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Survey Event No. **15**

Survey Name **N84 Luimnagh Realignment**

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N84 LUIMNAGH REALIGNMENT, COUNTY GALWAY

GEOPHYSICAL SURVEY REPORT

PROJECT CODE: LMR20051

DECEMBER 2005

LICENCE NUMBER 05D090

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REPORT PRODUCED FOR
GALWAY COUNTY COUNCIL

N84 LUIMNAGH REALIGNMENT, COUNTY GALWAY

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NON-TECHNICAL SUMMARY

Magnetic gradient and magnetic susceptibility surveys were commissioned by Galway County Council to assess the archaeological potential along the line of a proposed realignment of the N84 at Luimnagh, near Headford.

The susceptibility result was assessed relative to measurements at a known site GA56:012 adjacent to the realignment and proved to be inconclusive. Some enhancement in the vicinity of this monument was apparent but it could not be differentiated from enhancement elsewhere along the corridor due to modern land improvement.

However, the magnetic gradiometry survey did detect a low level of activity at various locations, sufficient to warrant further investigation. At one location, in Ballinduff townland, there are also low earthworks which coincide with magnetic disruption, perhaps the site of roadside buildings.

December 2005

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Interim		
Draft Full	20/12/05	MJR
Final Full	09/01/06	MJR
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D:\Templates & Macros\Document Templates\MS Word\Geophysics Report Template.dot		

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ILLUSTRATIONS

Section 1: THE PROJECT

1.1 Introduction

1.1.1.1 A magnetic survey was commissioned by Martin Jones of the National Roads Design Office (NRDO) on behalf of Galway County Council to investigate the line of a section of the N84 to be realigned at Luimnagh, avoiding the present pronounced bend in the road.

1.1.1.2 The region affected by the improvements is situated both sides of the existing N84 in County Galway, approximately 15 km north of Galway city and 7 km south of Headford and includes the junction with the side road to Ballinduff bay on the east side of Lough Corrib.

1.1.1.3 It passes through townlands Ballinduff, Ballydonnellan, Mausrevagh with Keernaun at the westernmost extent.

1.2 Outline Methodology

1.2.1.1 For detailed information on the structure of the site grid, instrumentation and data processing please see the tabulated metadata in the appendix entitled "Project Metadata".

1.2.1.2 The table below summarises the different survey methods used on this site as required by the NRDO specification on behalf of Galway County Council.

Survey Technique	Spatial Resolution	Area
Volumetric magnetic susceptibility	10m x 10m	1.68km length
Total field caesium vapour gradiometry	1.0m x 0.25m	1.68km x 15m

1.2.1.3 The principal elements of this specification were the collection of a set of magnetic susceptibility measurements on a loose 10m grid with a line 5m each side of the centreline of the proposed road. In addition, a narrow strip of magnetic gradiometry down the centre line of the proposed road was requested.

1.2.1.4 The magnetic susceptibility survey was to form a magnetic framework against which the gradiometry data, intended to reveal detail, could be compared. At each location a small number (2 or 3) measurements were taken to ensure a representative value was collected.

1.2.1.5 The background mapping used in this reporting is derived from CAD data supplied by Galway County Council.

1.2.1.6 Recording of the individual magnetic susceptibility values and their position was accomplished using a Leica 1200 Series GPS in RTK configuration. The same instrument was used to set out the centreline from which 7.5m spurs were set by optical square to form fiducial lines for the magnetic gradiometry.

1.2.1.7 In the townland of Ballinduff the proposed road corridor follows the line of the existing road for some 300m. The corridor then runs north of the road through this townland through a strip of woodland. This had apparently been cleared though this work was not associated with the proposed realignment and this did not correspond to the road corridor as outlined on maps supplied by Galway County Council. It was only possible to survey a green-field area near the southern limit of the route in this area.

1.2.1.8 The northern limit of the proposed realignment works through Keernaun consists mainly of the widening of the existing road and so was subjected to examination by the magnetic susceptibility technique only.

Section 2: RESULTS & DISCUSSION

2.1 Caveats

2.1.1.1 For some projects a third party may specify the methodology with only limited scope for expansion or redefinition by ArchaeoPhysica. In these cases any perceived failings of the methodology are the responsibility of the originator although ArchaeoPhysica remains responsible for any defects in its application.

2.1.1.2 All discussion of results in this report is based upon interpretation of the various data sets and examination of their context relative to other sources of information. ArchaeoPhysica cannot necessarily guarantee the correctness of third party sources though every attempt is made to verify these if they have a material affect upon the outcome of the project.

2.1.1.3 Any recommendations are made in the light of the surveys and other information made available to ArchaeoPhysica who offer no guarantee of their relevance to the overall project. ArchaeoPhysica cannot be responsible for the manner in which any of these recommendations are implemented by third parties, whether in whole or in part.

2.1.1.4 Finally, as with all remotely sensed data, the measurement process provides an indirect impression of buried or otherwise concealed features and the reader must be aware that multiple interpretations are possible in some cases. In addition, it can be difficult to accurately determine the exact extents of concealed features and hence any quoted dimensions must be regarded as indicative. Where different meaningful interpretations exist these will be indicated in the text. For geophysical data in particular the interpretative process is concerned primarily with the physical properties of a buried body that may or may not be manifest as an archaeological feature. Magnetic surveys of ditches are a common example; the geophysical data may suggest the presence of a ditch but can only describe the magnetic parts of its fill while the rest of the feature may not be apparent and hence appear quite different upon excavation.

2.2 Introduction

2.2.1.1 Magnetic susceptibility can be strongly influenced by differences in agricultural regime and the effect of this can become predominant in situations where the natural magnetic activity of the soil is low. This is the case in County Galway and the result of this project seems to demonstrate this though there is a lack of published material from the area against which the result can be compared. ArchaeoPhysica's own experience suggests the result from this project is likely to be fairly typical for the area with some low-level enhancement near established habitation sites but perhaps little or no enhancement detectable at the surface elsewhere.

2.2.1.2 In several locations the susceptibility result was essentially zero and in most cases this was seen to correspond to areas of limestone below as little as 0.1m of soil in places. An important result is the presence of negative values; these are a genuine response and have been found by ArchaeoPhysica in various locations in the county, e.g., along the line of the proposed Tuam N17 bypass. In some cases they are caused by geochemical processes relating to very high organic soil content, e.g., surface peat. In other cases they are due to a local characteristic of the limestone which displays weakly magnetic properties but in opposition to the applied magnetic field. This aspect of rock magnetism is not well understood but where these values occur in the absence of peat there is nearly always limestone very close to the ground surface.

2.2.1.3 In order to avoid problems related to instrument drift each measurement was taken within a few seconds of nulling the instrument in air (air having zero susceptibility).

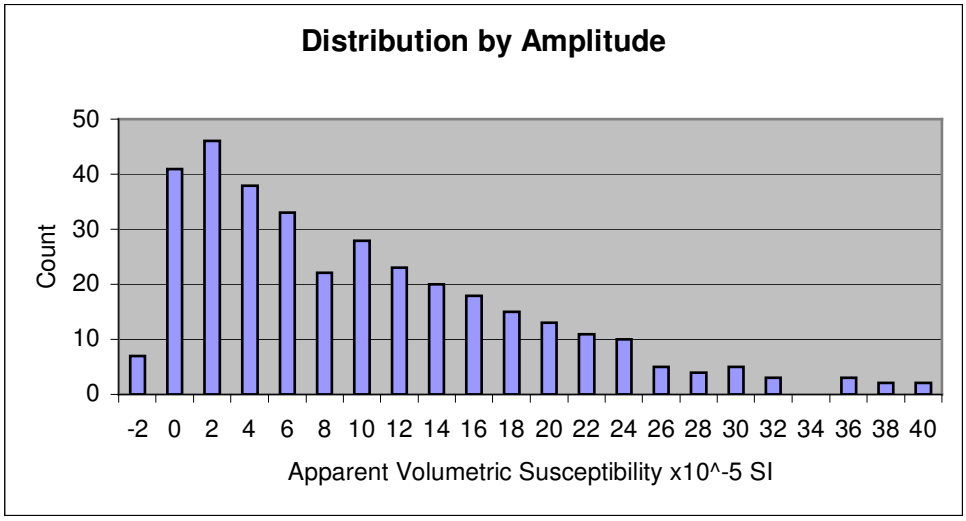
2.2.2 Note on the significance of magnetic susceptibility values

2.2.2.1 It is very difficult in regions with only low levels of natural magnetic susceptibility to be sure what can be classed as significant in an archaeological context. For this reason, representative values were sought for this project by examining the area around the ringfort at 130060, 242618, GA56:012 in Ballydonnellan townland. In theory, habitation sites like these should be associated with strong susceptibility enhancement due to a mixture of thermal and fermentation processes associated with normal domestic activities. This enhancement should be concentrated on the site itself and should decrease with increasing distance away. By examining the context of this fort it was hoped that such an effect would be apparent and then representative elevated and background values determined.

2.2.2.2 This analysis was successful as values of between 15 and 20 x 10^{-5}SI were noted close to the monument with a steady reduction to 2 to 5 x 10^{-5}SI further away. Higher values were noted very close to the monument within a tightly defined area on the east side, probably indicating an annexe used perhaps as a stock corral.

2.2.2.3 There are two parameters that have a large affect upon the result. If the search coil of the instrument is not in direct contact with the ground, the measured susceptibility is less than the true. If two measurements of volumetric susceptibility are made, one of improved soil and the other of unimproved, in general the improved will exhibit a higher apparent susceptibility value.

2.2.2.4 To be sure of applying a realistic assessment of significance to the result the graph below was quickly formed as a check. It shows that most values are in the 0 to 6 x 10^{-5}SI range that can be assumed to be genuine natural background, found to be associated with rougher less improved ground with shallow stony soil. However, a large amount of the available land had been improved and as this leads to a natural increase in susceptibility. There is a broad



tail to the distribution with no clear division between background and what are considered significant values on the basis of the field test described above. For this reason, magnetic susceptibility is not in this case a reliable indicator of past human activity as land improvement can have as large an affect. Only by taking a very large number of readings, generating a statistical probability model and then applying it only where ground conditions were accurately known could a reliable indicator based on susceptibility be formed in this case.

2.3 Discussion

2.3.1.1 Drawings DWG 09 onwards are annotated with significant points of interest along the route. These are numbered 1 to 22 and relate to the table below. MS refers to apparent volumetric magnetic susceptibility and MTFVG is the vertical gradient of the total magnetic field intensity.

ID	Near X	Near Y	Data Type	Description
1	130902	242297	MS	Area of relatively strong MS may relate to deeper and perhaps more cultivated soil. It is less marked near the road at the northwest end where other features exist and it seems to tail off at the southeast end. This may be of archaeological interest.
2	130927	242322	MTFVG	Area of general disturbance of the magnetic field, associated with low mounds and surface stone.
3	130952	242323	MTFVG	Area of low field gradient typical of buried stone or very shallow soil.
4	130935	242316	MTFVG	Strong disruption, probably buried debris, perhaps related to other features though may not be.
5	130995	242305	MTFVG	Line of enhanced magnetic gradient typical of a ditch fill. It seems to coincide with surface stone at 6 and may have been a field boundary.
6	131014	242277	MS	Surface stone associated with low MS values.
7	131092	242240	MTFVG	The pattern of cultivation furrows is distorted here which might suggest a former field boundary.
8	130102	242574	MS	This region is outside the road corridor but was subjected to a brief magnetic examination as it lies between the road and a ringfort. As expected, MS values increase towards the monument and there are signs of activity outside it.
9	130062	242534	MTFVG	Small slightly curving line of enhanced magnetic gradient, probably the fill of a small ditch or gully.
10	130034	242532	MTFVG	This may be the corner of a small stone-built structure or alternatively something trapped in an angled ditch.
11	130020	242571	MTFVG	Possible fill of a large pit; alternatively a pocket of deeper soil.
12	130009	242558	MTFVG	Possible fill of a large pit; alternatively a pocket of deeper soil.
13	130013	242553	MTFVG	There is a short length of reduced magnetic gradient, perhaps the base of a wall or stony bank.
14	130002	242566	MTFVG	This may be a region of shallow soil; on the other side of the field boundary there is stone very close to the present surface (though since removed).
15	129925	242676	MTFVG	Possible pit fill or perhaps just a pocket of deeper soil.
16	129935	242707	MTFVG	Area of low field gradient, perhaps marking the base of a stony bank or field wall.
17	129928	242724	MTFVG	Magnetic contamination from telegraph pole and steel stay.
18	129872	242826	MTFVG	Magnetic contamination from nearby steel gate and fence.
19	129862	242887	MS	Area of relatively elevated MS values, a typical occurrence around domestic sites, e.g., the adjacent farm complex.
20	129661	243256	MS	Very low MS values are here associated with an area of shallow soil over limestone pavement.
21	128983	243693	MS	Relatively elevated MS values in this area correspond to highly improved pasture and may relate to increased soil depth rather than archaeological material.
22	128770	243765	MS	Relatively high MS values may indicate archaeological features exist in this area. There is a standing stone associated with a slight platform in the same field.

2.4 Conclusions

2.4.1.1 The predominant component of the result is the strong correlation between magnetic susceptibility and the improvement of land with the most improved / tilled land exhibiting, in general, elevated values that are indistinguishable from those elevated by past human activity. This suggests that the technique is perhaps not the best indicator of past human activity in this area. In areas of heavily improved land such as this detailed magnetic field or gradient survey of the full width of the corridor would possibly produce better results.

2.4.1.2 There would appear to be a low level of past activity throughout the area and it is clear that much of the land was once cultivated using the lazy bed technique as relict furrows are visible in many places. Because of this it is difficult to be sure whether small discrete features survive or whether they have been removed in the past. In some areas modern land improvement activity, e.g., the fields at 129880, 242750 in Mausrevagh townland, has probably truncated many buried features as the favoured technique is to mechanically strip away the soil to a depth of 0.6m or more, remove the boulders and then backfill. This process was being used in the adjacent field to GA56:012 at the time of survey.

2.4.1.3 The western end of the survey in Ballinduff townland, at 130950, 242310, shows substantial disruption to the magnetic field and some extant earthworks. This may be the site of roadside cottages or other buildings. The generally elevated magnetic susceptibility result in this field may be of interest.

2.4.1.4 Magnetic susceptibility survey as a primary reconnaissance solution must be used with caution while its suitability is open to question. To date, the picture seems mixed with some degree of enhancement in the vicinity of monuments like ringworks but no susceptibility contrast between some major archaeological features like ditch fills and the soils around them.

2.5 Recommendations

2.5.1.1 It is the established policy of Galway County Council to carry out centre-line testing along the routes of national road schemes and this practice is also recommended in this instance due to the overall level of uncertainty associated with the geophysical result.

2.5.1.2 The work to date should be examined in retrospect and compared with the data from excavation to allow a realistic assessment of the reliability of magnetic susceptibility as an indicator of past human activity. This study should ideally be undertaken by an independent authority and published.

2.5.1.3 Proportionally more of the corridor should be covered in future contracts by conventional magnetic survey to ensure sufficient diagnostic information is collected. We believe that 15m wide strips are too narrow to permit this and that a 30m width should be considered instead, even if this results in total coverage of a road corridor.

Section 3: APPENDIX – PROJECT METADATA

3.1 Project		
	Name	*N84 Luimnagh Realignment*
	Code	*LMR20051*
	Client	*Galway County Council*
	Fieldwork Dates	*04/07/05 – 07/07/05 & 09/08/05*
	Personnel	*MJ Roseveare, ACK Roseveare, S Lowden*
	Draft Report Date	*20/12/05, delayed for technical discussion*
	Final Report Date	
3.2 Location		
	Country	*Republic of Ireland*
	County	*Galway*
	Nearest Town	*Headford*
	Landholding	*Various*
	Central Co-ordinates	*1300 2426*
	Co-ordinate System	*Irish National Grid IRL99*
3.3 Environment		
	Geology – Soil	*Mixed, thin peaty soil over limestone pavement and sand, deep loam over glacial moraine.*
	Geology – Parent	*Carboniferous Limestone*
	Topography	*Variable but mostly flat or gently sloping*
	Hydrology	*Free draining*
	Current Land Use	*Predominantly pasture*
	Historic Land Use	*Improved pasture and arable*
	Vegetation Cover	*Grazed grass*
	Sources of Interference	*Post and wire fences, passing traffic*
3.4 Survey Grid		
	Projection	*Transverse Mercator*
	Co-ordinate System	*IRL99*
	Bearing	*0 degrees*
	Precision	*0.05m relative to reference*
	Instrument Used	*Leica 1200 GPS, RTK configuration*
	Reference Points	*Local from Galway County Council mapping*
	References Definition	
3.5 Survey Method		
	Measured Variable	*Total magnetic vertical gradient units nT/m*
	Instrument	*Geometrics G858 MagMapper & dual Geometrics 823*
	Configuration	*Carried vertical gradiometer, sensors 0.8m apart*
	QA Procedure	*Static instrument test, relative noise floor assessment, temporal variation assessment*
	QA Result	

	Data Source Format	*Geometrics proprietary binary file, extension ".bin". Compressed, not human readable, variable between software and instrument versions*
	Measured Variable	*Apparent volumetric magnetic susceptibility, unitless, expressed as x10^{-5} SI*
	Instrument	*Bartington MS2 with 0.2m diameter field coil*
	Configuration	*Logged manually onto GPS, rezeroed at each measurement position*
	QA Procedure	*Repeated measurements at a point in continuous cycle mode*
	QA Result	*Measurement static to within 1 significant digit*
	Data Source Format	*ASCII Human readable table with positions*
	3.5.1 Processing	
	Purpose	*1. G858 Magnetometer Import* *2. Bartington MS2 Record*
	Software	*1. Geometrics MagMap 4.48* *2. N/A*
	Parameters	*N/A*
	File Format	*1. Geometrics binary ".bin"* *2. MS Excel 97 SR2*
	Filename Suffix	*N/A*
	Purpose	*1. Single point despike of caesium magnetometer*
	Software	*Geometrics MagMap 4.48*
	Parameters	*Spike width 1 datum only*
	File Format	*1. Geometrics "*.stn"* *2. ASCII ".dat", human readable*
	Filename Suffix	*"-s"*
	Purpose	*Heading error reduction*
	Software	*Geometrics MagMap 4.48*
	Parameters	*Maximum permitted change = 3nT*
	File Format	*ASCII data file, human readable*
	Filename Suffix	*"-h"*
	Purpose	*Gridding of XYZ data to Surfer 6 ASCII grid*
	Software	*AP CubicDat2Grd 1.0*
	Parameters	*Line separation 1.0m, interval 0.25m*
	File Format	*Surfer 6 ASCII grid*
	Filename Suffix	*".grd"*
	Purpose	*Interpolation*
	Software	*AP Interpolate2D 1.0*
	Parameters	*N/A*
	File Format	*Surfer 6 ASCII grid*
	Filename Suffix	*"I"*
3.6 Archive		
	Location	*ArchaeoPhysica Ltd*
	Primary Telephone	*+44 (0) 7050 369 789*
	Contact Name(s)	*Martin / Anne Roseveare / Any Director*

	Basic Description	*Archive contains all survey and project data, communications, field notes, reports and other related material including copies of 3rd party data (e.g., CAD mapping, etc) in digital form. Many are in proprietary formats while report components are available in PDF format.*
	Access	*By appointment with ArchaeoPhysica only. Some content is restricted and not available to 3rd parties. There is no automatic right of access to this archive by members of the public. Some material retains commercial value and a charge may be made for its use. An administrative charge may be made for some enquiries.*
	Dissemination	*It is the client's responsibility to ensure that reports are distributed to all parties with a necessary interest in the project, e.g., local government offices. ArchaeoPhysica reserves the right to display data from projects on its website and in other marketing or research publications, usually with the consent of the client. Information that might locate the project is normally removed unless otherwise authorised by the client.*

Section 4: APPENDIX – TECHNICAL REFERENCE

4.1 General Considerations

4.1.1 What is geophysics?

4.1.1.1 Geophysics is the application of measurements of the physical properties of materials to further our understanding of the Earth. As such it is a broad and diverse discipline with specialisms ranging from deep core and mantle studies through petroleum exploration to "shallow earth" environmental geophysics of which archaeological survey is just one example.

4.1.1.2 Archaeological geophysics is therefore the application of exploration techniques to the problem of detecting and mapping features of archaeological interest within the ground. It is a specialism which deals almost exclusively with one of the most complex and variable range of targets of environmental geophysics.

4.1.2 Design & specification

4.1.2.1 With this in mind, it must be understood that archaeological geophysics is not about the application of a narrow range of techniques to standardised specifications. For every problem there are different ways of proceeding, e.g., the choice of survey resolutions, the variable to be measured, what instrument to measure it with, how the resulting data should be handled and visualised, etc. It is unfortunate that for many users and practitioners of archaeological geophysics the spectrum of techniques is narrow, e.g., fluxgate gradiometry, electrical resistance survey, magnetic susceptibility and radar.

4.1.2.2 Part of ArchaeoPhysica's mission is the application of proper geophysical design to each project's individual needs and to deploy a range of techniques to suit. Examples include the mapping of buried land surfaces using electrical tomography, the detection of both discrete and laminar features using total field magnetometry and the use of electromagnetics to map accumulations of industrial debris buried more than a metre down, etc. Needless to say, a thorough understanding of techniques and the ground to which they are applied is a prerequisite to successful survey

4.1.2.3 In the same way that a geophysicist is needed to optimise archaeological exploration for the client and their project a geophysicist is also required to produce an accurate and reliable interpretation of the results. Geophysical anomalies are not archaeological features, they are perturbations of some quantity measured at the surface and caused by discontinuities in the ground. As such, geophysical survey cannot provide a definitive map of buried archaeology as for every anomaly there are a range of different interpretations that might apply depending on various factors, not least, survey design. Geophysical survey is, however, the fastest and most effective way of exploring an area and has the additional benefit of avoiding the need to break the surface.

4.1.2.4 The following sections describe technical aspects of the exploration techniques used for this project.

4.2 Magnetic Field Survey

4.2.1 Geomagnetism

4.2.1.1 The geomagnetic field is at any location the four-dimensional (space and time) vector sum of several discrete components. The temporal component has categories separated by the time over which any variation in their intensity becomes noticeable. Archaeological surveys

are concerned with the two most rapidly changing categories, micropulsations and the diurnal field. The former may only last a few seconds and have amplitudes comparable with anomalies from archaeological sources, e.g., 2-5nT. The second is the daily fluctuation in the regional field that is broadly predictable and varies by some 30-40nT per day. This can be complicated by magnetic storms which can contribute field variations of well over 100nT, frequently associated with intense bursts of magnetic noise within the spread of amplitudes associated with archaeological sources. A third temporal variation is due to variations in the distribution of magnetic sources within the Earth's core. Unlike the other two, these occur over years, influence both the amplitude and direction of the regional field and for archaeological purposes can be safely ignored.

4.2.1.2 The stationary (non-temporal) component of the magnetic field is the sum of the myriad of magnetic sources within the Earth's crust. These range from deeply buried magnetic minerals through to changes in soil structure and properties due to environmental, agricultural and of course archaeological sources. To provide a sense of scale, the deeply buried sources can contribute anomalies of a few thousand nT across many kilometres of landscape, though visible as changes of only a few nT across the sizes of areas associated with many archaeological projects. In contrast, the environmental and archaeological sources may contribute just 10nT or so, detectable at distances of no more than perhaps 3m for the larger anomalies.

4.2.1.3 Where anomalies exist of a larger spatial extent than the survey area they form part of the *regional* field and are caused by the deepest magnetic components of the ground. The remaining field is called the *residual* and represents roughly the sum of the magnetic sources present within the survey area, whatever their depth of burial. In basic terms, the more sensitive the instrument used to generate this data and the less cluttered the soil, the deeper the source that can be imaged magnetically, perhaps ditch fills or settlement sites concealed beneath marginal peat for example. A branch of geophysical processing called *potential field analysis* allows the geophysicist to further subdivide these sources, allowing the very shallowest ones, indicative of archaeological sources, to dominate the deeper.

4.2.2 The burial environment

4.2.2.1 Topsoil is usually fairly magnetic relative to other soils and hence is important for magnetic survey. If a topsoil is exceptionally deep it can mask more weakly magnetic features beneath it. Alternatively, regions where the topsoil is locally deeper than elsewhere are usually associated with enhanced magnetic field strength. Archaeological features that incorporate relict topsoil tend to enhance the magnetic field around them.

4.2.2.2 In some cases, features may exist magnetically that cannot be detected during excavation. This is normal, as some soils with enhanced magnetic properties do not exhibit any visible difference from their surroundings. In addition, some features survive as shadows in the topsoil after they have been physically removed by ploughing. The converse scenario is of course also true: there are many archaeological features that have no detectable magnetic component. Finally, sometimes it will be the case that the archaeological feature itself is not magnetic but some secondary characteristic still allows its detection by magnetic survey. An example is where a ditch has been filled, perhaps soon after excavation, with the same material as its surroundings and therefore lacks magnetic contrast with the surrounding material. As this fill settles, deeper topsoil (whether contemporary or modern) can accumulate in the resulting hollow, creating a local slightly positive magnetic anomaly. An example of this is a grave site where the grave itself is usually nonmagnetic but can occasionally be located by the disturbance of the contemporary surface. Of course if the top of the feature has been truncated by ploughing this effect will disappear.

4.2.2.3 Hearths, burnt or fired soil and clay, and similar contexts involving the application of heat to soil, tend to become strongly magnetic due to chemical changes in the soil, in particular the conversion of iron oxides to maghaemite and magnetite. Assuming there is adequate iron in the soil initially, the process results in a particularly strong enhancement that is effectively

permanent (the degradation that does occur can be regarded as negligible over usual archaeological time scales). This means that hearths can usually be detected with confidence. In addition the presence of domestic fires at settlement sites tends to lead to an accumulation of magnetic soil throughout the settled area and for a distance beyond. It is possible therefore that features that are undetectable away from a settlement will become more detectable the closer survey proceeds to the inhabited area, an effect that has been observed in large surveys.

4.2.2.4 A secondary effect of the same process is that the presence of non-magnetic features may become detectable if magnetic material has accumulated in or around them. A common example is wall footings against which magnetic soil has accumulated, even in trace quantities.

4.2.3 Configuration & measurement

4.2.3.1 The magnetic field has a direction and intensity and hence it is possible to measure either the intensity of a directional component or the total intensity. The total intensity is measured using a total field magnetometer, e.g., a caesium magnetometer but it is common in UK archaeological surveys to measure just the vertical component, using a fluxgate gradiometer.

4.2.3.2 In addition, magnetometers can be configured in different ways, usually as single sensor magnetometers or as gradiometers. For this discussion it is assumed that the gradiometer is vertical. A single magnetic sensor measures all components of the ambient field, including the temporal which is not desired and hence needs to be removed from the data during processing. This is usually achieved either through reduction using software or by using a base station magnetometer, one that does not move and simply records the temporal variations so that they can be subtracted from the field data later.

4.2.3.3 A gradiometer avoids this by having two sensors measuring simultaneously, one sensor being mounted higher than the other. By subtracting the data from the upper sensor from the lower, the temporal component, common to both sensors, is removed. This has a disadvantage in that unless the upper sensor is quite high above the ground, e.g., 3m, the data from it can contain a large component due to shallow and hence archaeological sources. When the data is subtracted this reduces the anomaly strength from shallow sources as well as deep. For gradiometers using widely spaced sensors, e.g., the Bartington Grad601-2 (1m) or the ArchaeoPhysica wheeled instrument (1.2m), this is much less of a problem than for shorter ones, e.g., the Geoscan Research FM36 (0.5m).

4.2.3.4 One advantage of vertical gradiometers is that they provide slightly better defined edges of anomalies due to magnetic sources close to them, e.g., magnetic fills in the tops of pits and ditches. A magnetometer, however, will quite often provide slightly larger anomaly strength and the calculated vertical gradient is nearly always a good model of the measured gradient.

4.2.3.5 Conversely, magnetometers are better at imaging laminar structures and can hence differentiate between soils at the same depth but with different magnetic susceptibility. This is of particular benefit when imaging small areas or sites with complex magnetic properties, e.g., settlement remains.

4.2.4 Instrumentation

4.2.4.1 ArchaeoPhysica uses a dual channel caesium vapour magnetometer with a resolution of about 0.03nT at normal operating speeds, increasing to 0.005nT for specialised projects.

4.2.4.2 The instrument is a Magmapper G858 manufactured by Geometrics Inc. in the USA and can be configured as a gradiometer (vertical or horizontal) or as two magnetometers. The latter is the usual configuration and is used in conjunction with a wheeled cart to ensure

exceptional stability of measurement with a minimum of electrical and operator-induced noise.

4.3 Technical bibliography

4.3.1.1 The following texts represent a selection from which a understanding of geophysical survey and its application to heritage issues can be gained. Some indication of the complexity of geophysical analysis is also evident from these.

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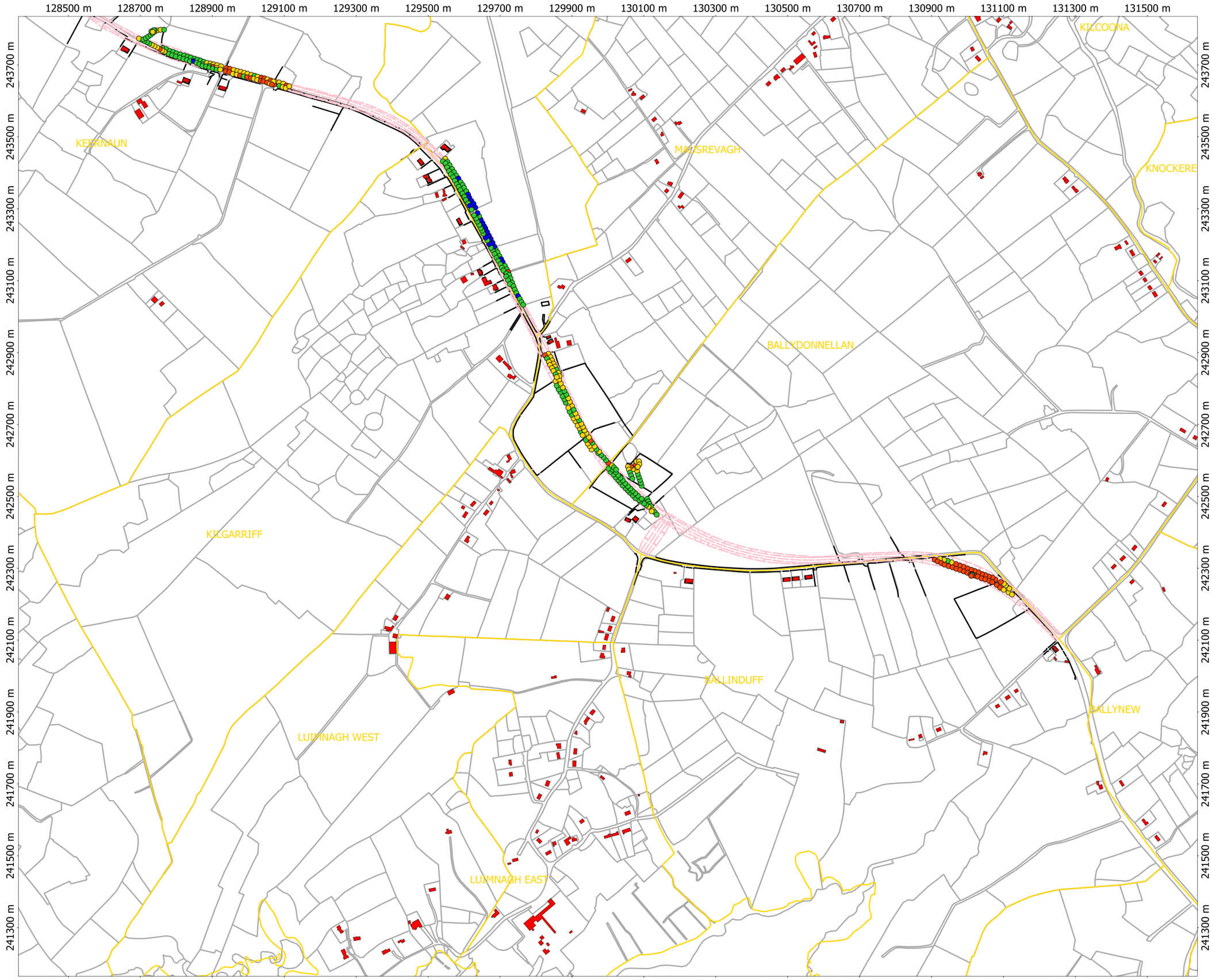

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Median Vol. Mag. Sus.
x 10 ^ -5 SI
<0
0...10
10...20
>20
Proposed Road
Lines
Base Map (IOS)
Land Parcels
Buildings
Townland Boundaries
text Townlands
Base Map (Surveyed)
Areas
Lines

N
W E
S

DWG 01
Overview of Location

ArchaeoPhysica Ltd

Orthographic
Centre X: 130000.00 m
Centre Y: 242500.00 m

Scale: 1:10000 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
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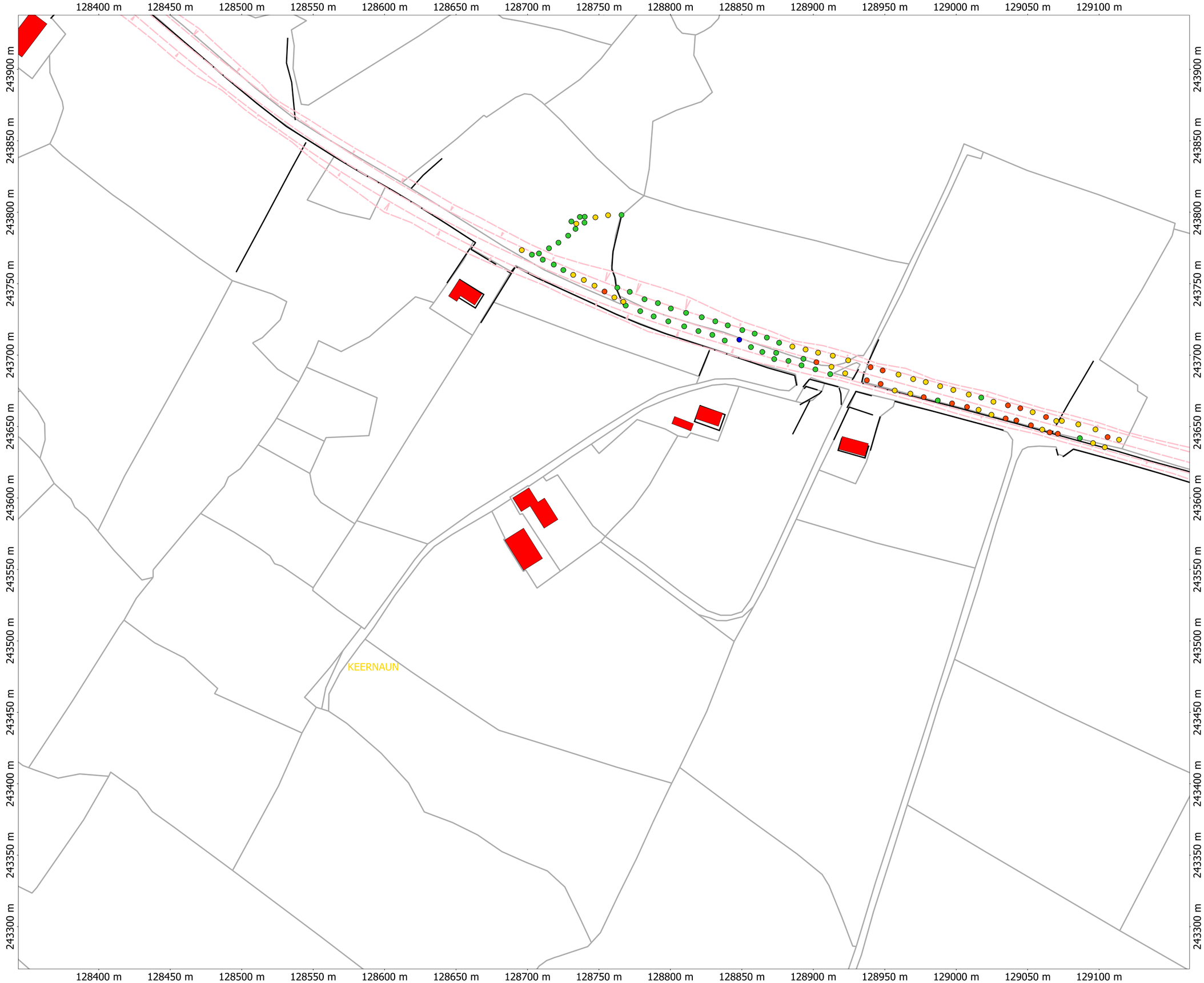
From
ACER-1 on 20/12/2005



Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Median Vol. Mag. Sus.
x 10 ^ -5 SI
<0
0...10
10...20
>20
Proposed Road
Lines
Base Map (IOS)
Land Parcels
Buildings
Townland Boundaries
text Townlands
Base Map (Surveyed)
Areas
Lines

N
W E
S

DWG 02
Detail of MS Result

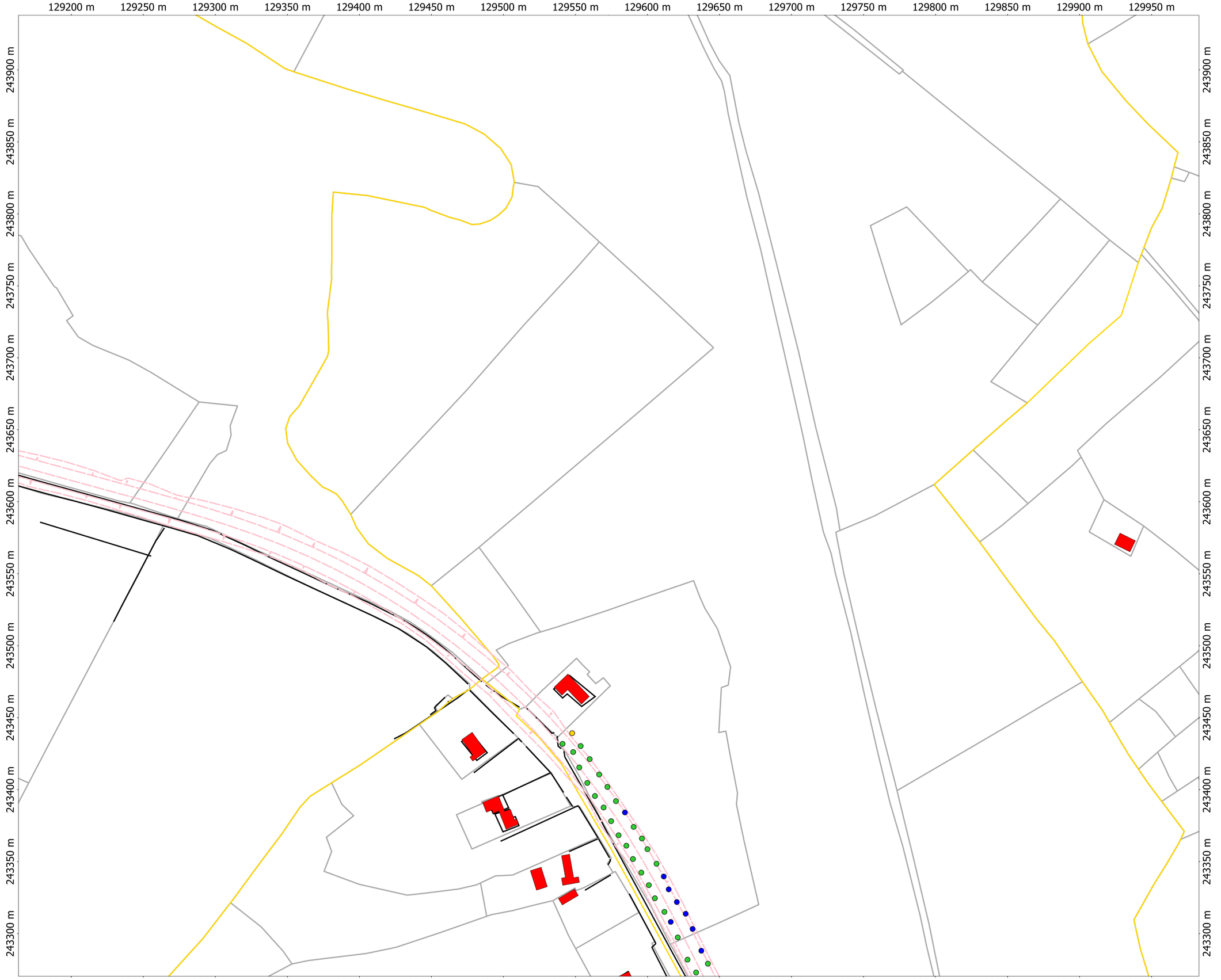
ArchaeoPhysica Ltd

Orthographic
Centre X: 128753.45 m
Centre Y: 243604.16 m

Scale: 1:2500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
\\ACER-2\Canon Bubble-Jet S4500
From
ACER-1 on 20/12/2005

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council



Median Vol. Mag. Sus.
x 10 ^ -5 SI
<0
0...10
10...20
>20
Proposed Road
Lines
Base Map (IOS)
Land Parcels
Buildings
Townland Boundaries
text Townlands
Base Map (Surveyed)
Areas
Lines

N
W E
S

DWG 03
Detail of MS Result

ArchaeoPhysica Ltd

Orthographic
Centre X: 129573.05 m
Centre Y: 243604.16 m

Scale: 1:2500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
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From
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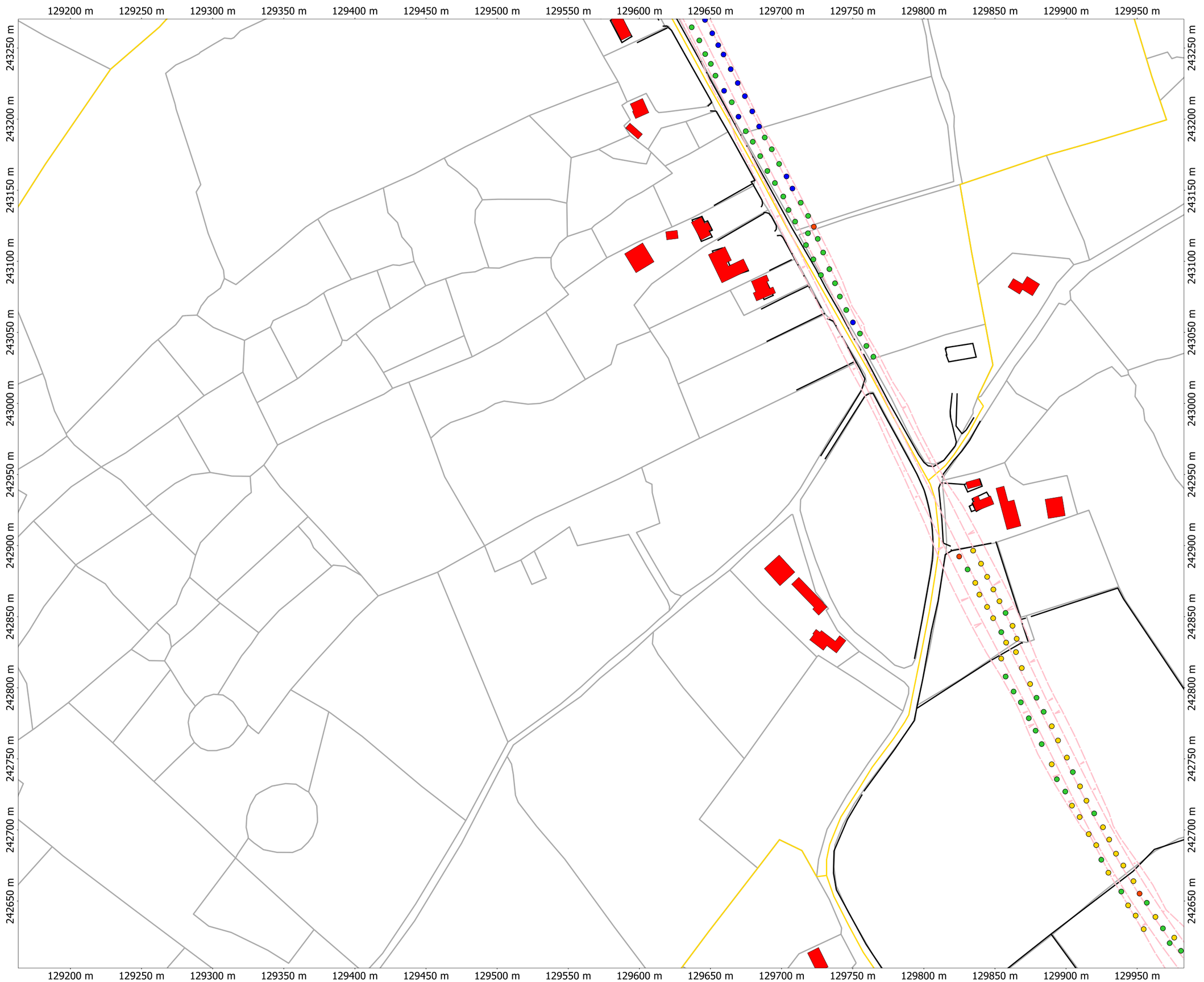

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Median Vol. Mag. Sus.
x 10 ^ -5 SI
<0
0...10
10...20
>20
Proposed Road
Lines
Base Map (IOS)
Land Parcels
Buildings
Townland Boundaries
text Townlands
Base Map (Surveyed)
Areas
Lines

N
W E
S

DWG 04
Detail of MS Result

ArchaeoPhysica Ltd

Orthographic
Centre X: 129573.05 m
Centre Y: 242936.62 m

Scale: 1:2500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
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From
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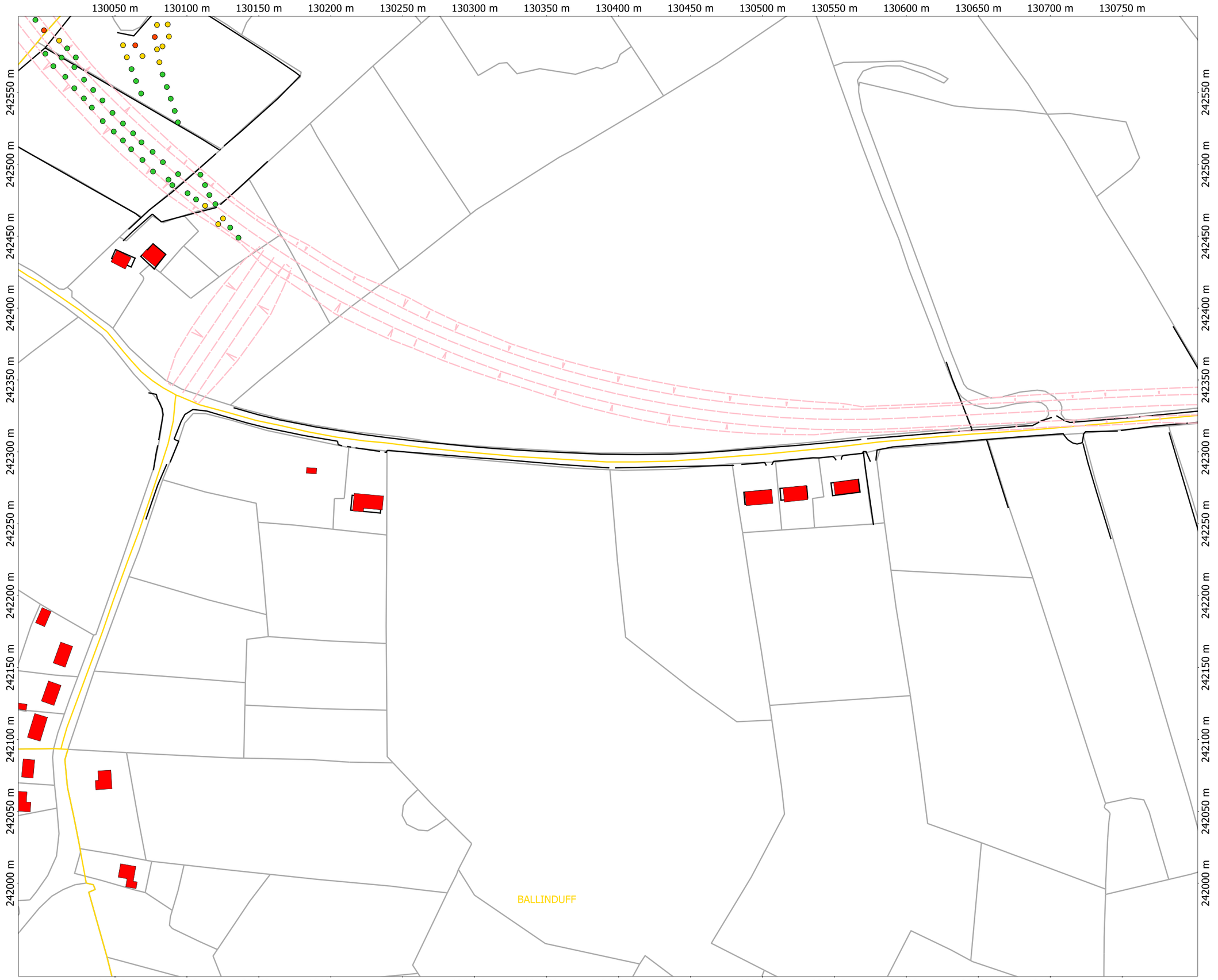

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Median Vol. Mag. Sus.
x 10 ^ -5 SI
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0...10
10...20
>20
Proposed Road
Lines
Base Map (IOS)
Land Parcels
Buildings
Townland Boundaries
text Townlands
Base Map (Surveyed)
Areas
Lines

N
W E
S

DWG 05
Detail of MS Result

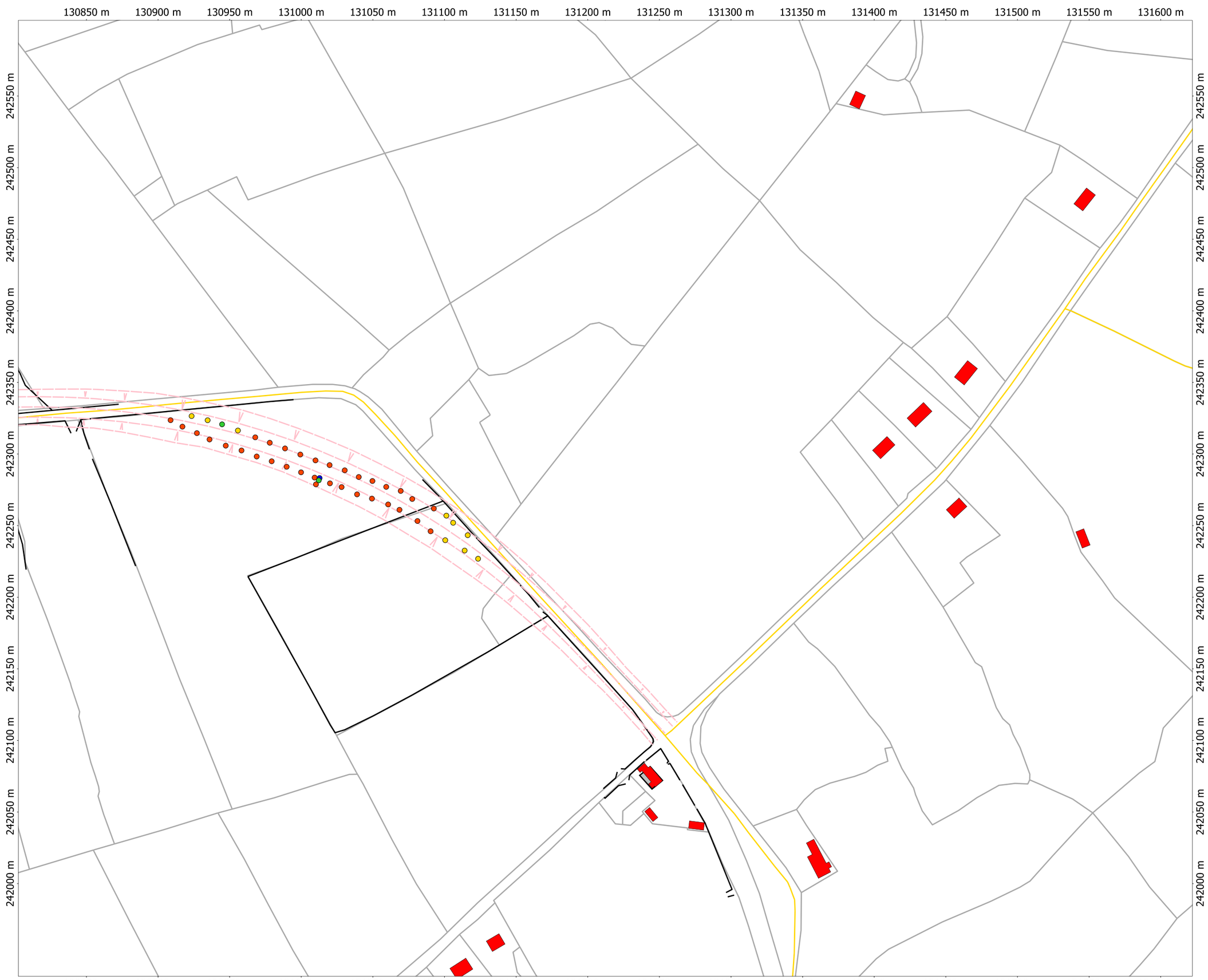
ArchaeoPhysica Ltd

Orthographic
Centre X: 130392.66 m
Centre Y: 242269.09 m

Scale: 1:2500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
\\ACER-2\Canon Bubble-Jet S4500
From
ACER-1 on 20/12/2005

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council



Median Vol. Mag. Sus.
x 10 ^ -5 SI
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0...10
10...20
>20
Proposed Road
Lines
Base Map (IOS)
Land Parcels
Buildings
Townland Boundaries
text Townlands
Base Map (Surveyed)
Areas
Lines

N
W E
S

DWG 06
Detail of MS Result

ArchaeoPhysica Ltd

Orthographic
Centre X: 131212.26 m
Centre Y: 242269.09 m

Scale: 1:2500 @ A3
Spatial Units: Meter

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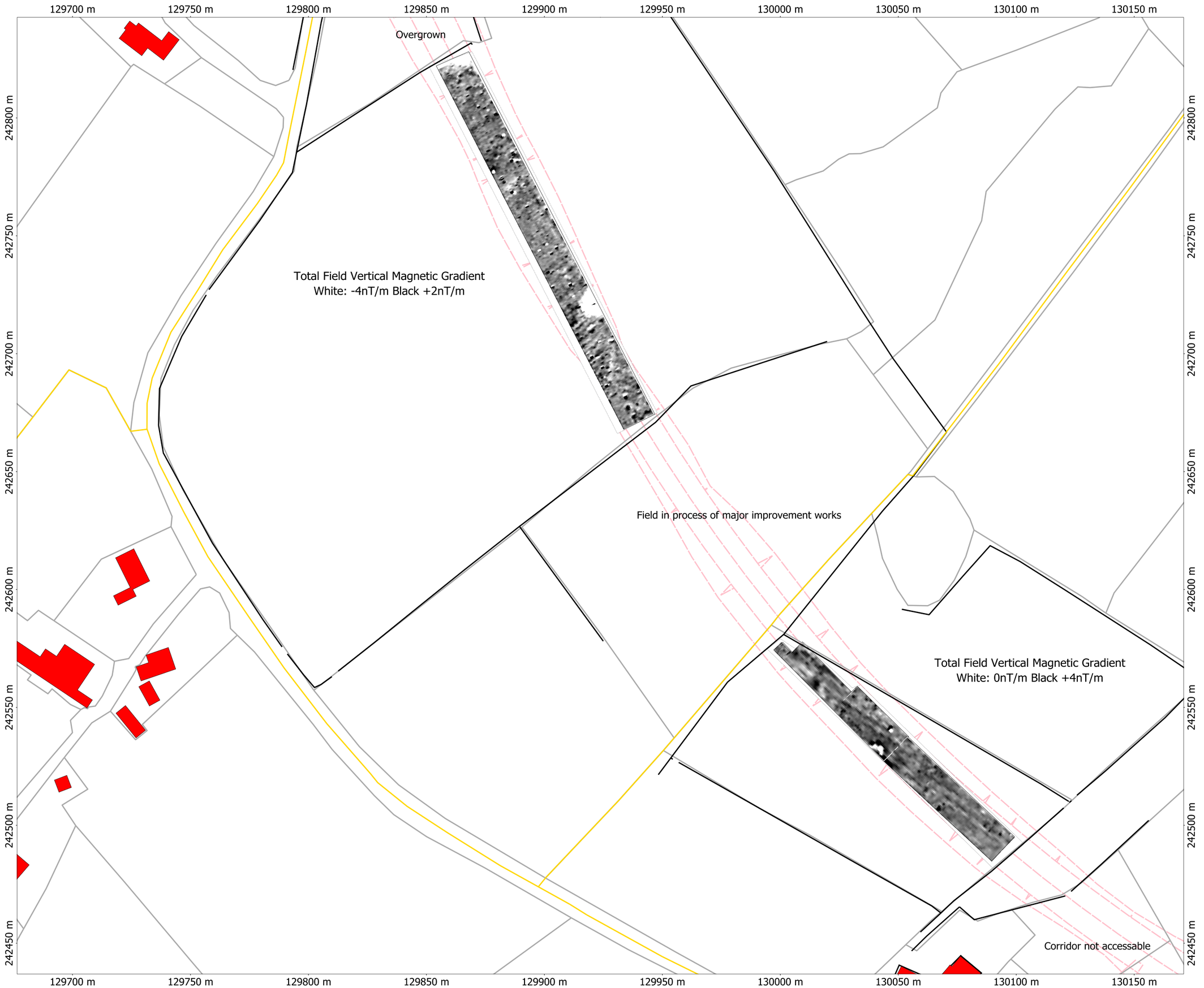

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Base Map
Buildings
text Townland
Townland boundaries
Land parcels
New Survey
Areas
Lines
Proposed Road
Lines

N
W E
S

DWG 07
Magnetic Data - Northwest

ArchaeoPhysica Ltd

Orthographic
Centre X: 129923.74 m
Centre Y: 242639.80 m

Scale: 1:1500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
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From
ACER-1 on 20/12/2005

130800 m 130850 m 130900 m 130950 m 131000 m 131050 m 131100 m 131150 m 131200 m 131250 m

242450 m 242400 m 242350 m 242300 m 242250 m 242200 m 242150 m 242100 m

Dense scrubby woodland & boulders from here westwards

Total Field Vertical Magnetic Gradient
White: -4nT/m Black +2nT/m

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Base Map
Buildings
text Townland
Townland boundaries
Land parcels
New Survey
Areas
Lines
Proposed Road
Lines

N
W E
S

DWG 08
Magnetic Data - Southeast

ArchaeoPhysica Ltd

Orthographic
Centre X: 131026.19 m
Centre Y: 242283.33 m

Scale: 1:1500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
\\ACER-2\Canon Bubble-Jet S4500
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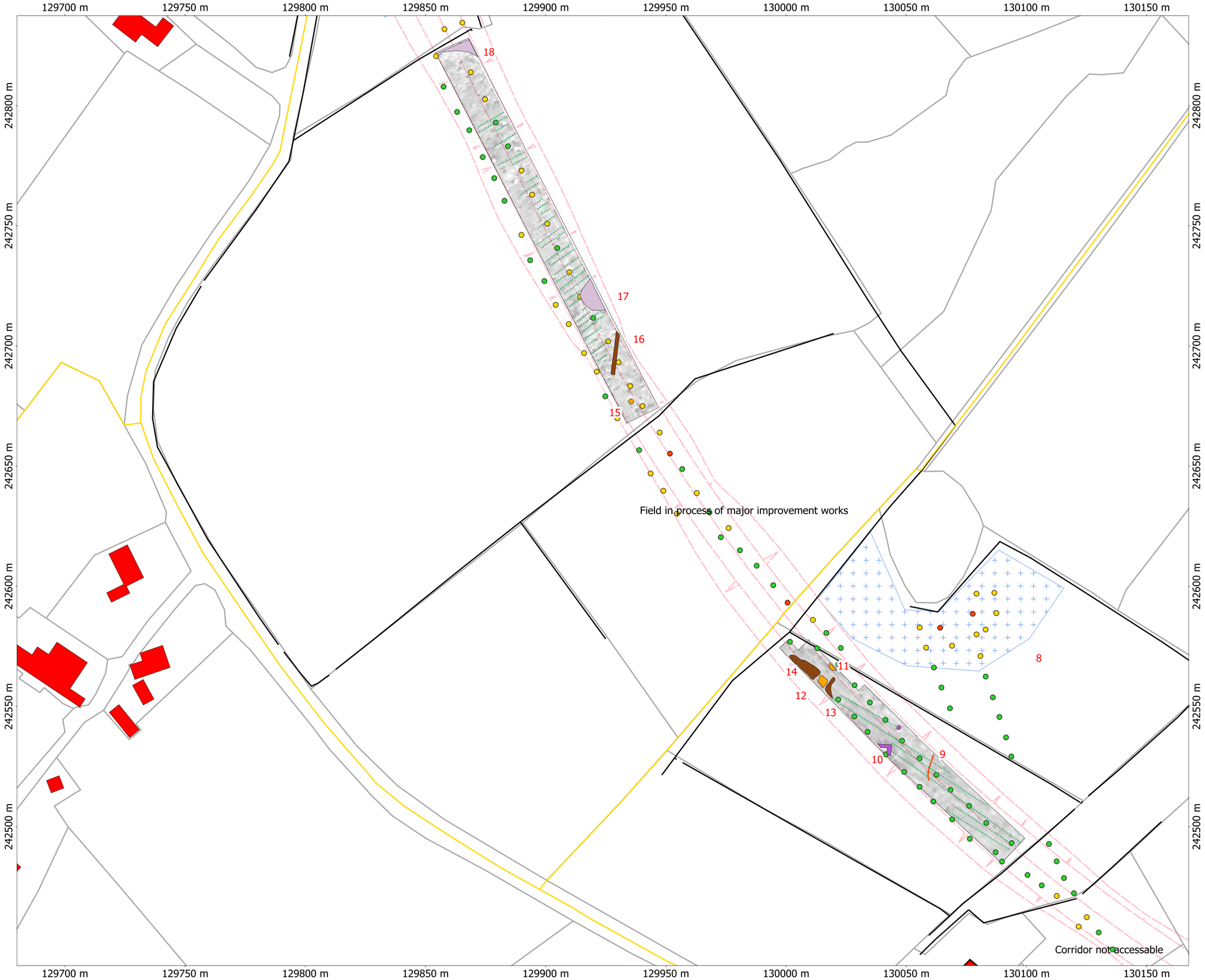
Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council



Base Map
- Buildings
- text — Townland
- Townland boundaries
- Land parcels

New Survey
- Areas
- Lines

Proposed Road
- Lines

Interpretation
- Ditch fills / Deep soil
- Gully fills / Deep soil
- Stony ground / Shallow soil
- Surface Sources
- Cultivation furrows
- Significant MS result
- Fired, burnt or metallic
- Pit fills / Deep soil
- text — Refer to report text

N
W E
S

DWG 09
Interpretation Summary - Northwest

ArchaeoPhysica Ltd

Orthographic
Centre X: 129923.74 m
Centre Y: 242639.80 m

Scale: 1:1500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
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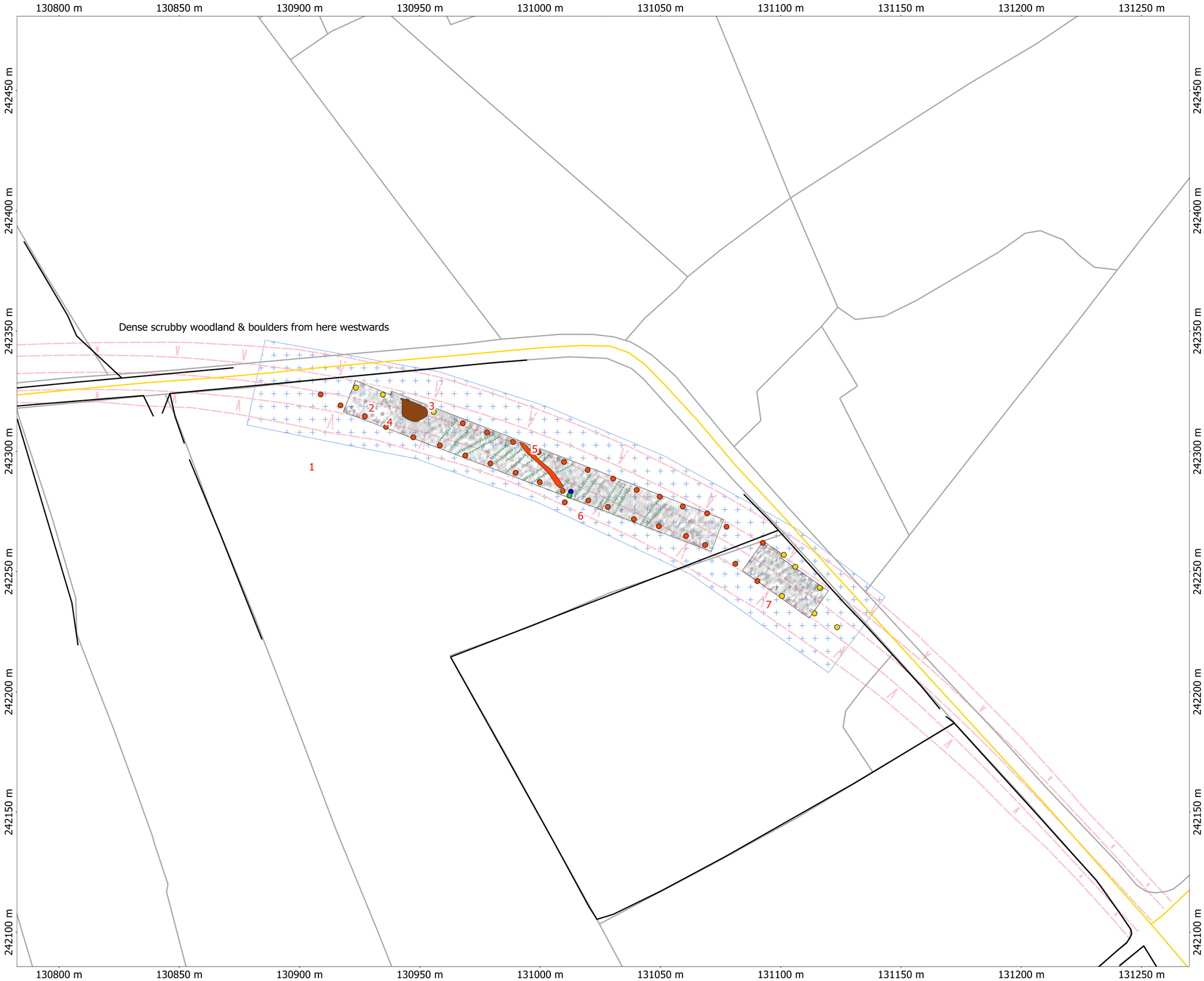
From
ACER-1 on 9/1/2006



Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Base Map
Buildings
text Townland
Townland boundaries
Land parcels
New Survey
Areas
Lines
Proposed Road
Lines
Interpretation
Ditch fills / Deep soil
Gully fills / Deep soil
Stony ground / Shallow soil
Surface Sources
Cultivation furrows
Significant MS result
Fired, burnt or metallic
Pit fills / Deep soil
text Refer to report text

N
W E
S

DWG 10
Interpretation Summary - Southeast

ArchaeoPhysica Ltd

Orthographic
Centre X: 131026.19 m
Centre Y: 242283.33 m

Scale: 1:1500 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
Printed by:
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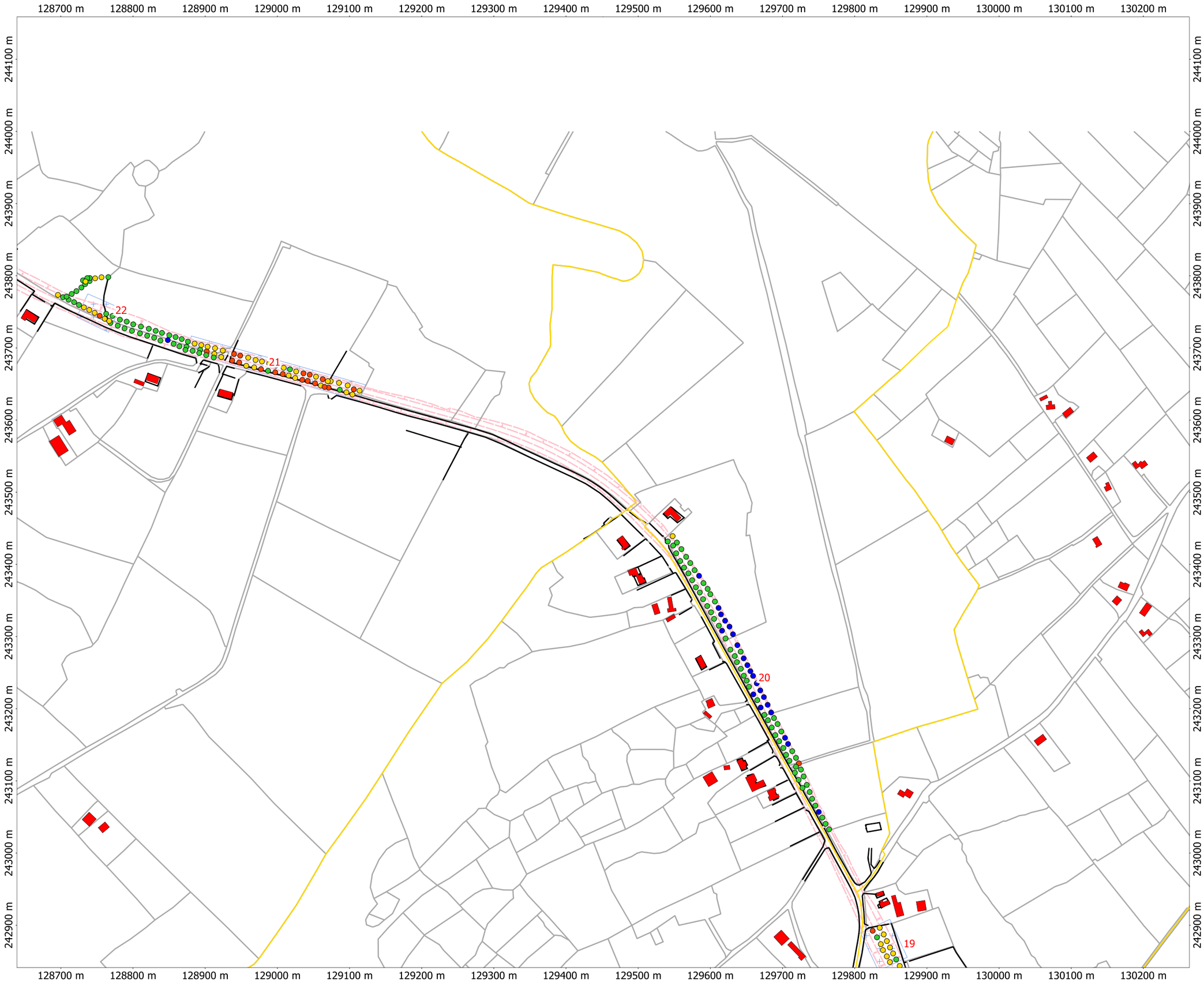

Project Name:
N28 Luimnagh Realignment
Project Code:
LMR20051
Client:
Galway County Council

Base Map
Buildings
text — Townland
Townland boundaries
Land parcels
New Survey
Areas
Lines
Proposed Road
Lines
Interpretation
Ditch fills / Deep soil
Gully fills / Deep soil
Stony ground / Shallow soil
Surface Sources
Cultivation furrows
Significant MS result
Fired, burnt or metallic
Pit fills / Deep soil
text — Refer to report text

N
W E
S

DWG 11
Interpretation - Northern MS

ArchaeoPhysica Ltd

Orthographic
Centre X: 129451.43 m
Centre Y: 243500.00 m

Scale: 1:5000 @ A3
Spatial Units: Meter

File: LMR20051 GIS1
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From
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