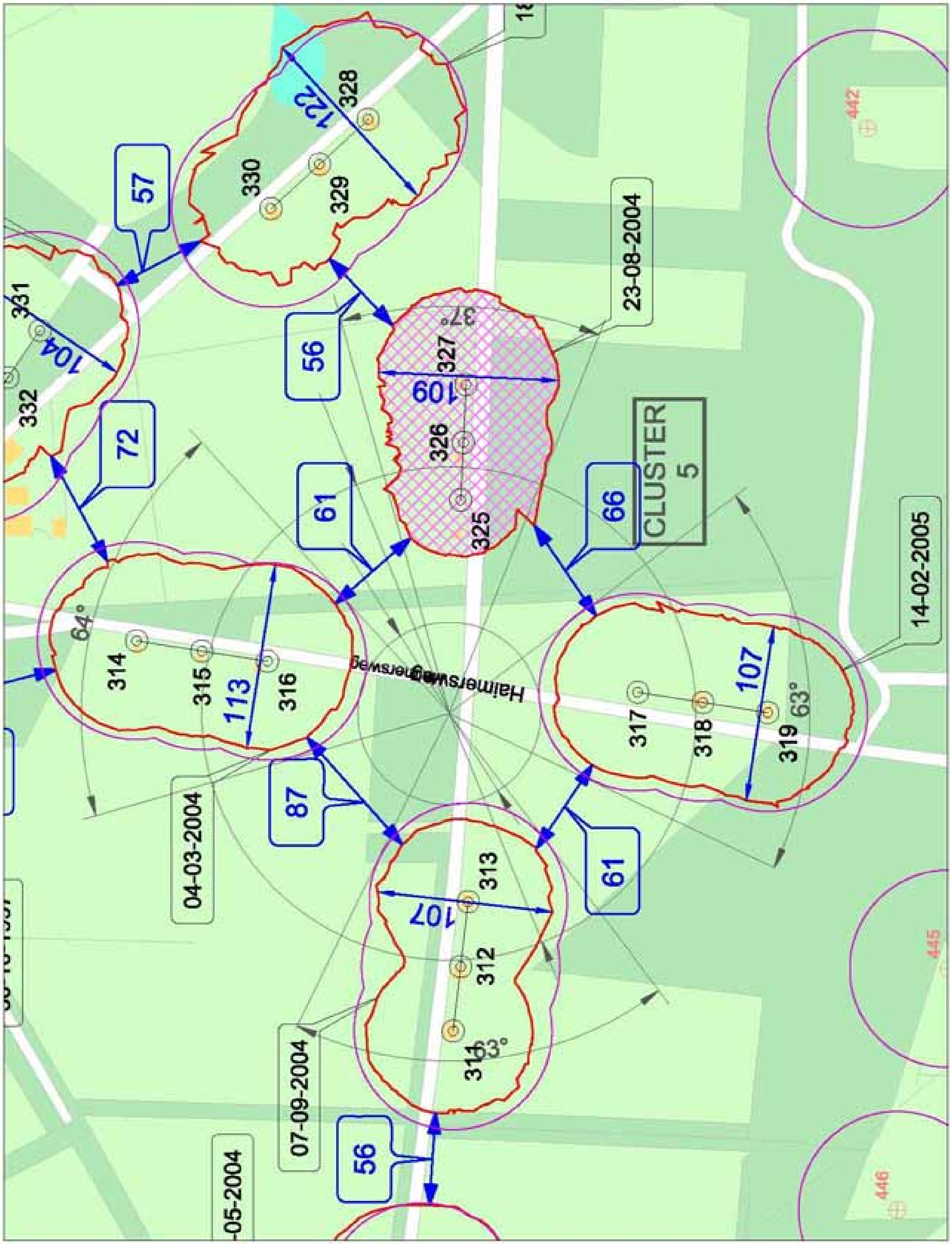
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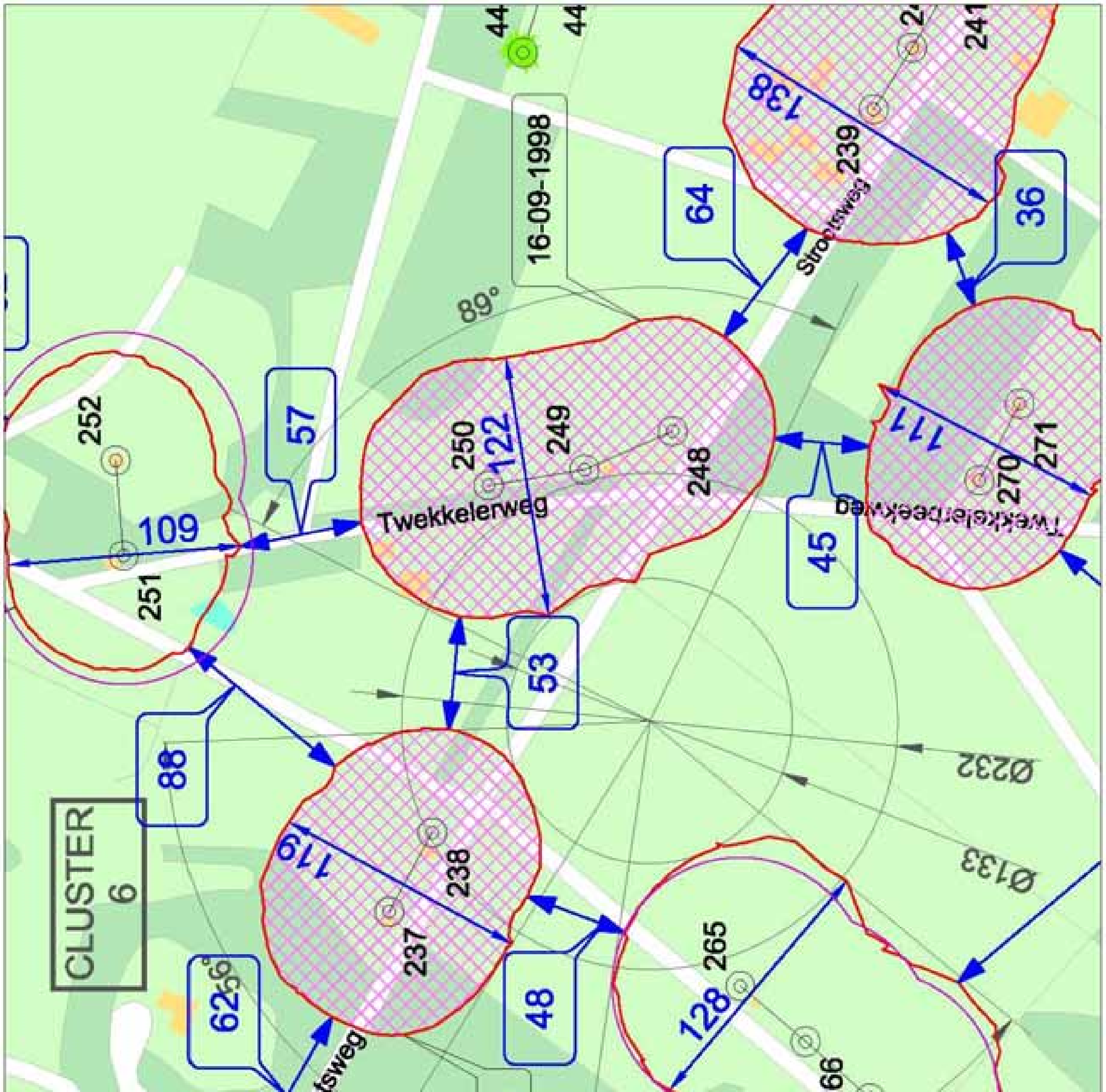
122
328
330
329
331
104
332
72
56
327
37°
109
326
325
23-08-2004
CLUSTER
5
66
61
64°
314
315
113
316
Haimersweg
317
318
107
319
63°
14-02-2005
04-03-2004
87
61
313
107
312
311
63°
07-09-2004
56
-05-2004
442
445
446


CLUSTER 6
Strootsweg
Twekkelerweg
Twekkelerbeekweg
Grote Esweg
16-09-1998
25-04-2001
12-03-2002
Ø232
Ø133
89°
59°
234
235
236
237
238
239
248
249
250
251
252
265
266
267
270
271
109
57
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64
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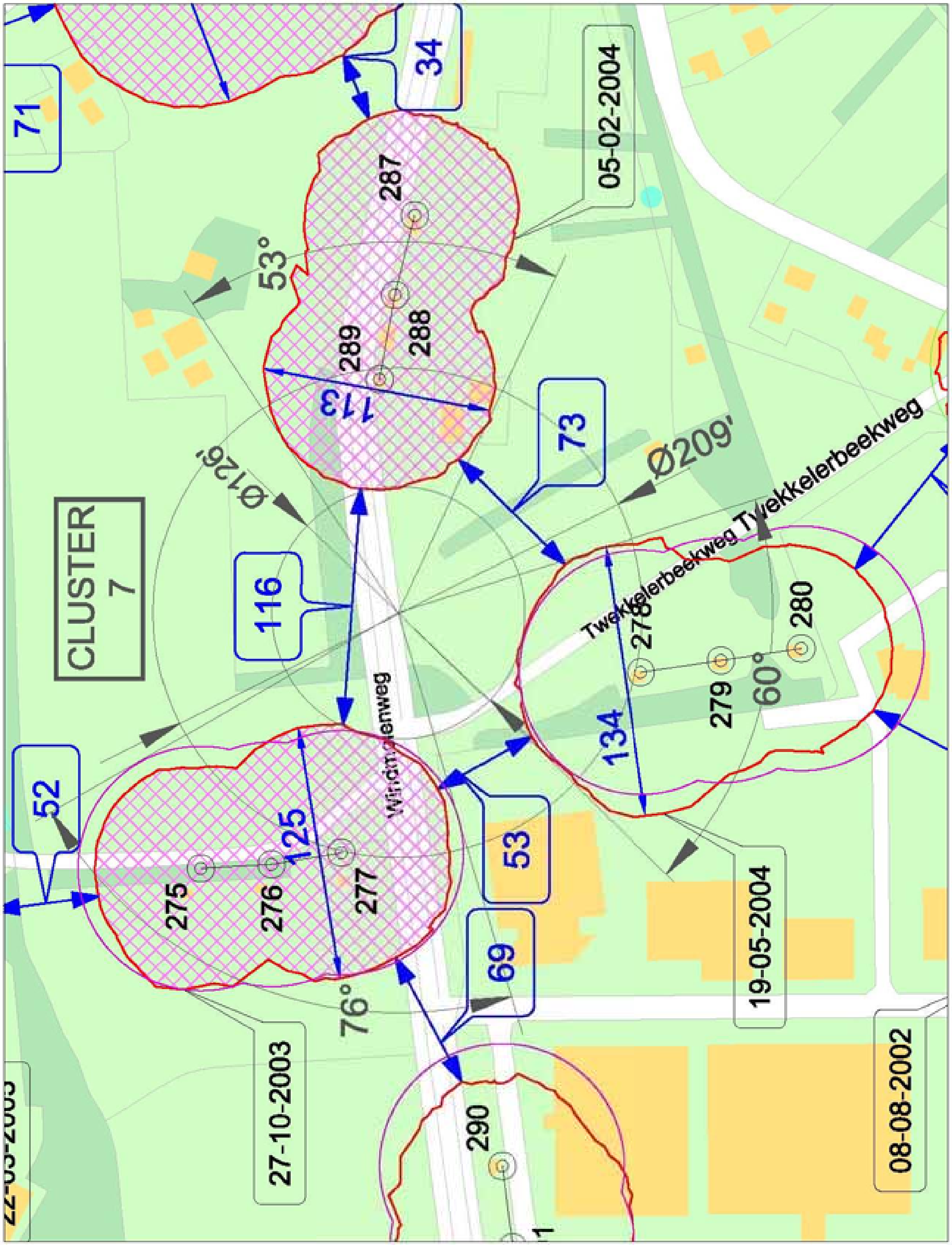
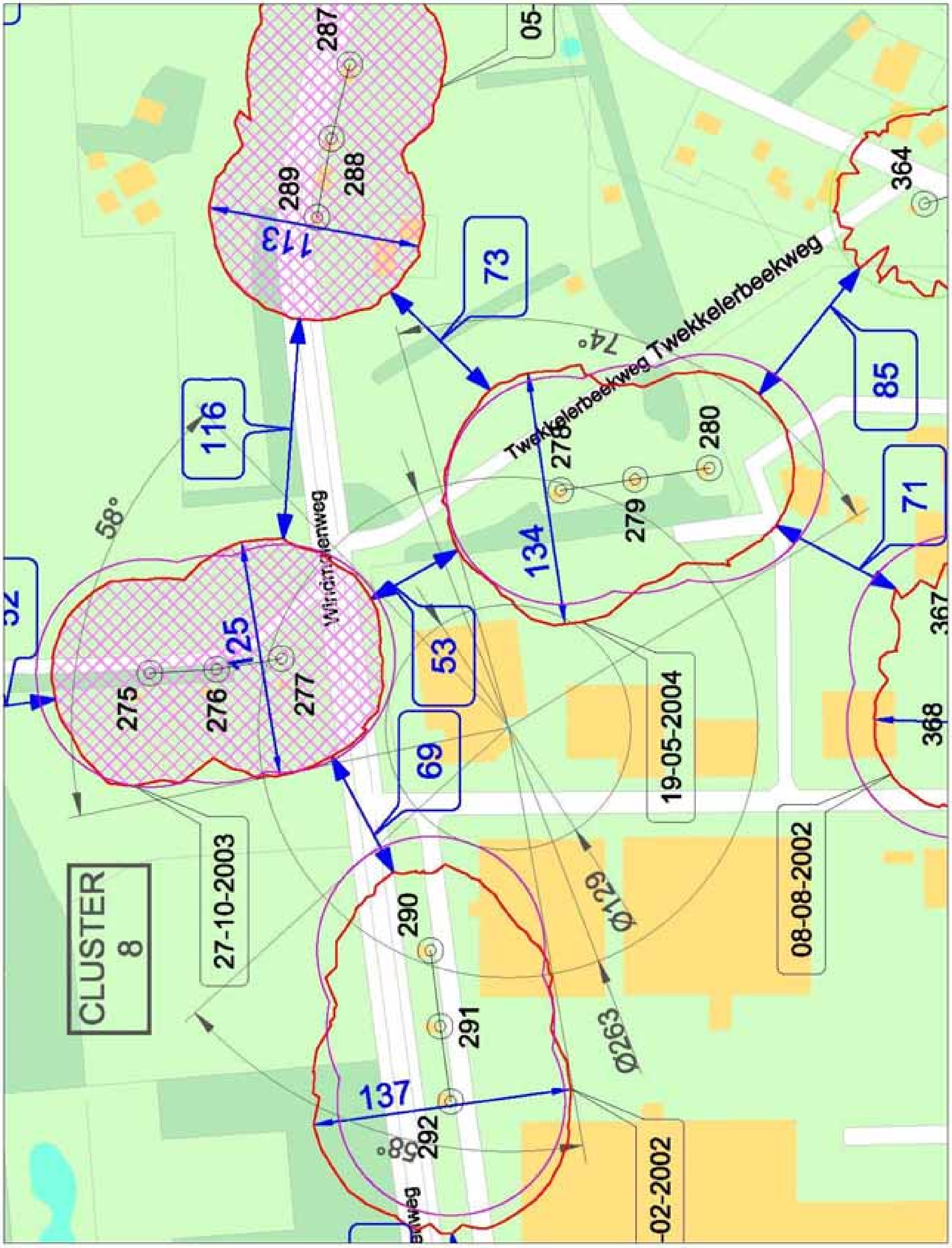
36
45
111
53
88
119
48
128
62
34


CLUSTER 7
71
34
05-02-2004
287
288
289
53°
113
Ø126'
73
Ø209'
Twekkelerbeekweg
Twekkelerbeekweg
116
Windmolenweg
278
279
280
60°
134
52
53
125
275
276
277
69
76°
19-05-2004
27-10-2003
290
08-08-2002


CLUSTER
8
27-10-2003
19-05-2004
08-08-2002
-02-2002
05-
Twekkelerbeekweg
Twekkelerbeekweg
Windmolenweg
275
276
277
278
279
280
287
288
289
290
291
292
364
367
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134
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73
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71
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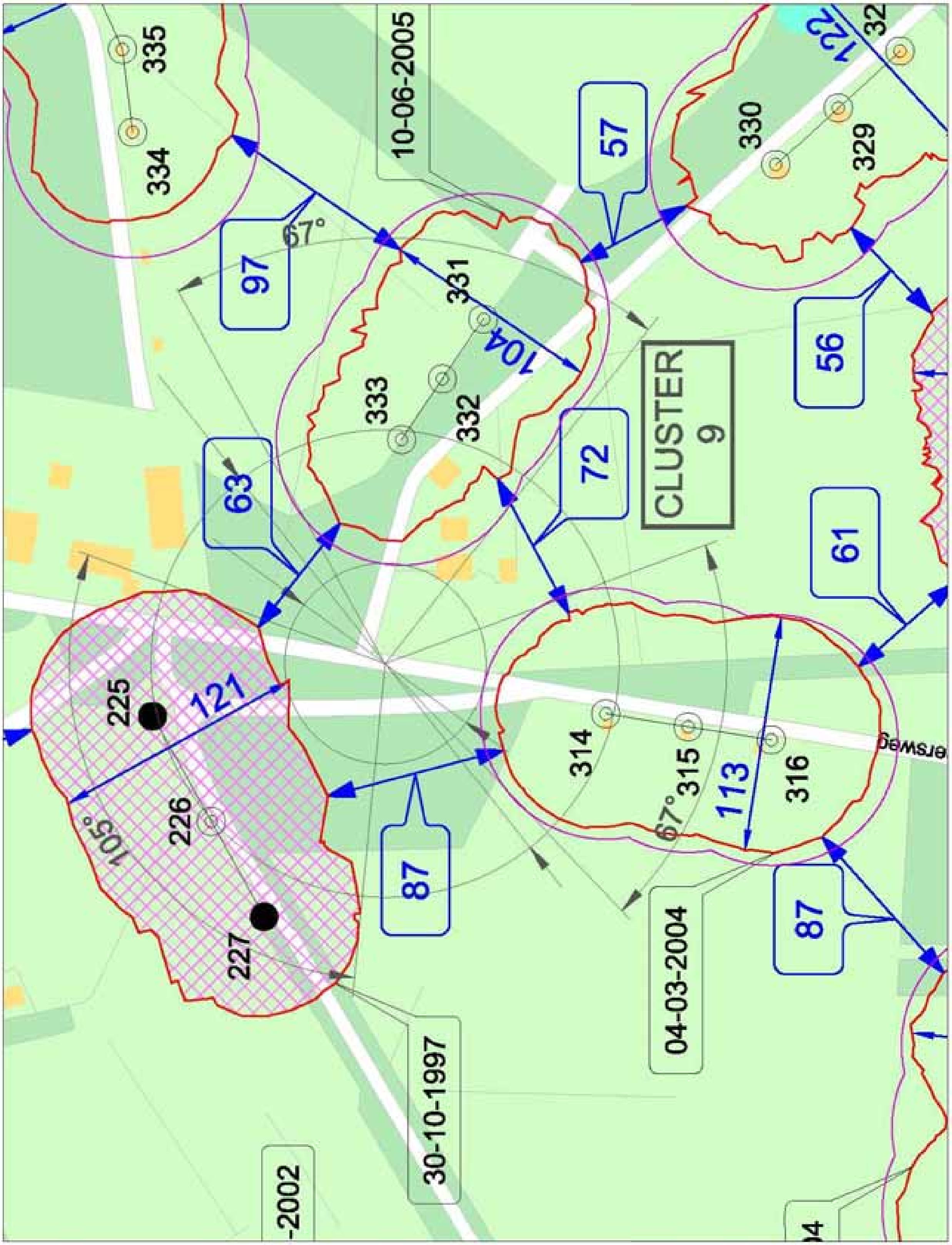
58°
58°
74°
Ø129
Ø263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-2002
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329
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332
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63
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87
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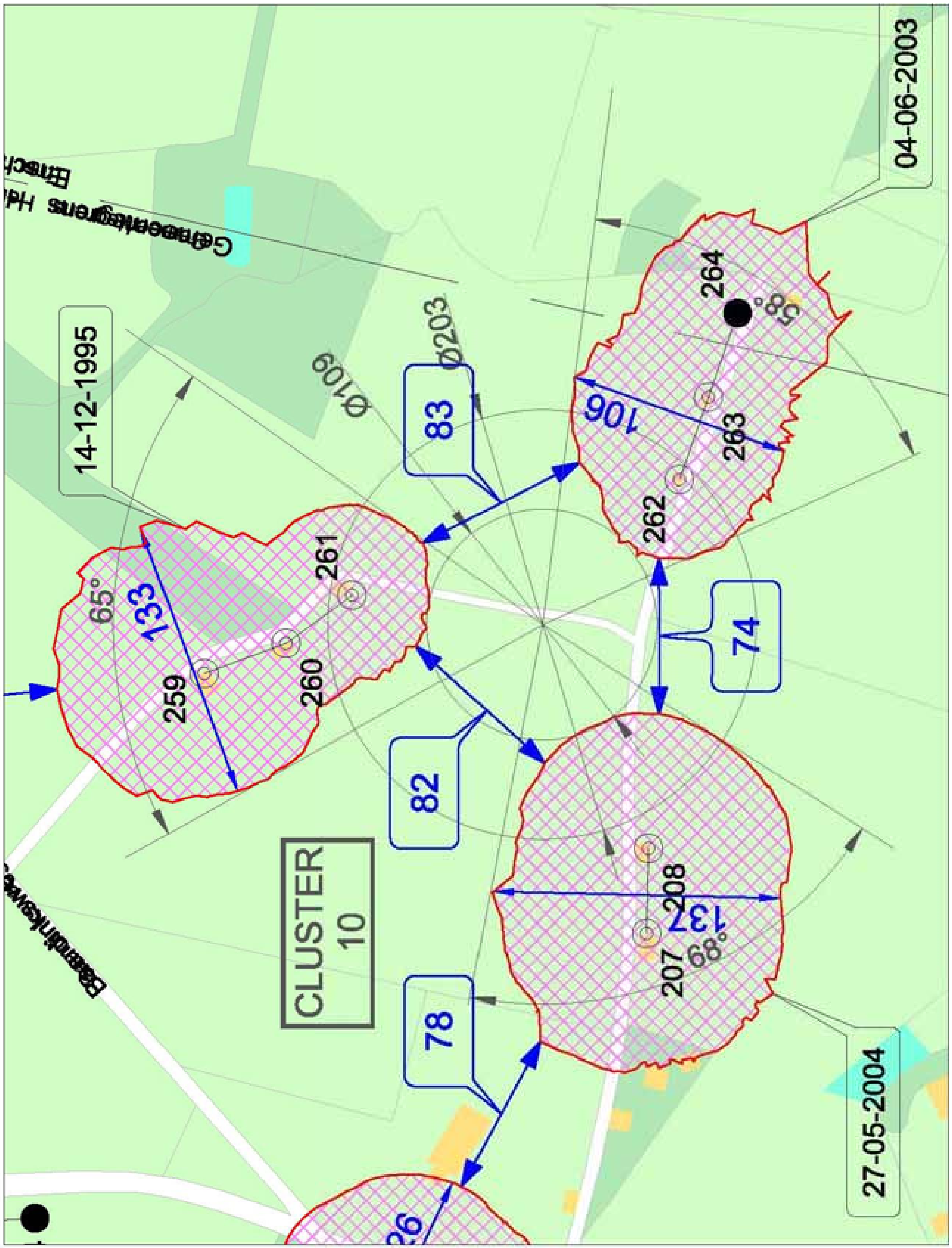
67°
105°
67°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27-05-2004
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10
83
74
82
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68°
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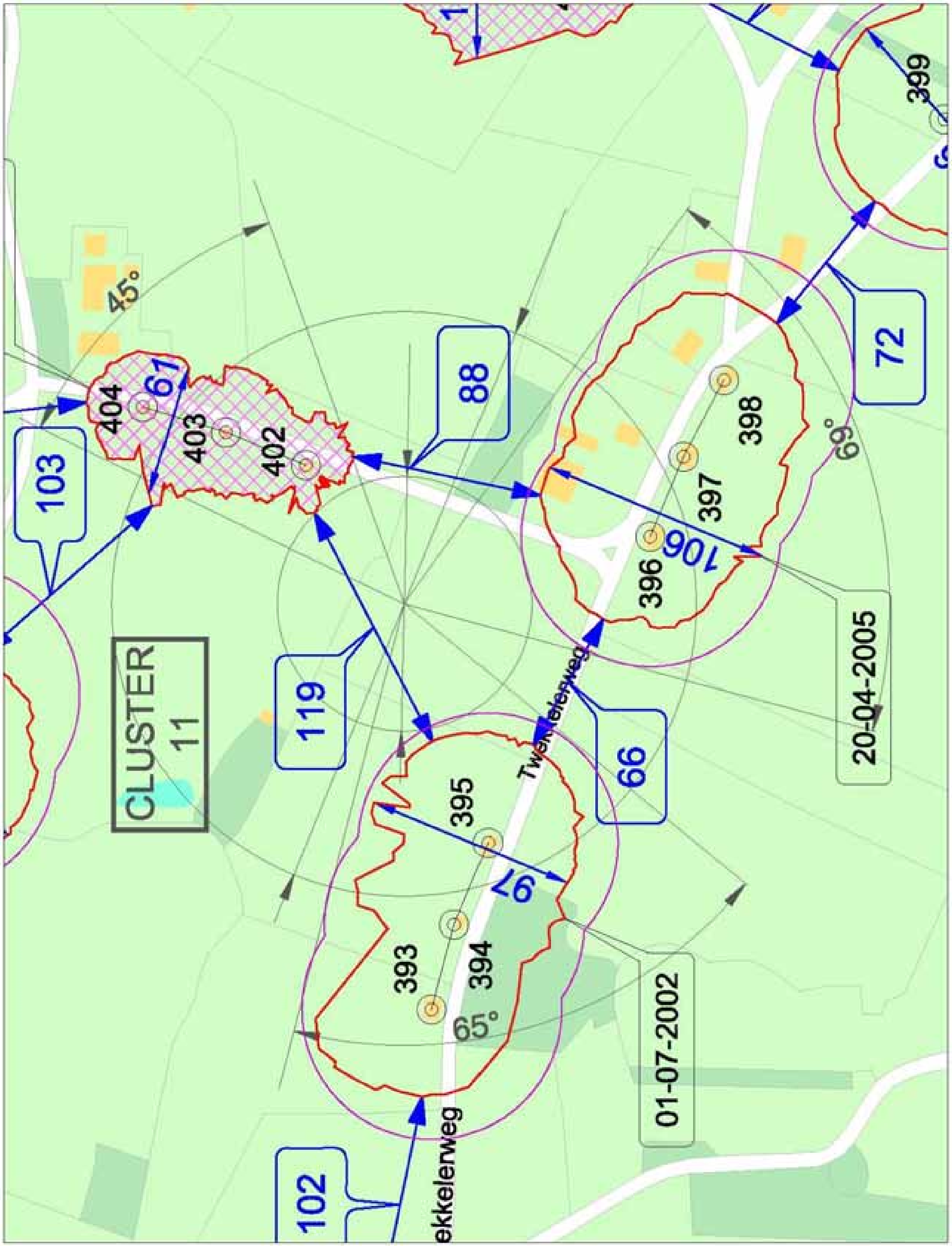
262
263
264
207
208
Ø109
Ø203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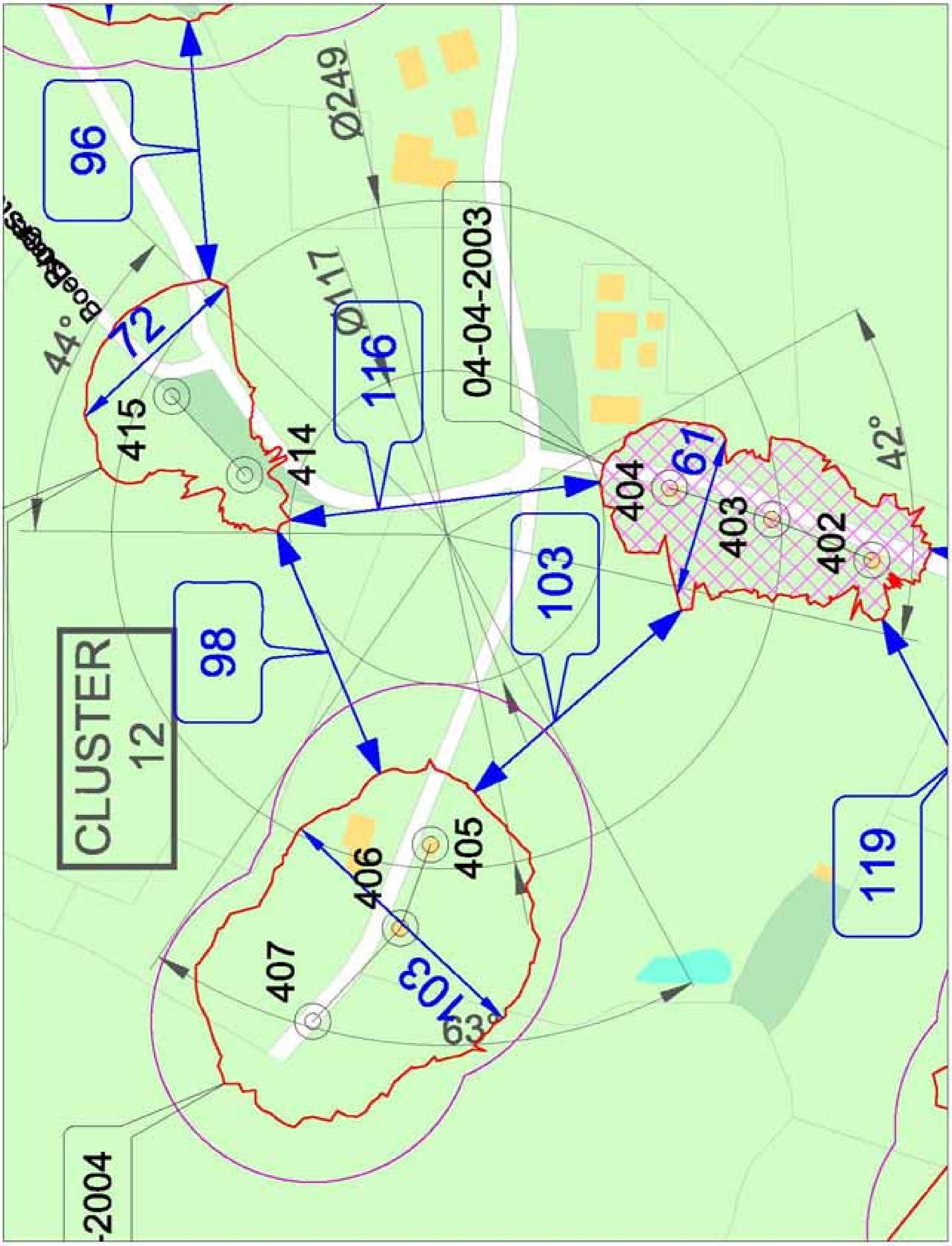
103
61
404
403
402
45°
88
72
398
397
396
106
69°
20-04-2005
119
66
Twekkelerweg
395
97
393
394
65°
01-07-2002
102
ekkelerweg
399



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Ø249
04-04-2003
Ø117
116
72
44°
415
414
CLUSTER
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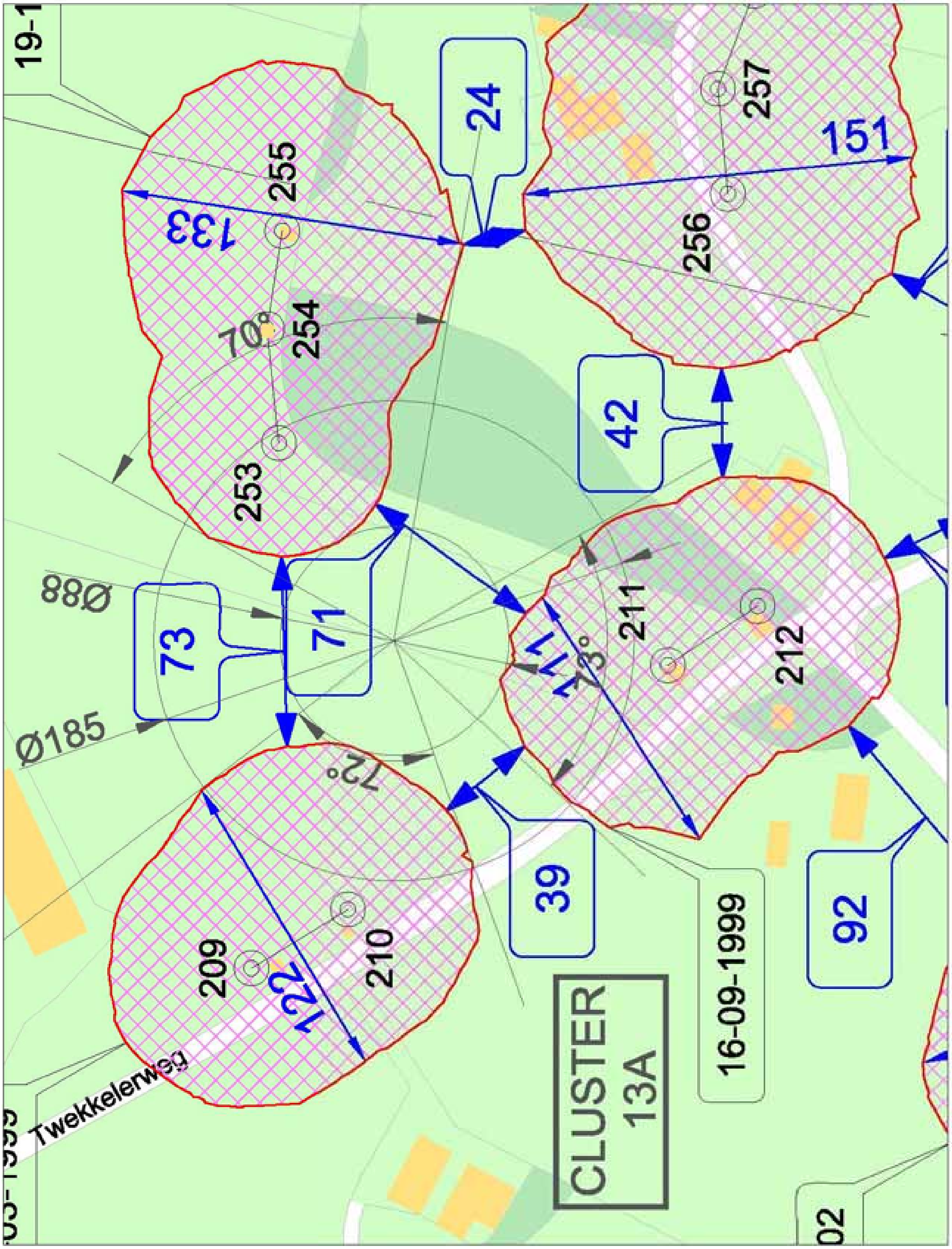
98
103
404
61
403
402
42°
405
406
407
103
63°
119
-2004

>



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70°
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42
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72°
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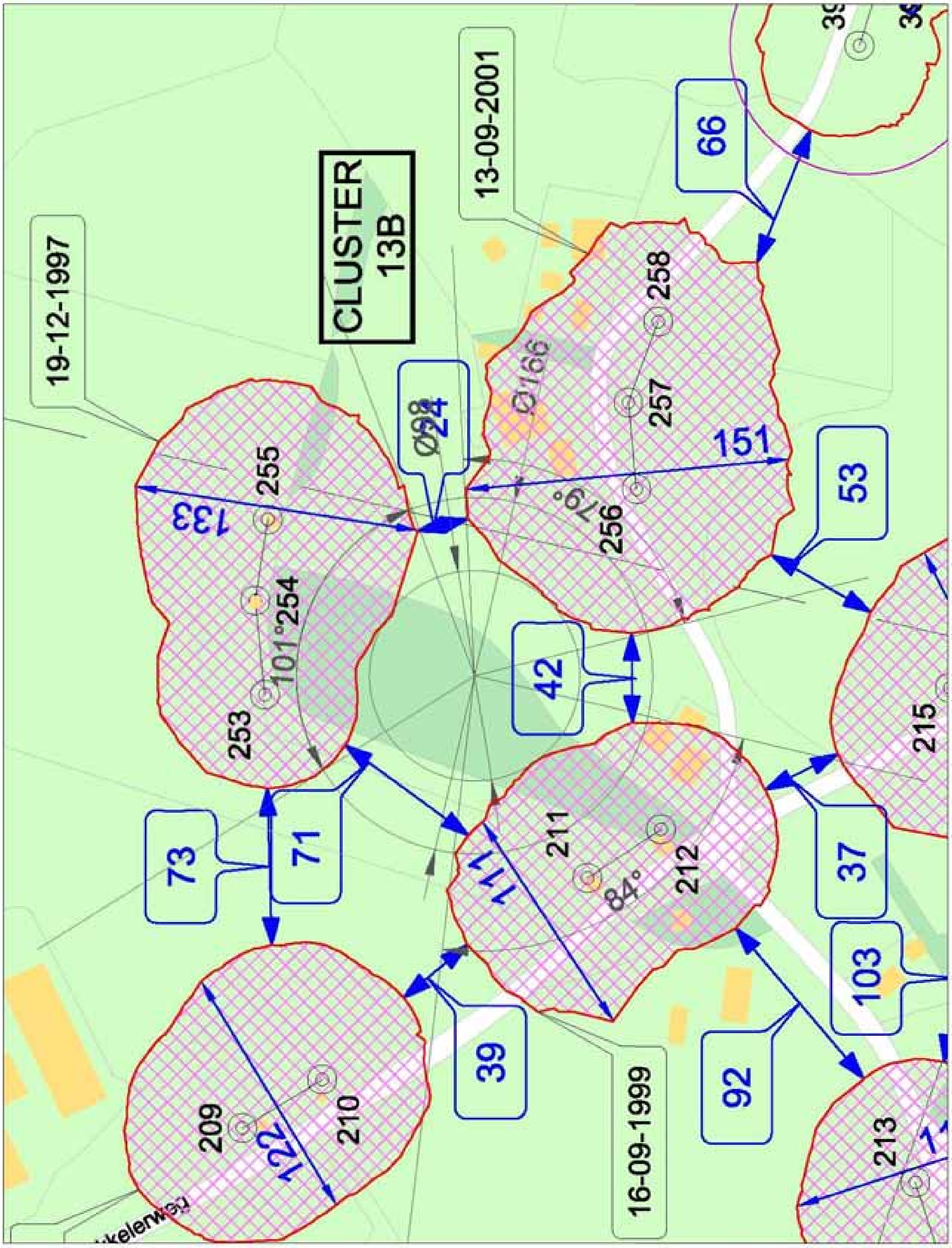
16-09-1999
92
209
210
122
Twekkelerweg
CLUSTER
13A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13-09-2001
16-09-1999
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66
151
53
133
42
73
71
37
103
39
92
122
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101°
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84°
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254
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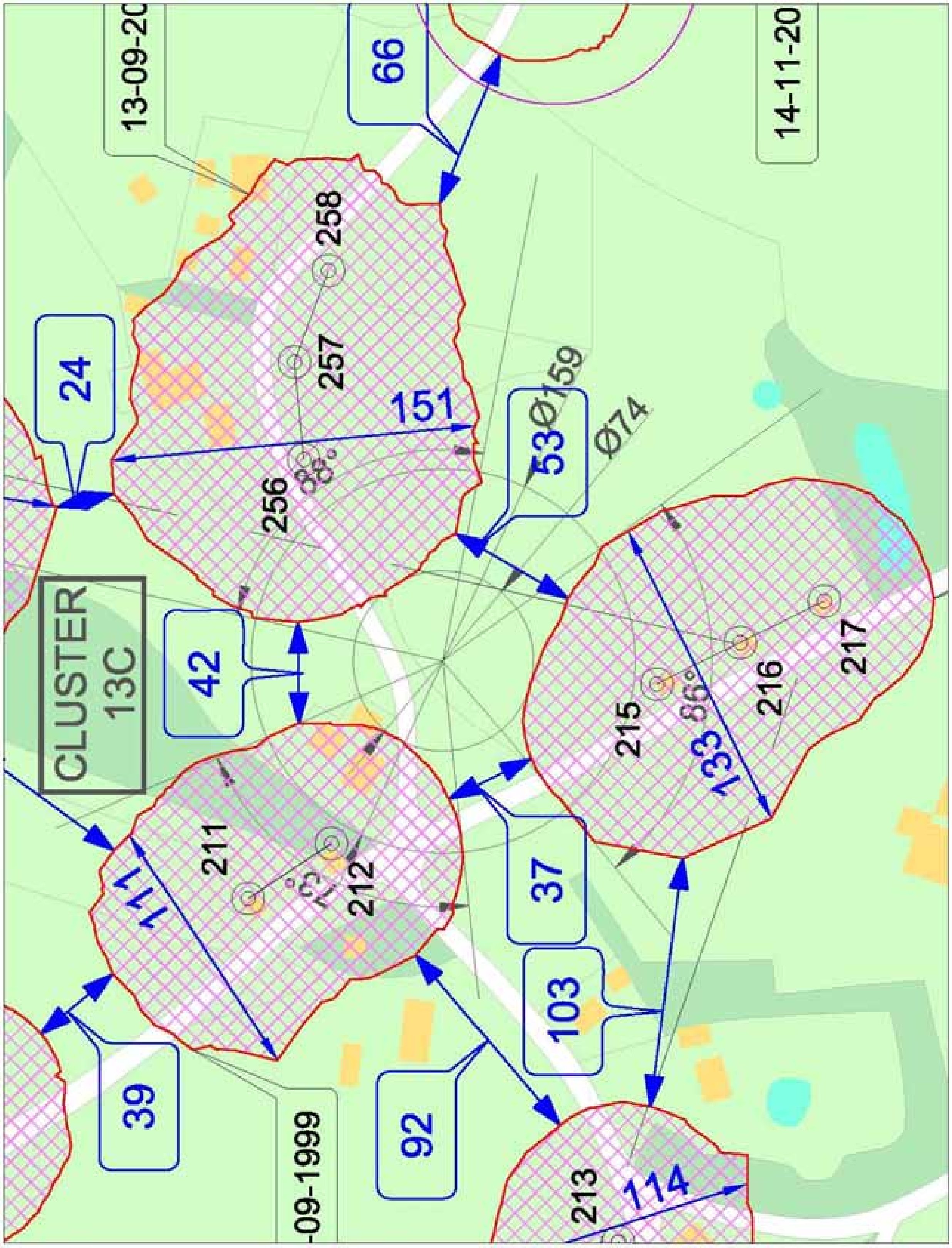

CLUSTER
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13-09-20
14-11-20
-09-1999
24
66
151
42
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Ø159
Ø74
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92
39
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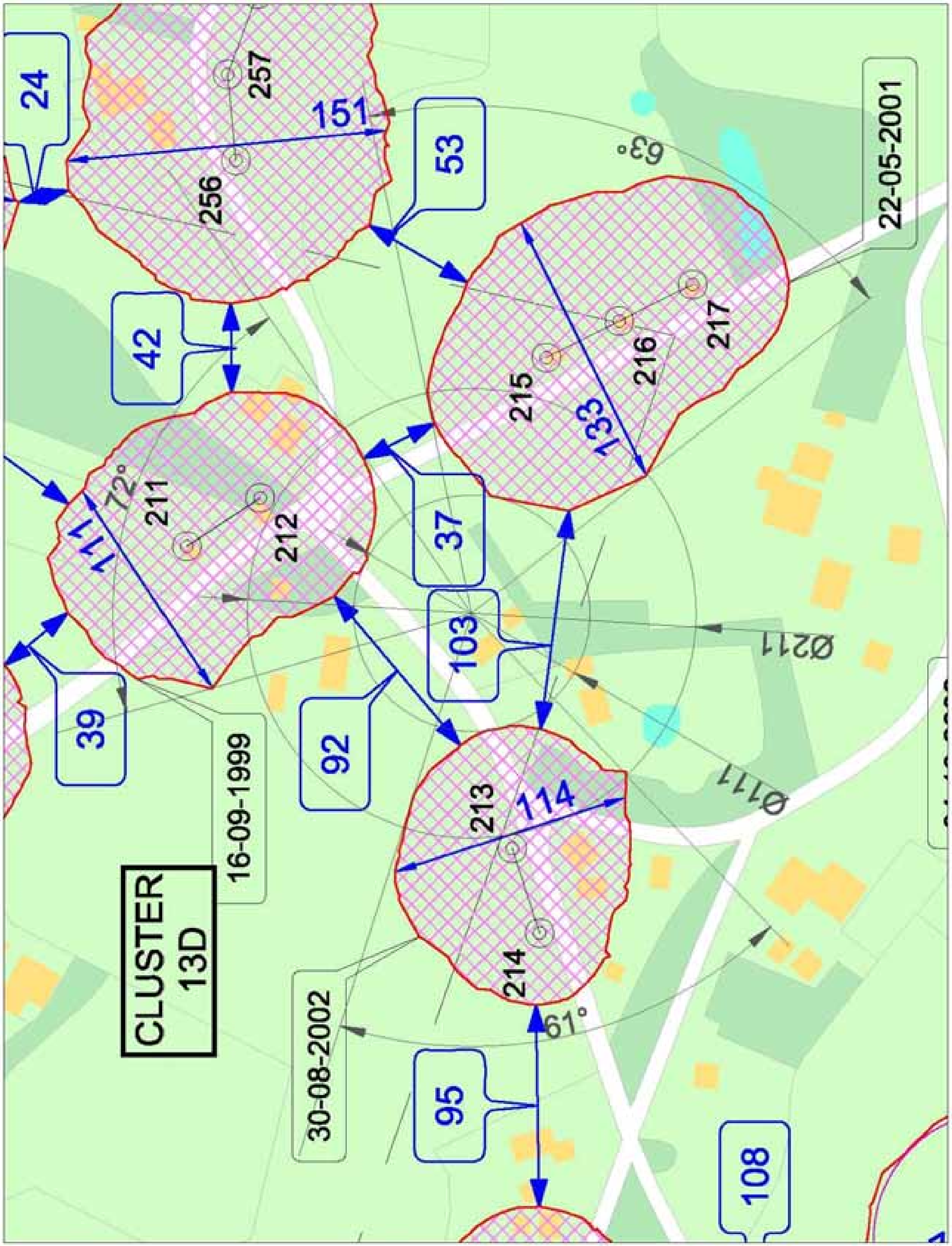
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16-09-1999
30-08-2002
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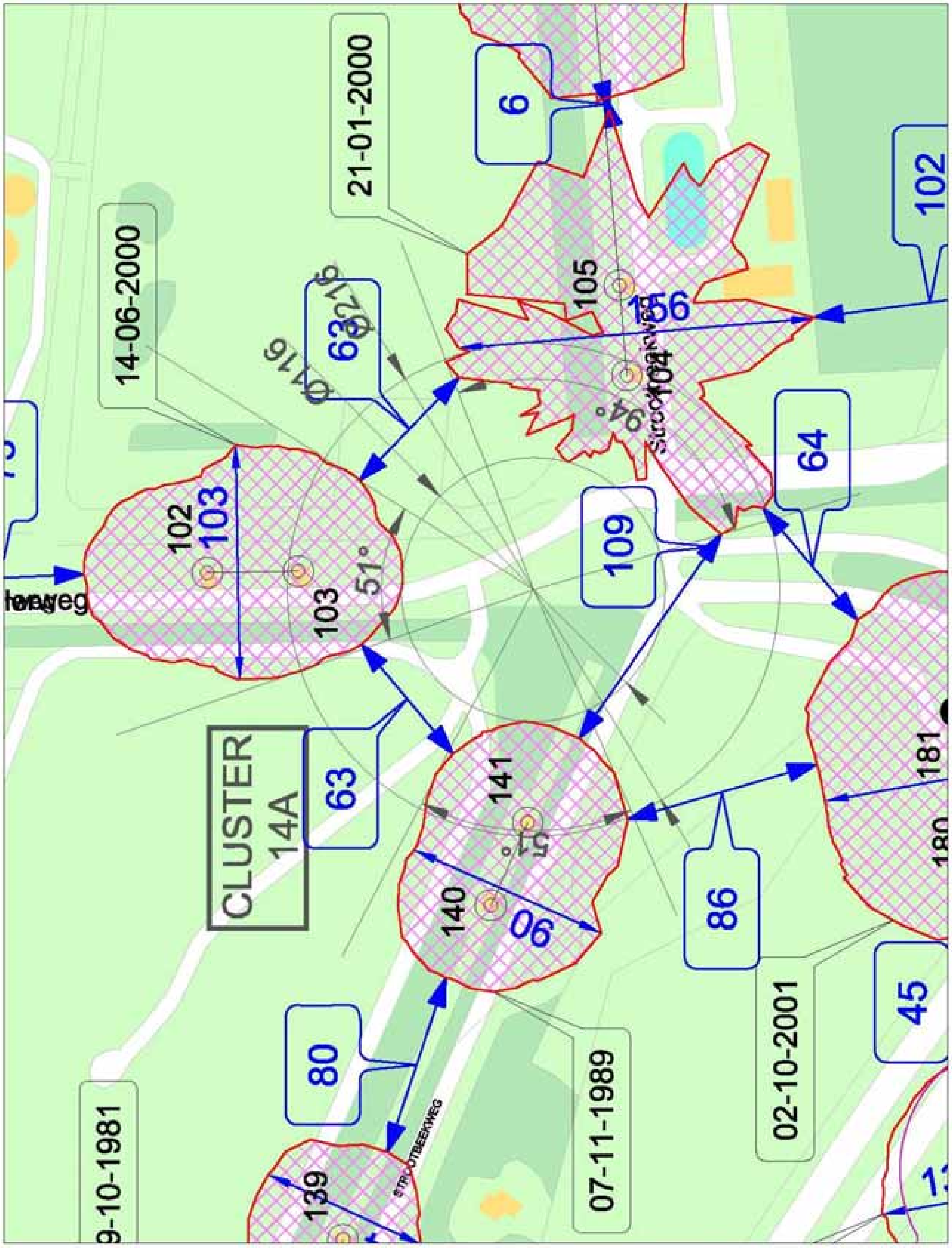
CLUSTER
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14-06-2000
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6
102
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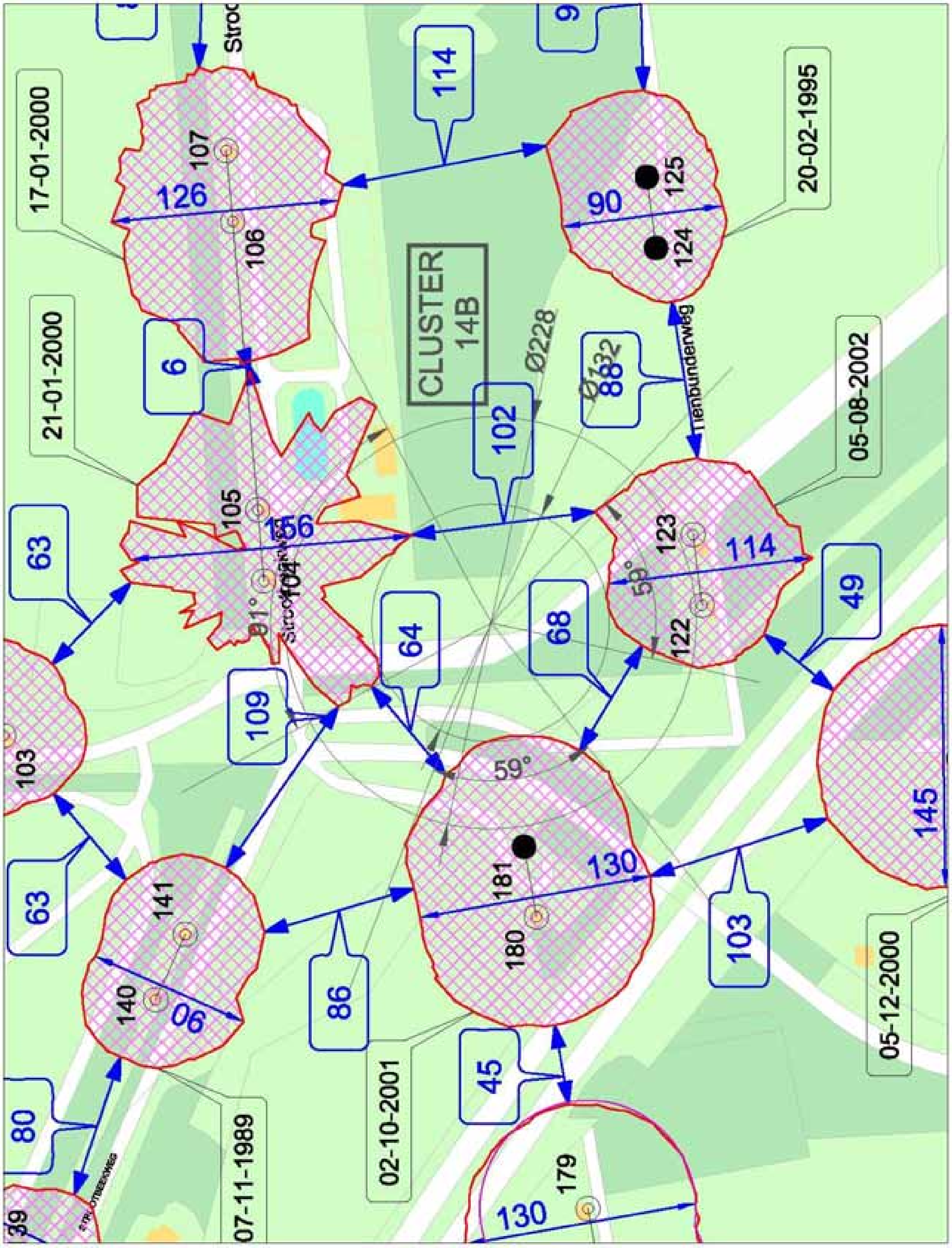
51°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07-11-1989
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Tienbunderweg
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64
68
109
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86
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103
49
6
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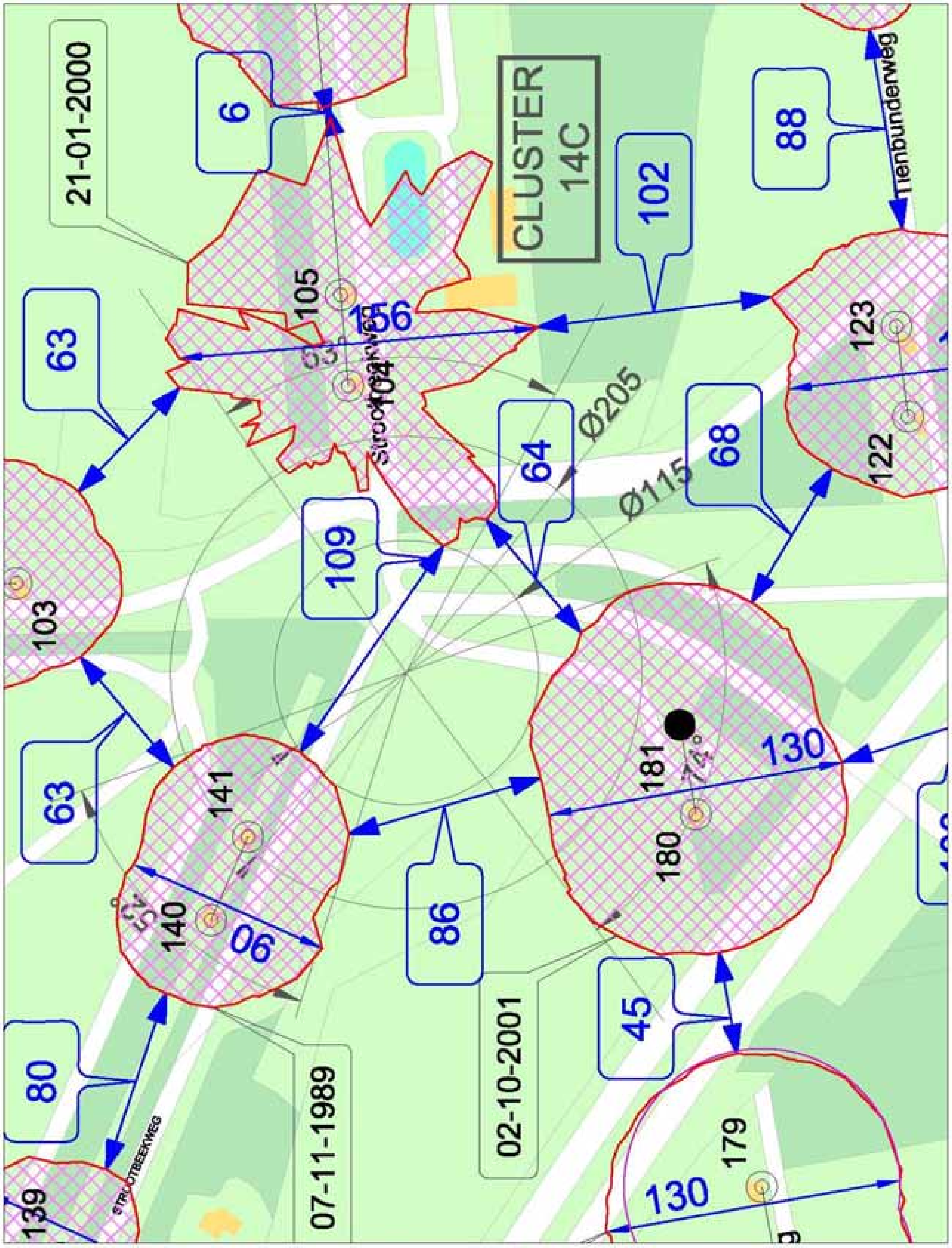
59°
91°


CLUSTER
14C
21-01-2000
02-10-2001
07-11-1989
Tienbunderweg
Strootbeekweg
STROOTBEEKWEG
Ø205
Ø115
6
63
63
80
86
88
90
45
64
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102
109
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156
103
104
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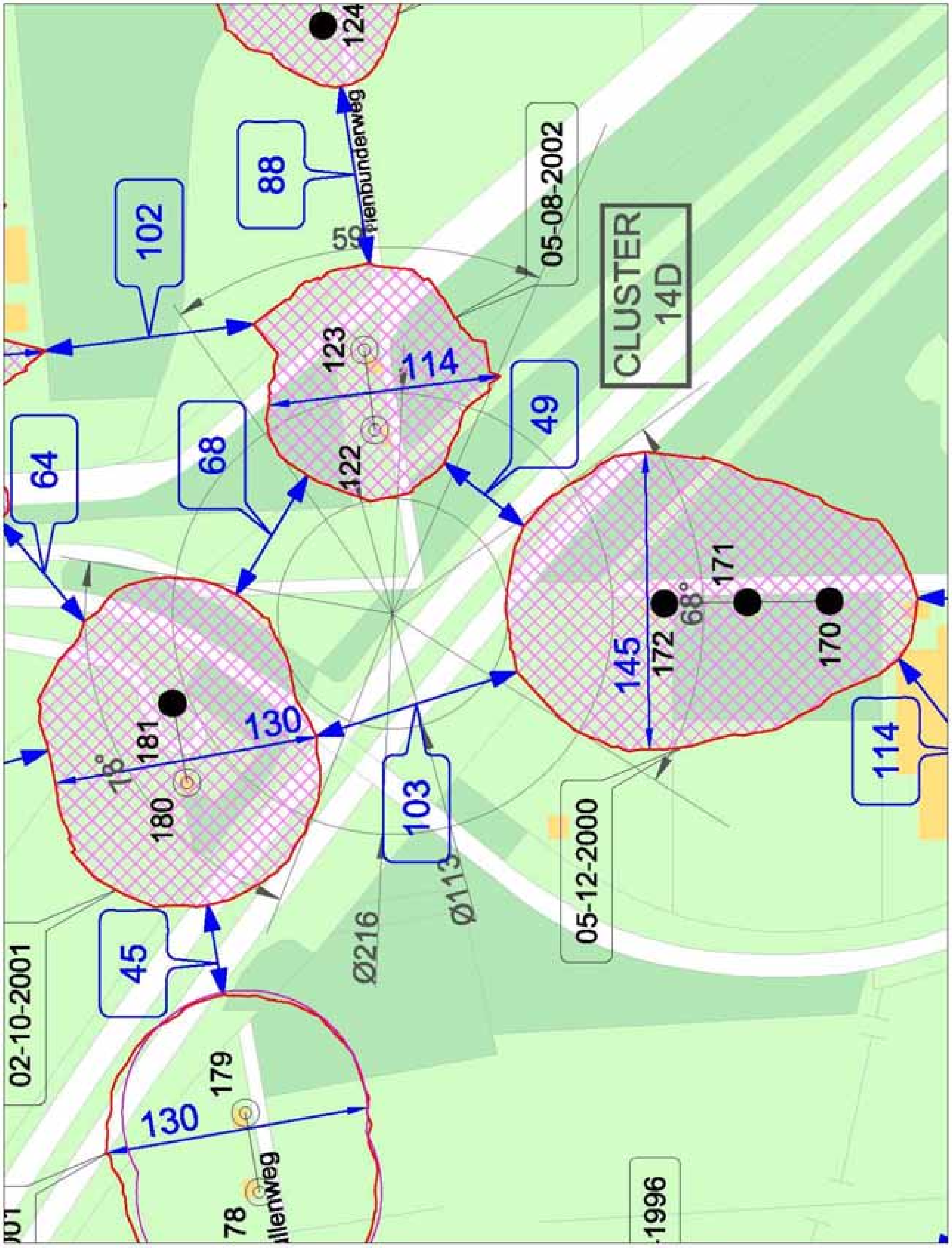
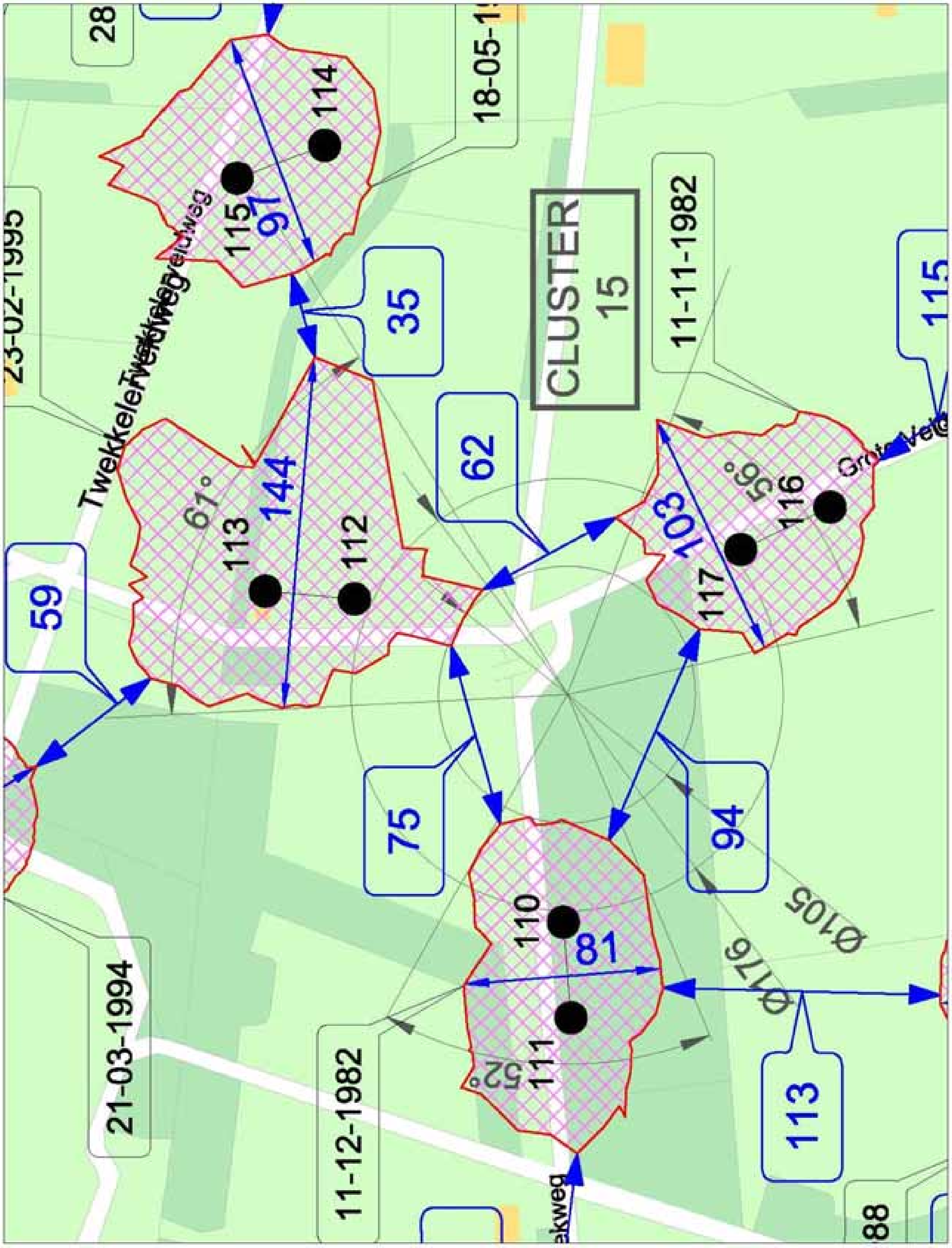


124
88
102
59
05-08-2002
CLUSTER
14D
123
114
122
49
64
68
171
68°
172
170
145
181
130
18°
180
103
114
Ø216
Ø113
05-12-2000
02-10-2001
45
179
130
78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15
11-11-1982
11-12-1982
21-03-1994
Twekkelerveldweg
59
35
62
75
94
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103
81
61°
56°
52°
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113
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115
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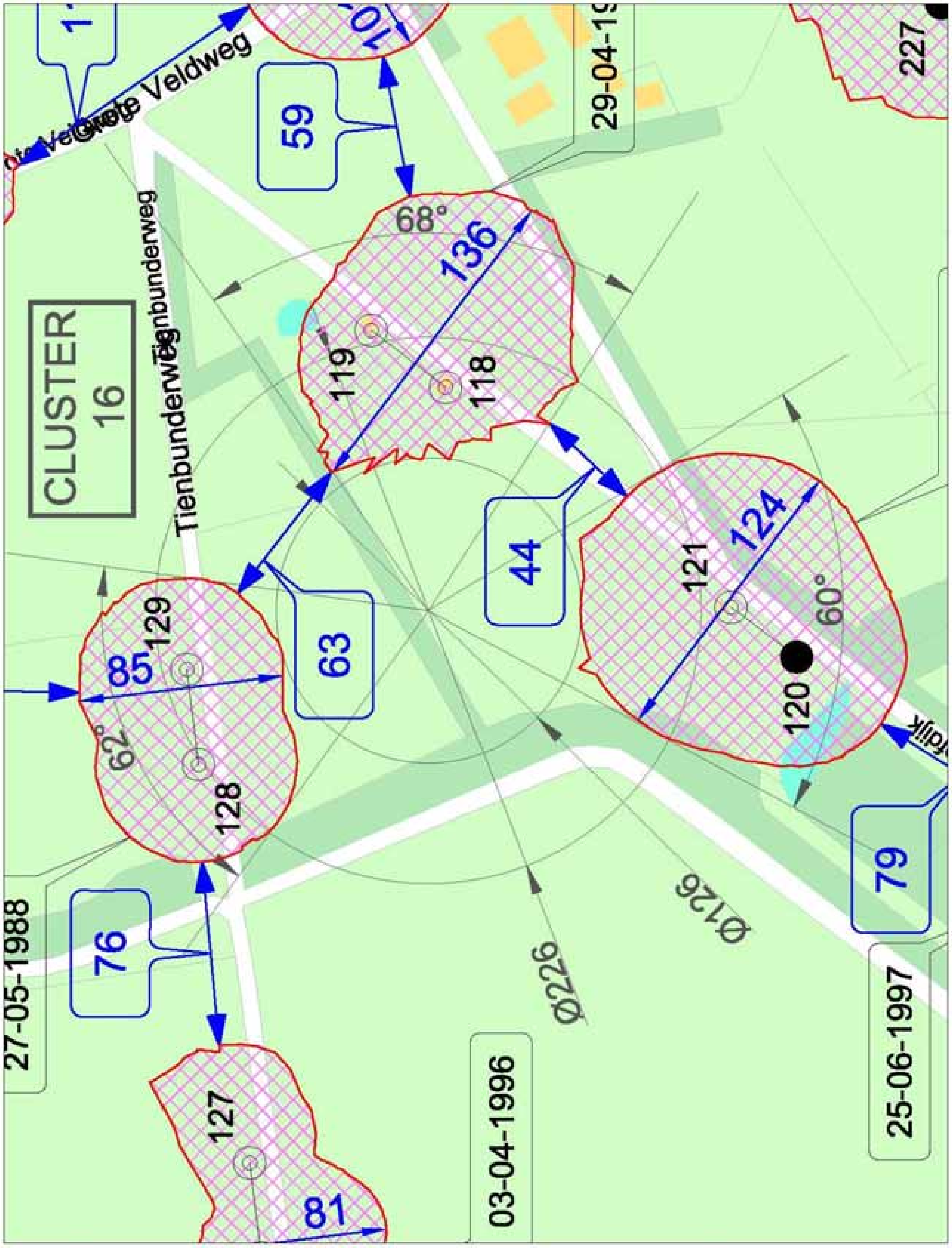
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Grote Veldweg
Tienbunderweg
Tienbunderweg
59
136
68°
119
118
44
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60°
120
63
85
129
62°
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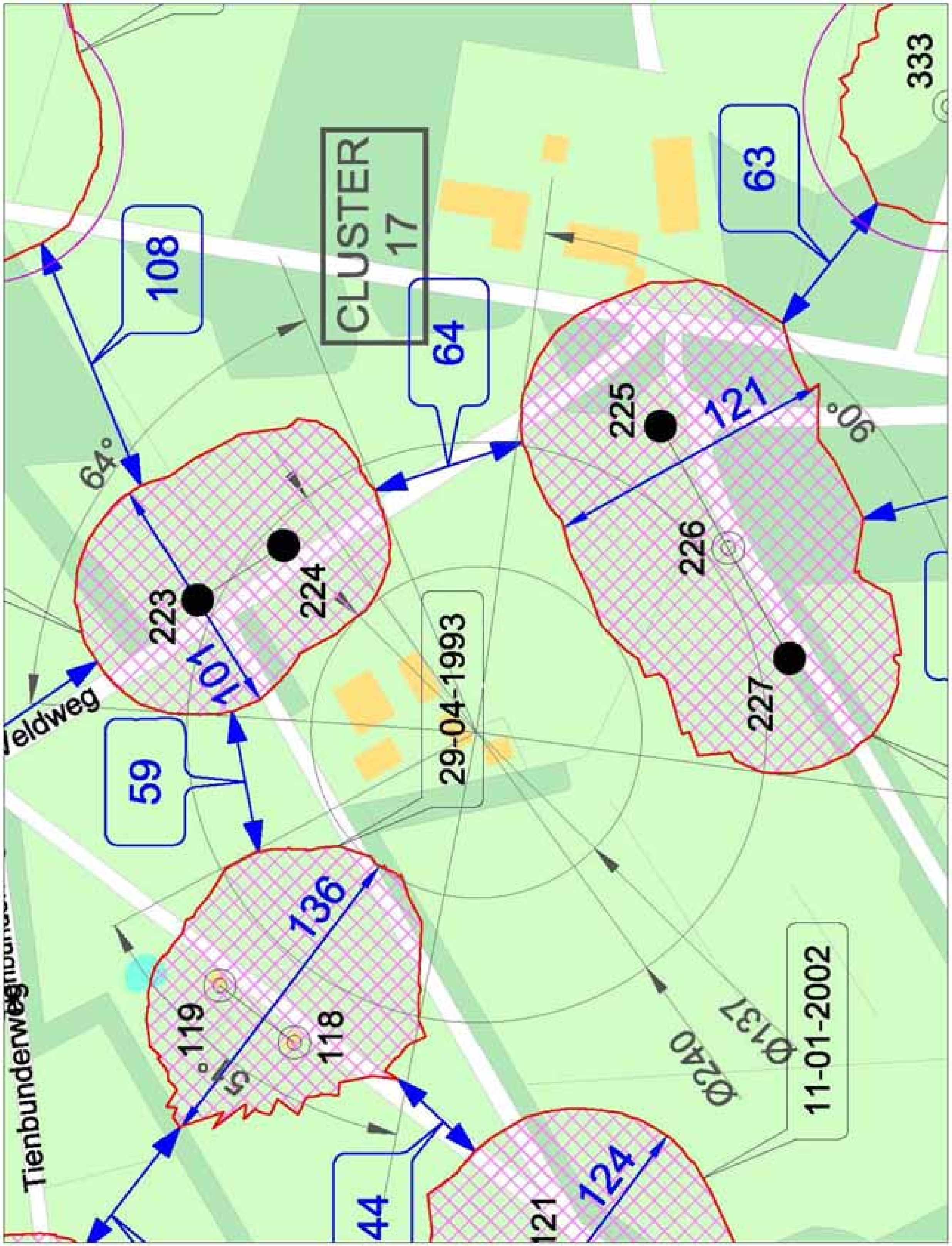
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108
64
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90°
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227
223
224
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44
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11-01-2002
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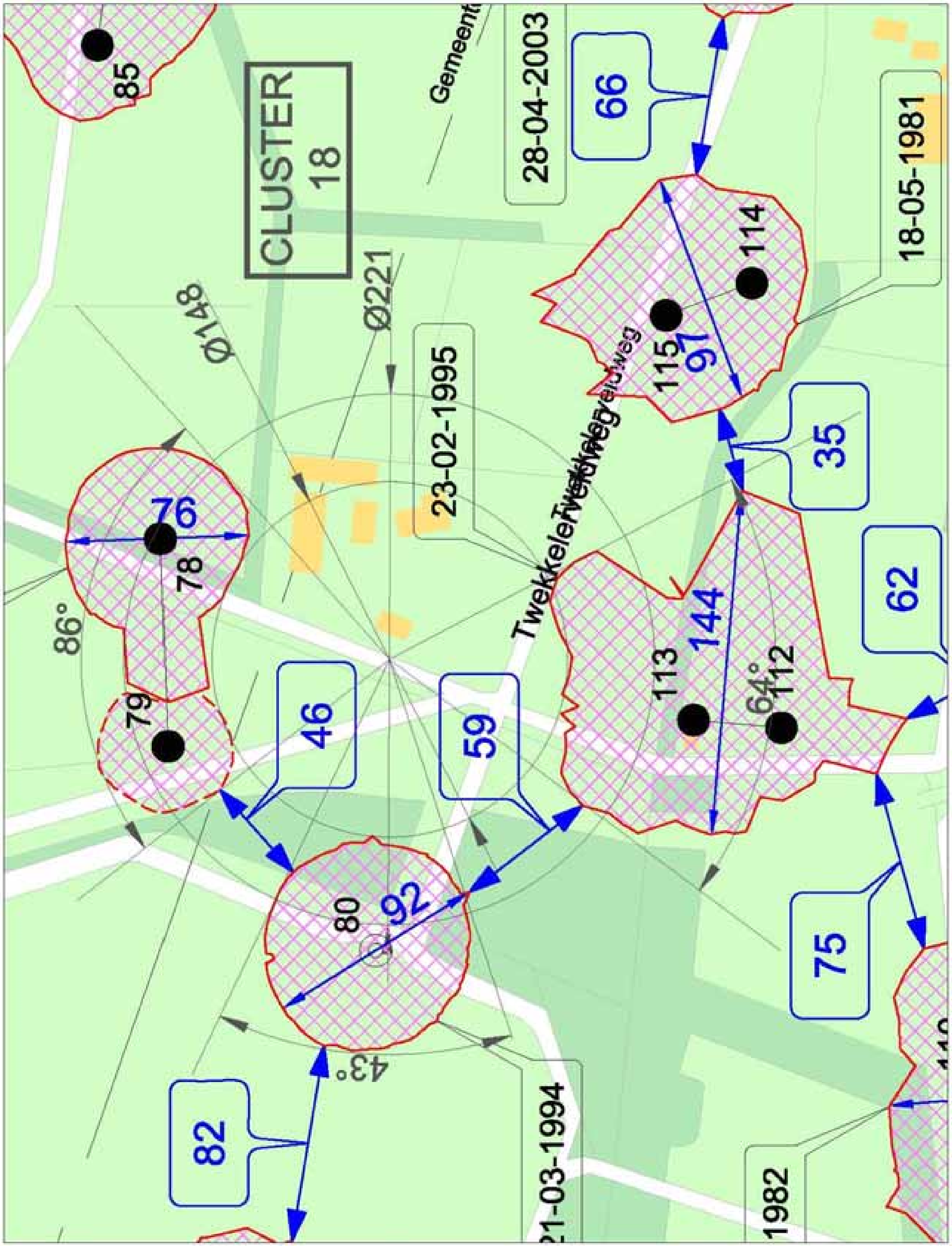

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18
Gemeent
28-04-2003
18-05-1981
23-02-1995
21-03-1994
1982
Twekkelerveldweg
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Ø221
86°
64°
43°
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76
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79
80
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82
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114
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113
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62
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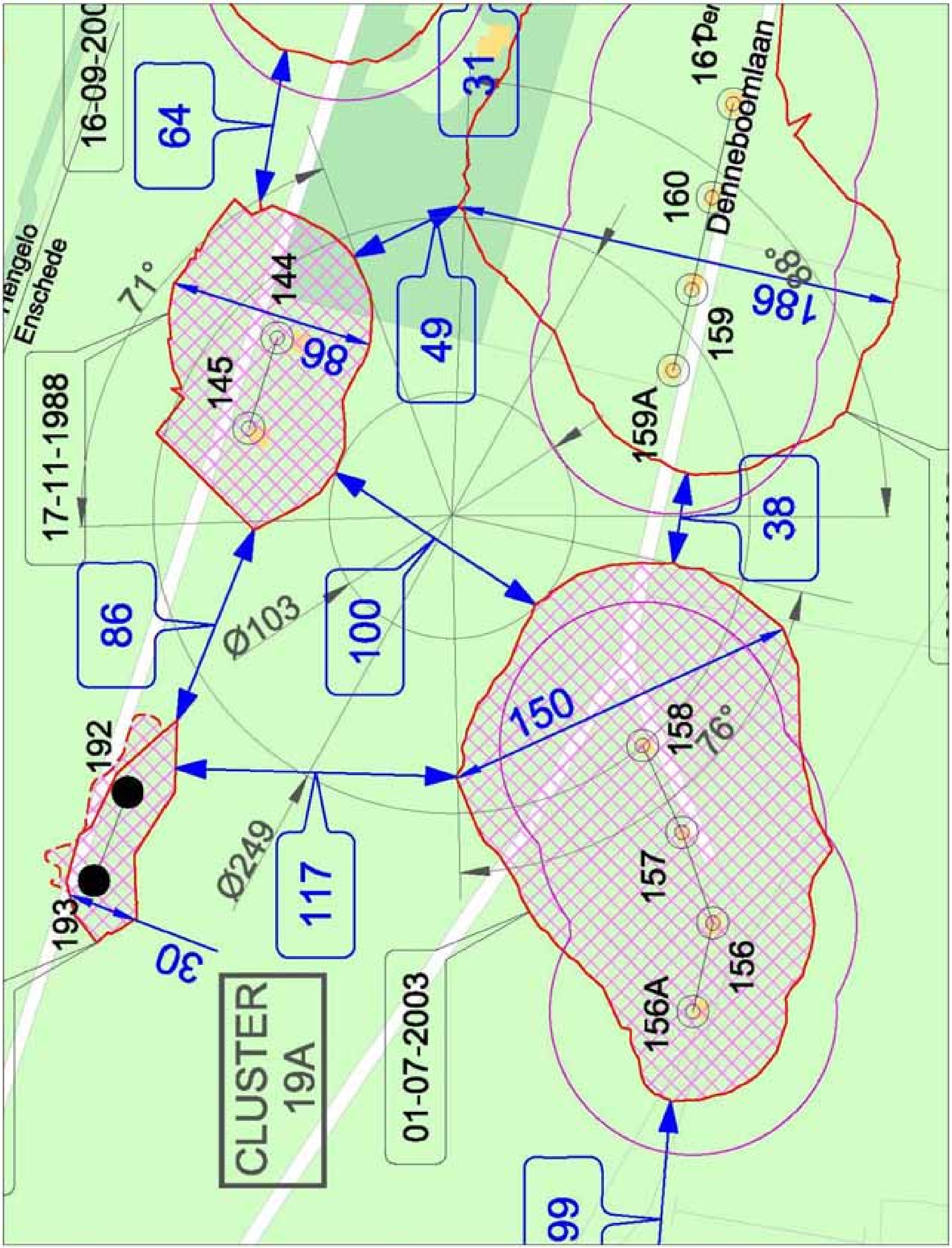
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19A
Hengelo
Enschede
16-09-200
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01-07-2003
Denneboomlaan
64
31
49
98
186
38
86
100
150
117
30
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76°
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160
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156A
156
157
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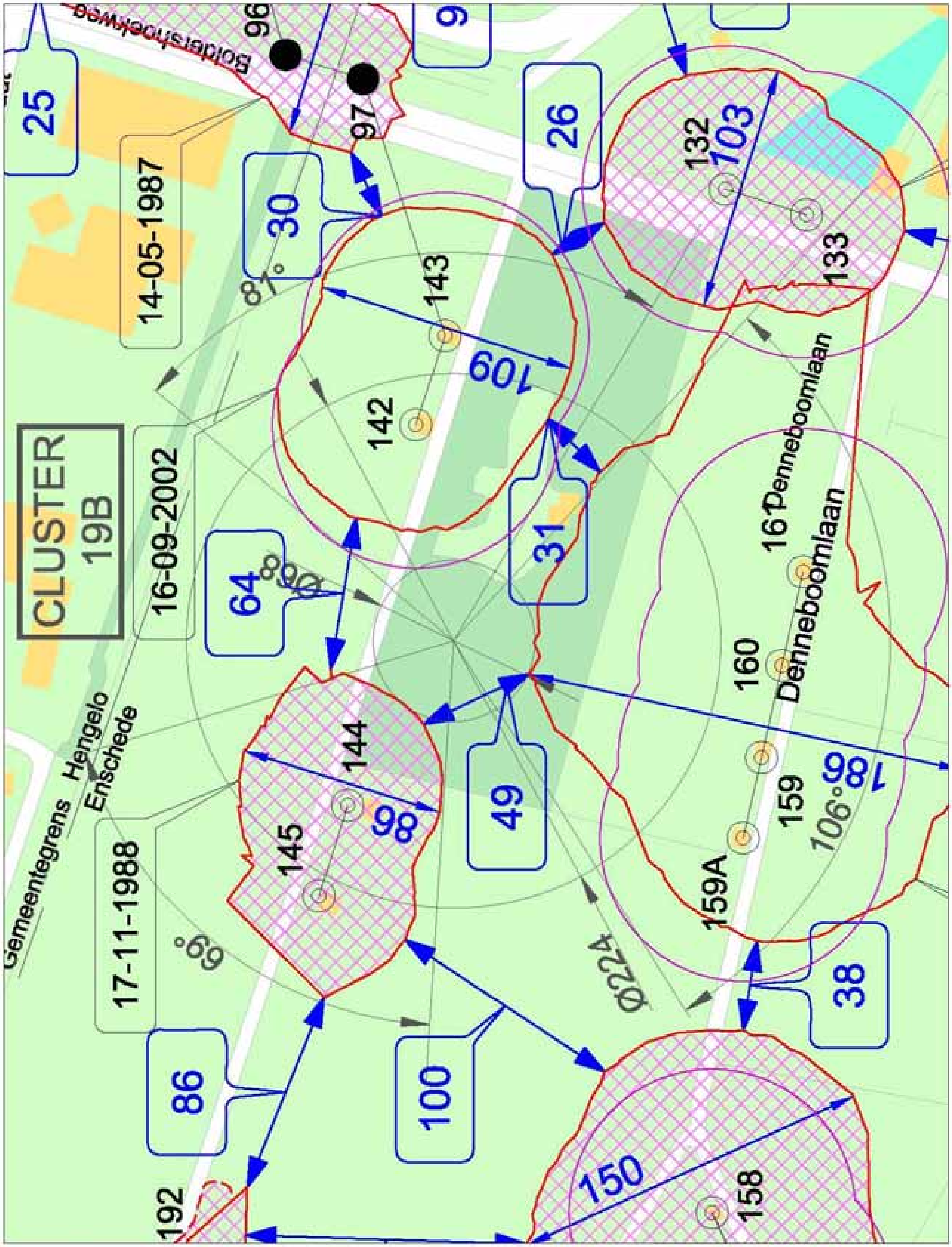
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Enschede
Denneboomlaan
Denneboomlaan
25
26
30
31
38
49
64
86
100
103
109
98
150
186
81°
90°
69°
106°
Ø224
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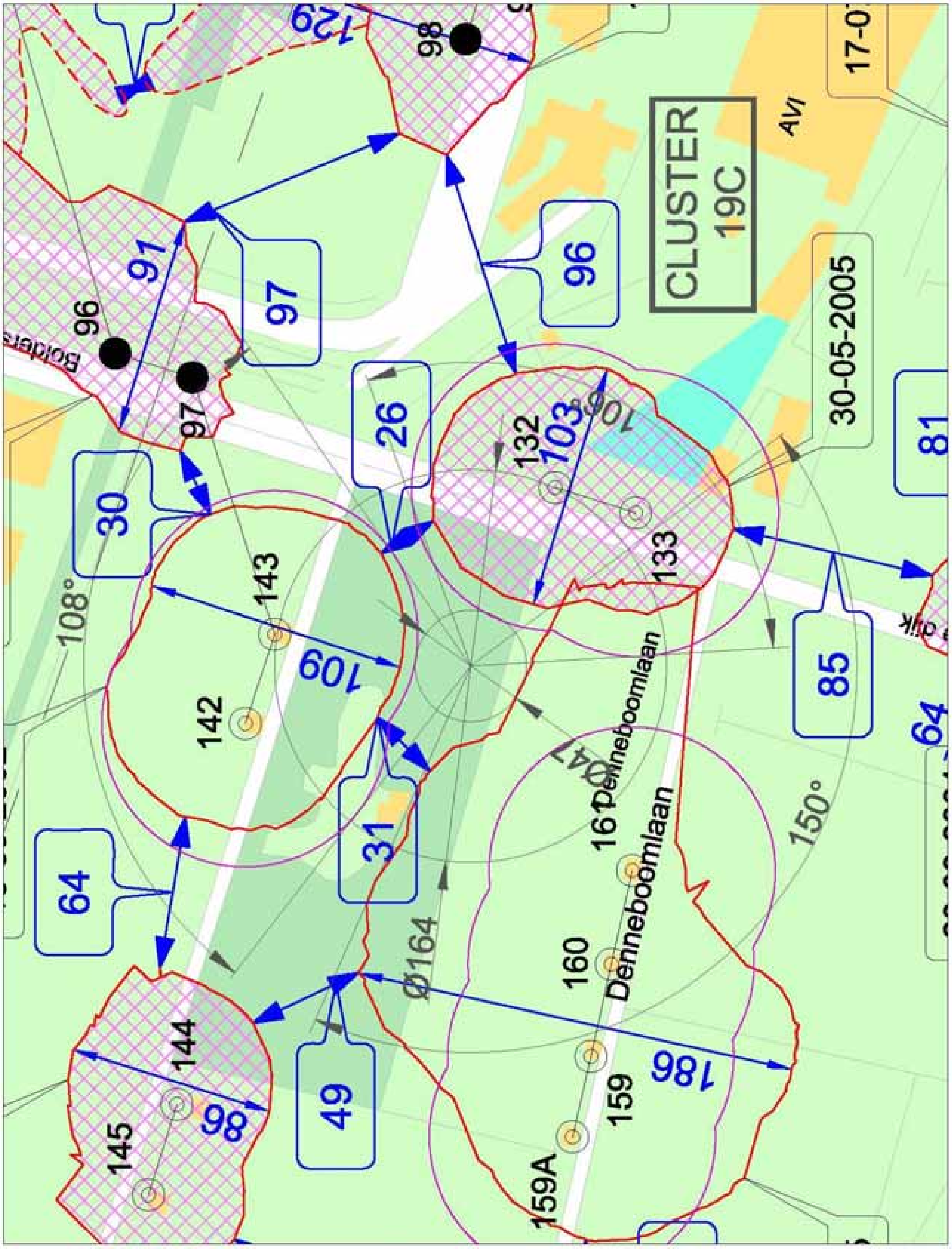
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19C
30-05-2005
Denneboomlaan
Denneboomlaan
108°
150°
Ø164
97
96
26
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64
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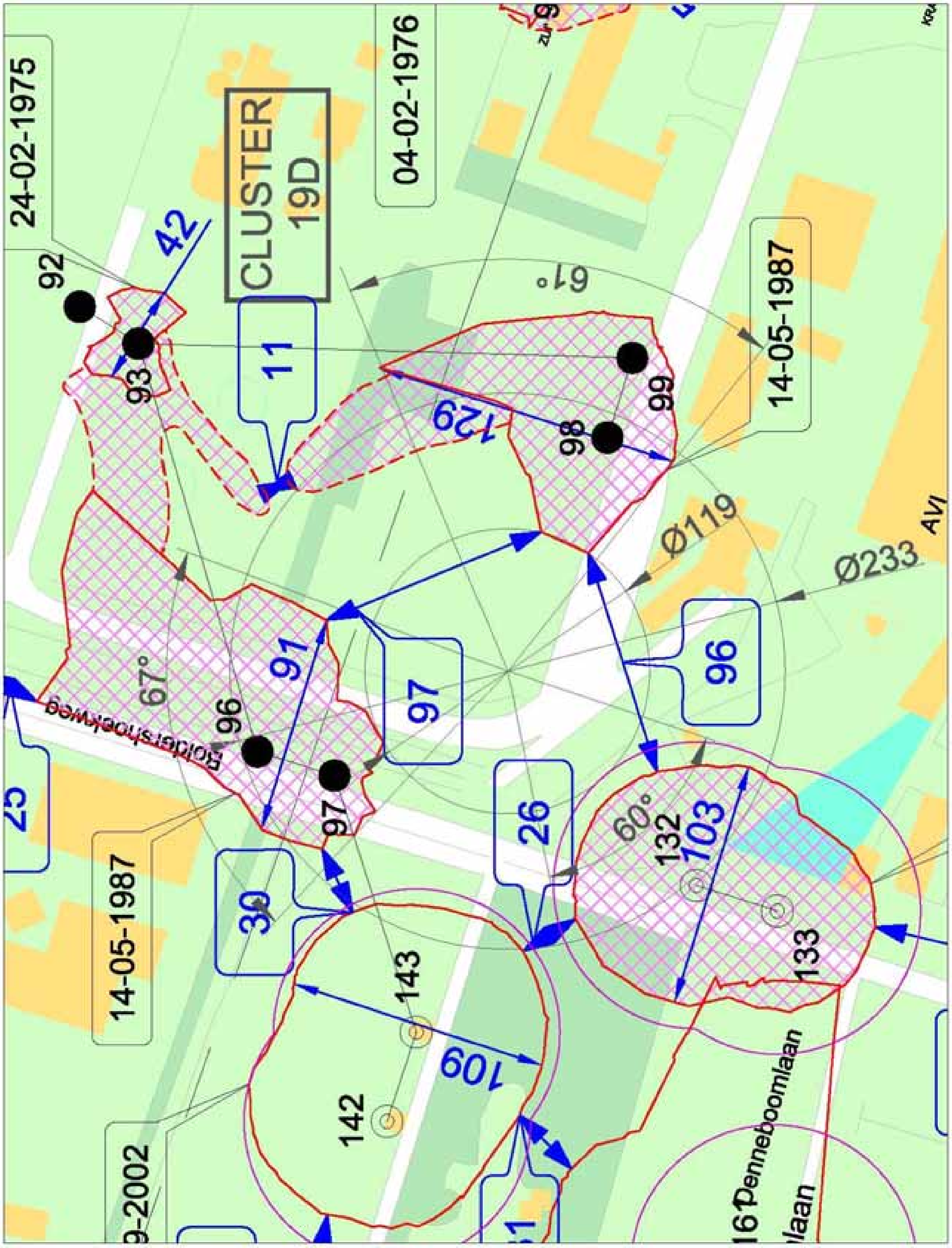
159A
160
161
AVI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19D
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04-02-1976
14-05-1987
14-05-1987
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Ø233
61°
67°
60°
Boldershoekweg
Penneboomlaan
AVI
11
42
91
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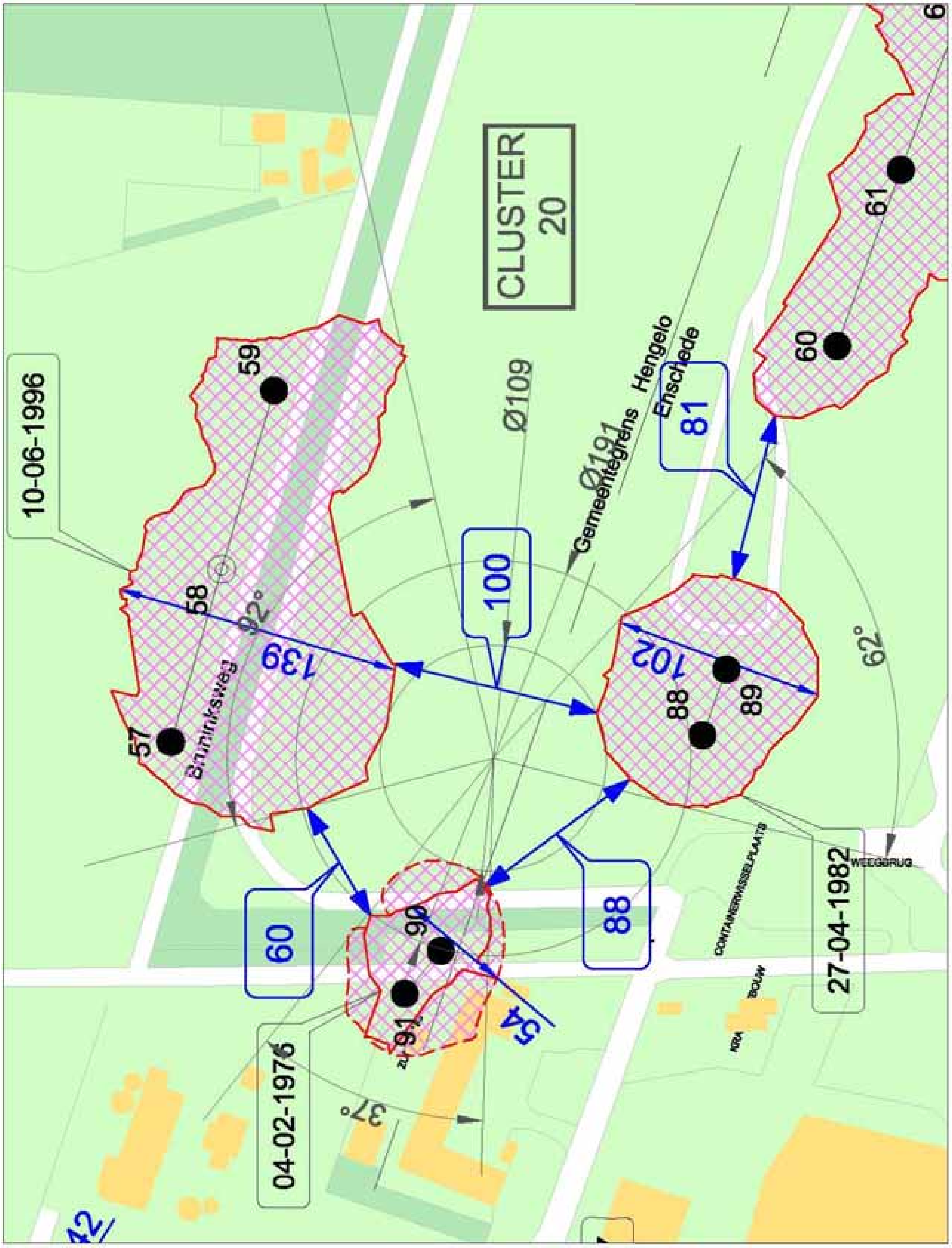
CLUSTER
20
10-06-1996
27-04-1982
04-02-1976
57
58
59
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88
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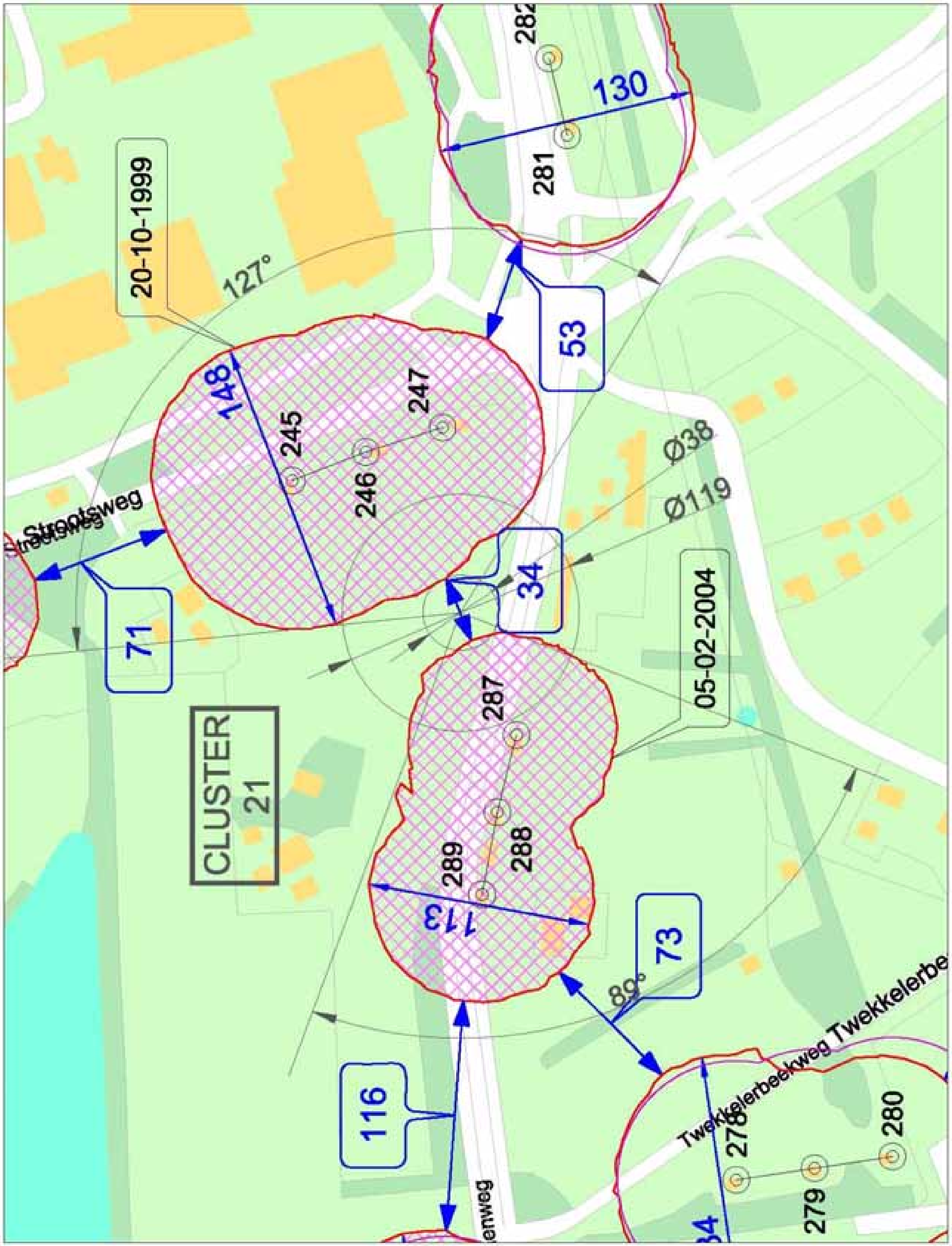
60
54
92°
62°
37°
Ø109
Ø191
Gemeentegrens Hengelo
Enschede
WEEGBRUG


20-10-1999
127°
148
245
246
247
53
130
281
Strootsweg
71
34
Ø38
Ø119
05-02-2004
CLUSTER
21
287
288
289
113
73
89°
116
Twekkelerbeekweg
278
279
280