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Transport Scotland
Forth Replacement Crossing

Network Connections – South
South Queensferry Cutting

December 2010

Jacobs Arup - Jacobs U.K. Limited and Ove Arup & Partners International Limited Consortium
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1 Introduction

The proposed South Queensferry Cutting is located within the FRC Network Connections South area between Chainage 3000m and 4300m. The cutting is approximately 1300m long and curves around the western and south-western edges of South Queensferry, reaching a maximum depth of 10m below existing ground level.

Given the proximity of the houses at Echline Corner and Springfield to the proposed cutting, (site location plan, FRC/H/SOUTH/OBJ/0001 provided in Appendix A) a hydrogeological study was undertaken to assess whether groundwater would be lowered as a result of constructing the cutting. The drawdown of groundwater could result in a potential for settlement to occur as a result of an increase in the effective density of the soil being dewatered.

Should settlement occur due to dewatering it will largely occur across the whole area at the same rate, and as such there would generally be no effect on the adjacent houses. However there will be a gradual lowering of the groundwater (phreatic surface) towards the cutting beneath the properties, resulting in potential differential settlement. It is differential settlement that could have a detrimental effect on the adjacent houses.

This report has been undertaken as a requirement of the FRC Environmental Statement (Jacobs Arup JV, 2008), stated in Chapter 8:

> 8.5.42 The permeability tests proposed along the mainline cutting ch3200-4150 in paragraph 8.5.38, coupled with the installation of additional piezometers to the west of the cutting and adjacent to the Queensferry urban area, will form the basis upon which a detailed assessment will be carried out in Autumn/Winter 2009 by Jacobs Arup as part of the pre-construction advance works, to estimate the groundwater drawdown below the properties at risk. This will enable a quantitative stability analyses to be carried out and will determine whether some properties are at risk of settlement (mitigation item G26).
>
> 8.5.43 In the eventuality of some properties being confirmed as at risk, appropriate measures including condition surveys, and monitoring of buildings and groundwater level changes may be required (mitigation item G26).

Mitigation item G26 of the Environmental Commitments Schedule also stated:

> 'Quantitative stability analyses based on results of 2009 GI (Ground Investigation) will be carried out to determine if any properties are at risk of settlement. In the eventuality of some properties being confirmed as at risk, appropriate measures including condition surveys and monitoring of buildings and groundwater levels may be required.'

This assessment has been undertaken based on available information obtained to date (November 2010), as part of the FRC project and assumes that all adjacent structures are founded on uniform foundations (assumed to be spread, strip or pad foundations) and have been appropriately designed and constructed.

2 Existing Conditions

A review of available intrusive ground investigation information, obtained as part of the proposed route alignment study, has been undertaken within the immediate vicinity of the Springfield/Echline area.

A plan showing the exploratory hole locations is provided in Appendix B, FRC/H/SOUTH/OBJ/0002, while a geological cross section through the cutting is provided in Appendix C, FRC/H/SOUTH/OBJ/0003. A summary of the ground conditions within the residential housing area is provided below in Table 1:

Strata	Depth from Surface (m)		Thickness (m)	
	Min	Max	Min	Max
Topsoil	0.15	0.45	0.15	0.45
Weathered Glacial Till	1.2	3.0	0.9	2.75
Granular Glacial Till	1.4	4.1	0.3	2.9
Fresh Glacial Till	1.9	21.3	0.4	14.25

NOTE: Glacial till deposits are underlain by rock. Thickness of Fresh Glacial Till is only based on boreholes where rockhead was proven.

Table 1 – Ground Conditions

Table 1 is based on the following exploratory hole records: BHS92 to BHS95, DPS24, HBR608, HBR610, HBR611, HBR612, HBR614, HBR615, HBR617-619, HBR622 and HBR624.

Groundwater Monitoring Data -

No long term monitoring has been undertaken within the housing areas; however the following boreholes within the vicinity have been constructed with installations and have been monitored on a monthly basis since they were installed. The results are shown below in Table 2:

Borehole Location	Date Installed	Minimum Groundwater Depth (mbgl)	Maximum Groundwater Depth (mbgl)	Response Zone (mbgl)	Response Stratum
BHS94	22/05/09	1.79	6.52	Standpipe - 2.3 - 13m	Rock
BHS95	14/05/09	12.23	Dry	Standpipe - 11 - 14m	Rock
DPS24	12/04/10	1.56	2.83	Piezo tip at 3.5m, 1m zone	Granular Glacial Till

mbgl – meters below ground level

NOTE: The table has been updated by examining monthly monitoring data received to November 2010.

Table 2 – Installation Details

Three historical trial pits recorded groundwater seepages between 1.05 - 1.5mbgl, additionally water strikes were recorded at 3.9mbgl and 8.5mbgl during the drilling of DPS24.

However, it should be noted that groundwater monitored in drift deposits and/or seepages and strikes encountered during trial pitting and borehole drilling fall under four main categories:

- There is evidence of a laterally continuous shallow groundwater body to the south and east of South Queensferry Cutting. This drift groundwater body is understood to have a degree of connectivity with the underlying bedrock aquifer;

- There is evidence of a laterally discontinuous shallow groundwater body immediately to the north of South Queensferry Cutting but this drift groundwater body is understood to have a certain degree of connectivity with the underlying bedrock aquifer;

- To the north and east of the Echline corner, there is evidence of dry drift deposits; and

- Further to the north, in the vicinity of Springfield, there is evidence of occasional water seepages in the upper part of drift deposits. Based on the local geology, these seepages are believed to be isolated from the bedrock aquifer. Based on the interruption of water in drift deposits as described above (i.e. to the north and east of the Echline corner), these seepages are also assessed as laterally discontinued with the main drift water body encountered to the south and east of South Queensferry Cutting.

3 Modflow Analysis

A Modflow based hydrogeological modelling exercise was undertaken to simulate the effect of the proposed Queensferry Cutting on groundwater levels within the drift and bedrock deposits. The model was based on geological and hydrogeological information derived from all available information obtained as part of the FRC project (i.e. boreholes logs, groundwater level monitoring and permeability tests). This model is a steady-state simulation exercise representing current average and long term average groundwater conditions in the Queensferry Cutting area.

The model was first calibrated to represent the current hydrologeological setting of the site, then the cutting was modelled and the comparison between the two situations represents the potential dewatering effect. The model considers groundwater monitoring results received to date (November 2010).

The results of this assessment are provided in Appendix D, with the following figures:

- Figure 1 shows the extent of saturated drift deposits in the current (Figure 1a) and post cutting conditions (Figure 1b). The non-highlighted areas represent dry deposits or drift deposits containing perched and/or laterally isolated bodies of water non-connected to groundwater in drift and bedrock that will be intercepted by the Queensferry cutting;

- Figure 2 shows the post cutting drawdown contours in drift deposits as a result of the cutting dewatering effect. Yellow represents the areas of drift that are expected to dry out as a result of the dewatering effect from the cutting and black represents the areas already dry in the current conditions.

4 Geotechnical Analysis

It can be seen in Figure 1a in Appendix D that within the majority of the Echline/Springfield residential area, drift deposits are considered dry or not connected to the groundwater within the cutting. It is therefore considered that no settlement will occur within the majority of the Echline/Springfield residential area due to dewatering as a result of constructing the cutting.

However, within the residential area to the east of Echline Corner, there is the potential for dewatering to occur within the drift deposits (Figure 1b, Appendix D). Figure 2 within Appendix D shows the drawdown within this area to be up to 2m.

As noted in the introduction, by lowering the groundwater in the superficials, the effective stress of the soil is increased and as such there is an increase in overburden pressure to the underlying soils, therefore potentially causing settlement.

Settlements were calculated in accordance with the guidance provided in Foundation Design and Construction, 7th Edition, MJ Tomlinson, based on a worst case ground profile and conservative design parameters as detailed below:

GL – 1.75mbgl – Weathered Glacial Till (m_v – 0.30m^2/MN)
1.75 – 3.0mbgl – Firm Glacial Till (m_v – 0.15m^2/MN)
3.0 – 10.75mbgl – Stiff Glacial Till (m_v – 0.05m^2/MN)

It should be noted that this assessment is based on the assumption that the foundations of the adjacent properties have been designed and constructed appropriately.

Although total settlement in the order of 10mm has been calculated, as noted in the introduction this type of settlement is not considered an issue for adjacent structures, as the majority of this settlement would occur uniformly across the local area and the building footprint. The primary concern regarding the potential effect on a building from settlement due to dewatering would be from any differential settlement which occurs across the building footprint. The sketch below provides a schematic of the dewatering due to the cutting, which has been grossly emphasised for the purpose of this explanation.

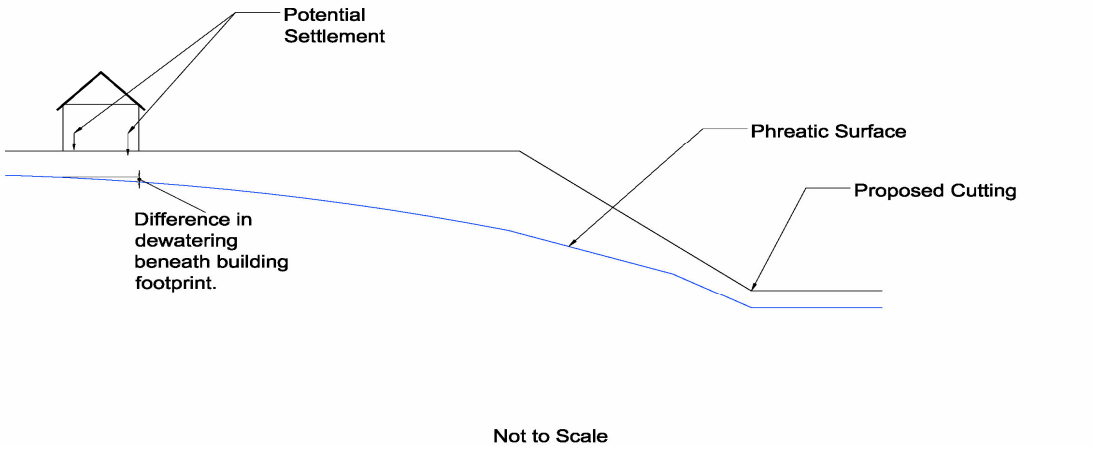

Figure A – Drawdown Schematic

The Modflow analysis suggests the phreatic surface will change by <2^{o} across the footprint of a typical building. This difference in phreatic surface level would result in negligible differential settlement.

5 Conclusions and Recommendations

It has been analysed through Modflow that superficial deposits across the majority of the Springfield/Echline area will not be influenced by the dewatering of Queensferry Cutting. However, some groundwater lowering may occur to the east of Echline Corner area.

Within this area it has been shown that the maximum total settlement would be less than 10mm. However, as discussed in the report it is differential settlement that would potentially cause concern for any adjacent properties.

Ground conditions are generally uniform across the site area and as such differential settlement from varying ground conditions is considered negligible. The potential for differential settlement caused as a result of the difference in phreatic surface depth is considered to be negligible.

As a result of dewatering for the construction of South Queensferry Cutting it is considered that the impact from total and differential settlement on adjacent housing is negligible, on the assumption that the properties foundations have been designed and constructed appropriately.

It would be prudent however for specific monitoring to be undertaken during the construction period to regularly monitor both ground and groundwater levels, giving an opportunity to stop excavation works should changes in levels behave differently from those predicted.

Appendix A Location Plan

Appendix B Relevant Ground Investigation Information

Appendix C Cross Section

Appendix D Groundwater Model

Figure 1a – Groundwater Current Condition - Dry drift cells (non-highlighted areas)

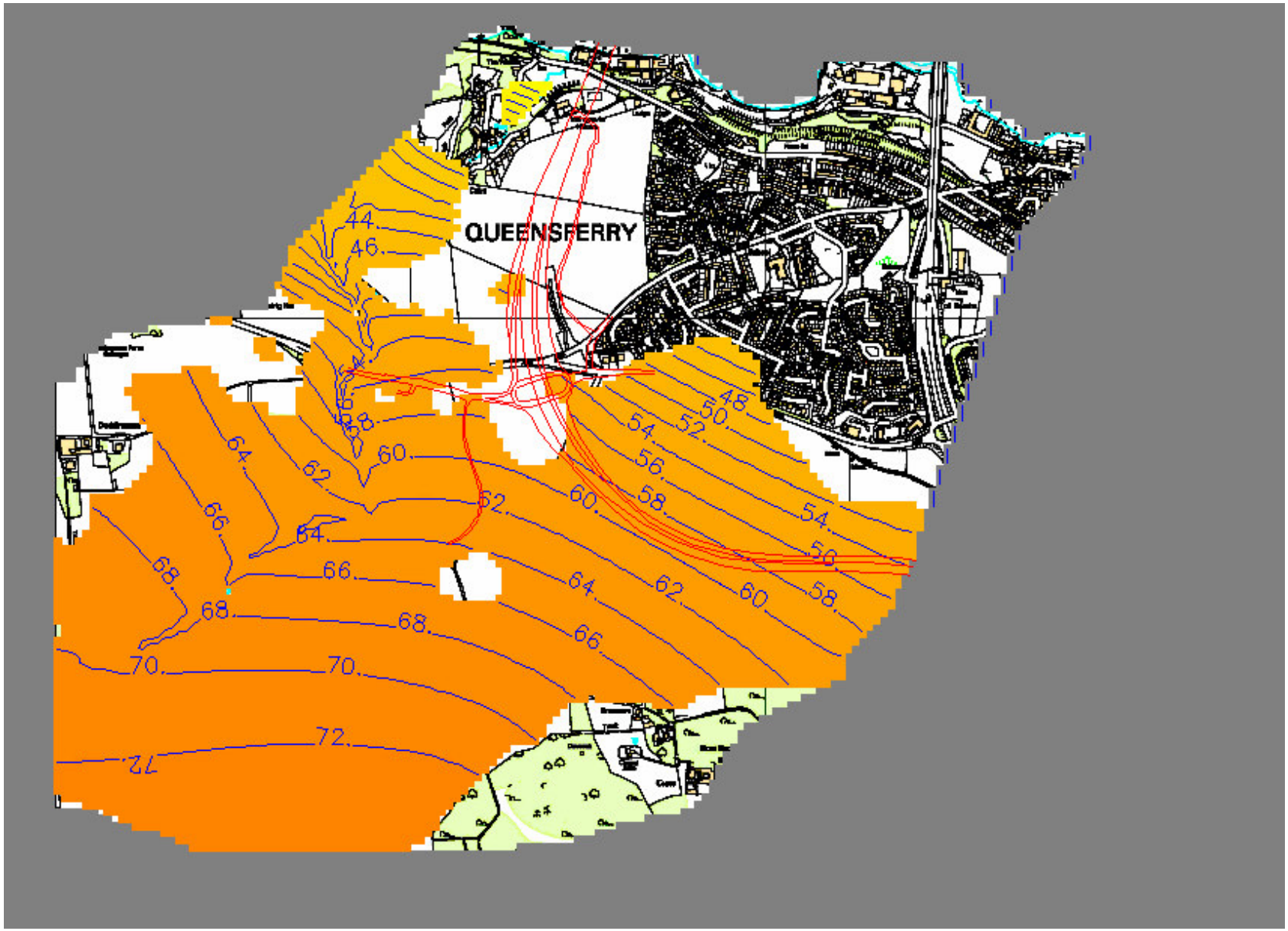

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Figure 1b – Groundwater Cutting Condition - Dry drift cells (non-highlighted areas)

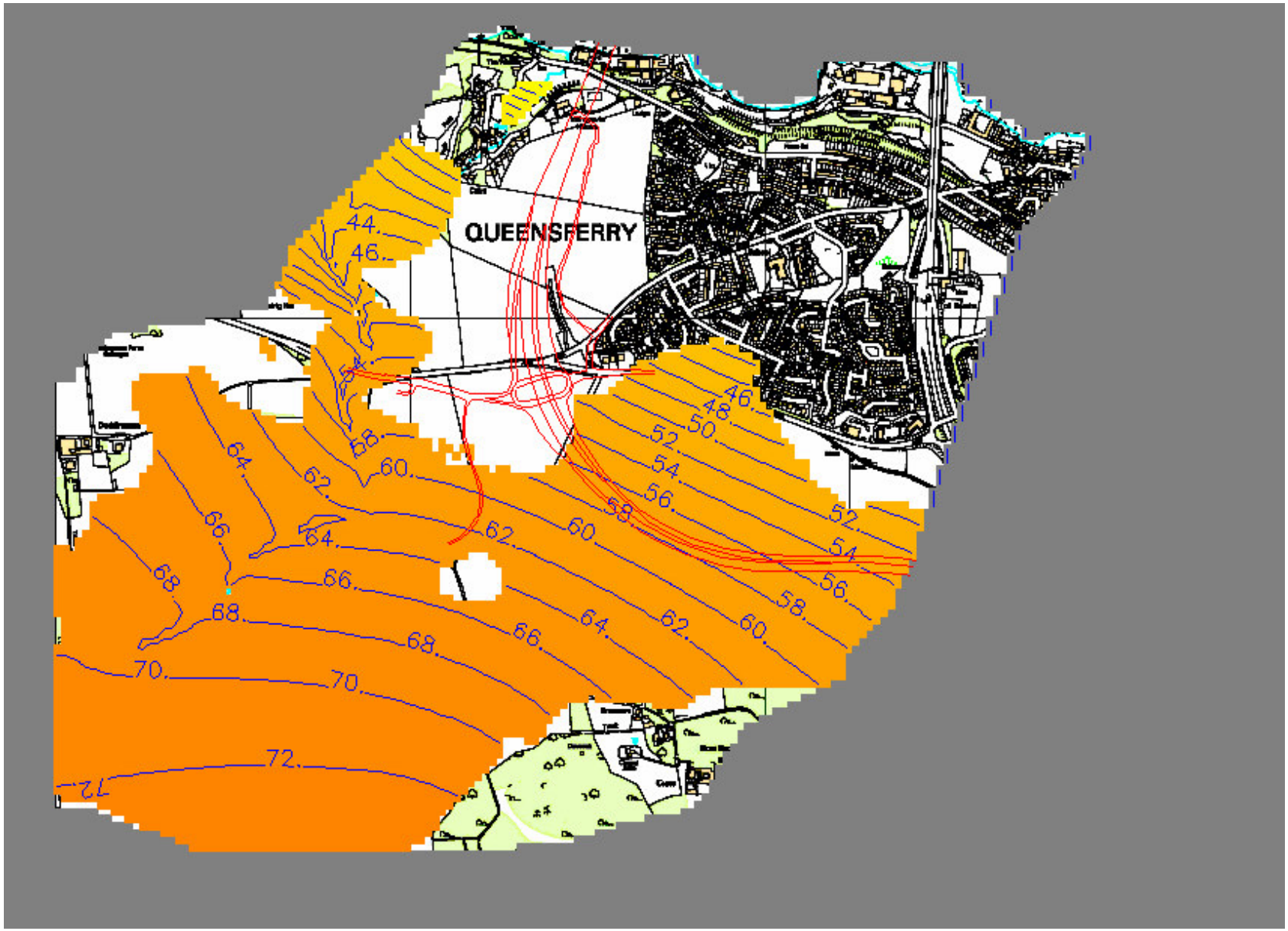

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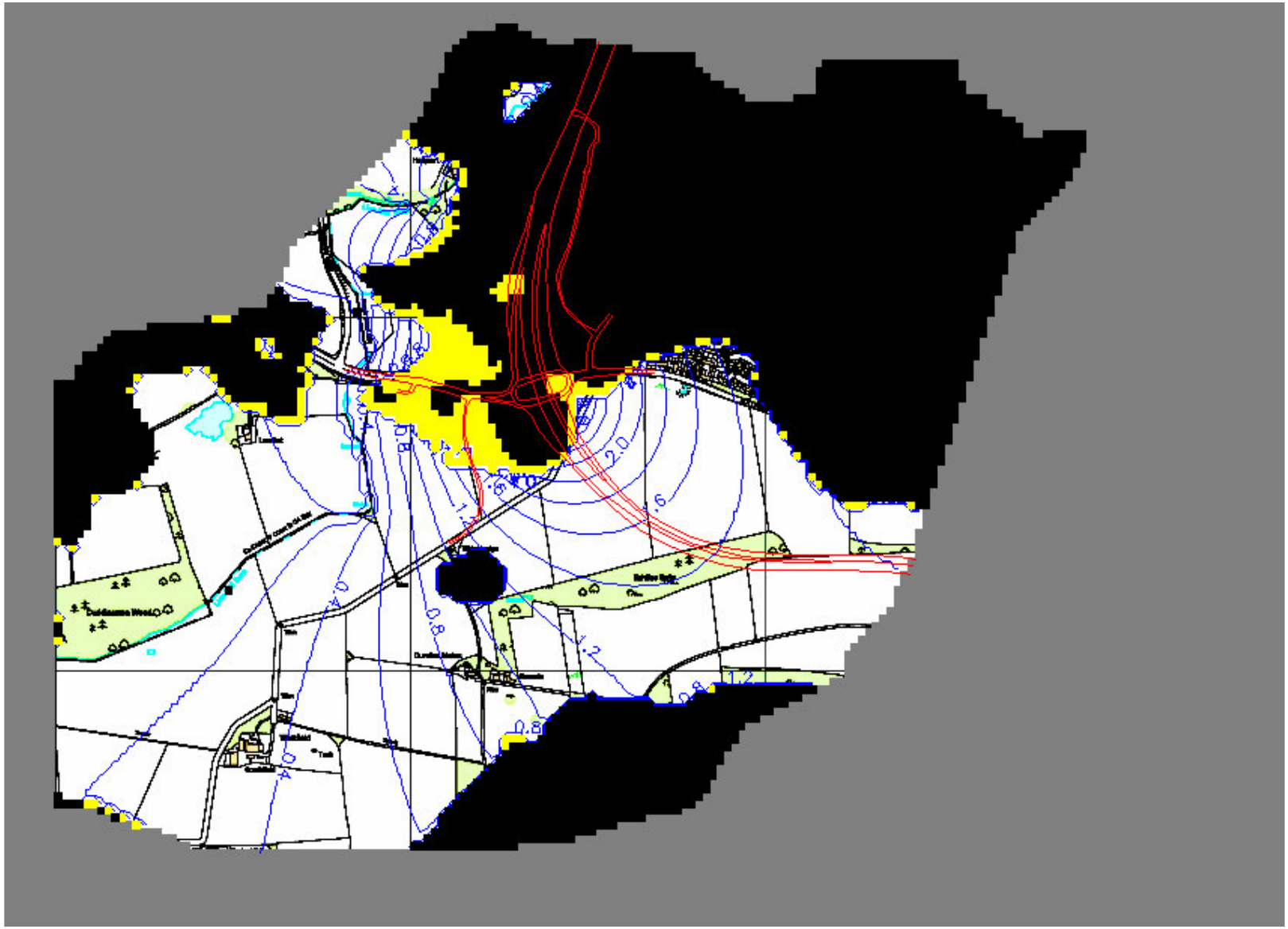
Figure 2 - Groundwater drawdown in drift - Drift deposits dried as a result of cutting in yellow and drift deposits originally dry in black



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