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GROUNDWATER IMPACTS FROM ENGINEERING PROJECTS. GROUNDWATER: A RESOURCE AT RISK?

GROUNDWATER IMPACTS FROM ENGINEERING PROJECTS

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ABSTRACT

A wide range of engineering works have the potential to cause detrimental impacts on the groundwater environment. Traditionally, the primary impacts that were of concern were the effects on groundwater levels and the derogation of groundwater sources as a result of dewatering abstractions. However, there is increasing recognition that there are risks of significant groundwater impacts even where dewatering pumping is not a major factor, for example if the project results in the creation of artificial barriers or pathways for groundwater flow. This paper summarises the major types of impact that can potentially occur when engineering projects interact with the groundwater regime.

INTRODUCTION

Water resource specialists such as hydrogeologists typically view groundwater as a 'good thing'. From their point of view groundwater is a potential *resource* to be used. Traditionally the primary use of water was for drinking water or industrial process use. In recent years other beneficial uses of groundwater have emerged, such as so-called ground source energy systems where groundwater can be used as a source of heating and cooling for buildings (Banks, 2007).

In stark contrast, construction engineers involved in major below-ground engineering works (deep basements, tunnels, metro systems, etc) traditionally view groundwater as a 'bad thing'. On these projects groundwater is a *problem*. If an engineering project penetrates down to water-bearing strata this will require the use of groundwater control measures (Preene *et al.*, 2000) such as dewatering pumping and low permeability cut-off walls.

Where engineering projects interact with the groundwater regime, there is the risk that detrimental impacts may result. Partly as a result of the requirements of the Water Framework Directive, there is currently increased interest in such impacts. For example, in the UK, the Environment Agency has recently developed guidelines on carrying out hydrogeological impact appraisals (HIA) for dewatering projects (Boak *et al.*, 2007). However, the Environment Agency methodology concentrates on the impacts resulting from groundwater abstraction. In reality, these impacts are only a sub-set of the groundwater impacts that can potentially result from engineering projects. This paper will summarise the major types of impact that can potentially occur when engineering projects interact with the groundwater regime.

POTENTIAL GROUNDWATER IMPACTS

The major potential groundwater impacts from civil engineering works were categorised by Preene and Brassington (2003), reproduced as Table 1. These impacts are grouped into five main categories:

1. Abstraction from aquifers.
2. Physical disturbance of aquifers creating pathways for groundwater flow.
3. Physical disturbance of aquifers creating barriers to groundwater flow.
4. Discharges to groundwaters.
5. Discharges to surface waters.

ABSTRACTION FROM AQUIFERS – TEMPORARY

Groundwater abstraction, in the form of temporary dewatering pumping can be used to allow construction below groundwater level. The methods available include pumping from sumps, wells or wellpoints (Preene *et al.*, 2000).

A number of groundwater impacts may result. These include:

i. ground settlement
ii. depletion of groundwater dependent features
iii. effects on water levels and water quality in the aquifer as a whole
iv. derogation of individual borehole or spring sources.

Ground Settlement

Ground settlement will occur whenever groundwater levels are lowered by abstraction. However, for the great majority of sites in Ireland settlements from dewatering abstraction are so small that no distortion or damage is apparent in nearby buildings. Ground settlements large enough to cause consequential damage are most likely to occur at sites where significant thicknesses of soft peat and alluvial soils are present and are underlain by permeable strata that require dewatering.

Depletion of Groundwater Dependent Features

The degradation of groundwater dependent features by groundwater lowering caused by abstraction for water supply is an issue that is widely recognised in water resource planning. However, Acreman *et al.* (2000) noted that in some cases degradation of the aquatic environment believed to be linked to groundwater abstraction may be due, at least in part, to other factors such as changes in land drainage, river channelisation and climate change.

For most construction projects, it is likely that many dewatering abstractions will be sufficiently short term and small in volume to avoid significant effects on groundwater dependent surface features (unless they are immediately adjacent to the dewatering works). If significant impacts are predicted, possible mitigation measures include:

i. Installation of a groundwater cut-off barrier (although the cut-off wall may itself detrimentally affect groundwater flow).
ii. Artificial recharge of groundwater or surface water. The temperature, chemistry and sediment content of the water must be assessed to ensure this will not itself cause adverse impacts.

Effects on Water Levels and Water Quality in the Aquifer as a Whole

Only the largest and longest duration temporary dewatering systems are likely to have a significant effect on groundwater resources in an aquifer as a whole. Indeed dewatering operations are often carried out in strata of low to moderate permeability, classified as non-aquifers in terms of their potential for supply, where the effects on groundwater supply are, by definition, minimal.

Concerns are also sometimes raised that prolonged dewatering abstractions may affect aquifer water quality by drawing in contaminated water from nearby sites. This includes: lateral migration of leachate contaminated plumes beneath non-engineered landfills; or vertical downward migration of pollutants from near surface contamination from current or historic industrial activity. In such cases extensive datasets of baseline water quality are needed to allow the risk of the impact to be assessed. Numerical modelling of the dewatering system could be used at project design stage to specify location, depth, screen intervals, pumping regimes, etc. of dewatering boreholes to reduce the threat to aquifer water quality.

Derogation of Individual Borehole or Spring Sources
Any construction projects planned near public or private water supply boreholes have the potential to cause a reduction in yield associated with lowering of groundwater levels for the duration of dewatering works. These impacts may require mitigation in the form of replacement of lost yield with tanker or bottled water supplies or modification of the borehole or spring source itself.

ABSTRACTION FROM AQUIFERS – PERMANENT
It is not widely recognised that many structures and engineered features that extend below groundwater level involve some form of permanent drainage system. For basements and tunnels a pumping system may be involved, or for road and rail cuttings discharge may be by gravity if the topography allows. These drainage systems are effectively long-term abstractions.

These abstractions can cause the same types of groundwater impacts as for temporary abstractions. In reality, drainage systems for discrete structures of limited extent such as basements are unlikely to have a significant effect on groundwater levels apart from very locally. In contrast, more extensive structures such as tunnels, pipelines and deep road and rail cuttings with associated drainage may cause greater impacts. Their linear extent can allow them to intercept and discharge considerable groundwater flow. This can result in derogation of supply boreholes and depletion of springs which may be used for supply or which support groundwater dependent features.

This impact can be mitigated by designing the structure to be watertight, without the need for groundwater drainage. If this cannot be done, replacement or upgraded water supplies may be required in the affected area, together with compensation flows to groundwater dependent features.

PHYSICAL DISTURBANCE OF AQUIFERS – PATHWAYS FOR GROUNDWATER FLOW
Engineering projects may inadvertently form permeable pathways along which groundwater may flow. Pathways may be temporary (such as investigation and dewatering boreholes) and can be sealed on completion. Other pathways could be formed by parts of the structure or works and may exist in perpetuity. Examples of permanent pathways include the granular bedding of pipelines (which may allow horizontal flow) or some types of piling or ground improvement processes (which can form vertical pathways). Open excavations such as road or rail cuttings may themselves form vertical pathways.

The consequential impacts of these pathways include (Figure 1):

1. Loss of yield if horizontal pathways act to divert water away from springs or supply boreholes.
2. Increased risk of aquifer pollution from land use or near surface activities. This is of particular concern if the confining bed above an aquifer is punctured by the works, especially if the near surface strata have been contaminated by historic or ongoing polluting industries.
3. Changes in groundwater quality if pathways are formed between different aquifer units. For example, poorly sealed investigation boreholes could allow mixing of fresh and more saline water in aquifers where groundwater quality is stratified, or polluted groundwater at shallow depth may be able to flow into deeper aquifers.
4. Uncontrolled flowing artesian discharges through inadequately sealed site investigation or dewatering boreholes.

Awareness of these impacts is important when designing boreholes. For example, all site investigation boreholes and dewatering boreholes must be adequately sealed on completion. Similarly, dewatering boreholes should ideally not be screened in more than one aquifer unit and should have grout seals at suitable levels to prevent the gravel pack acting as a pathway for vertical flow.

Deep structures such as shafts or basements should be designed to limit the potential for creation of vertical flow paths – for example by using raft foundations in preference to piles that would puncture low permeability aquitard layers. If piling or ground improvement methods have to be used, methods should minimise the formation of vertical flow paths.

Horizontal structures such as pipelines should have anti-seepage collars (known as 'stanks') at regular intervals along their route.

PHYSICAL DISTURBANCE OF AQUIFERS – BARRIERS TO GROUNDWATER FLOW

Closely spaced heavy-duty foundations may interrupt horizontal groundwater flow, causing a damming effect (Figure 2). Groundwater levels may rise on the upstream side of the structure, and be lowered on the downstream side. These effects may not be significant unless large structures fully penetrate significant aquifer horizons.

If these impacts are of concern the designer could consider using raft foundations or limiting the depth of piles or cut-off walls, to reduce aquifer penetration. Any continuous impermeable cut-off walls used for groundwater control during construction could be designed not to form permanent barriers to groundwater flow once construction is completed.

DISCHARGES TO GROUNDWATERS

Construction activities can create the potential for discharges to groundwaters, with the consequent risk of pollution and degradation of groundwater quality. The main sources of potentially polluting discharges are: leakages and spills of fuels and lubricants from plant and vehicles; run-off from operations such as concrete placement; and run-off of turbid surface water as a result of topsoil removal and excavation. Normally, the risk of polluting discharges can be reduced by the adoption of good practice, based on guidance from the environmental regulators for the site locality.

The risk of pollution is increased if pathways for groundwater flow are associated with the works. Often, open excavations form a ready pathway for inadvertent discharges to groundwater. Good site practice should include prohibiting refuelling of plant (and storage of fuels) in or near excavations. Surface water drainage should be arranged to reduce the risk of spills or run-off entering the excavation.

Structures with deep basements or below-ground spaces may also provide potential for discharges to groundwater in the longer term. If the structures are not watertight and penetrate confining beds over aquifers, leaks, spillages or surface water flooding may be able to percolate more freely into groundwater. Individually, such leakages may be small but their combined effect may lead to significant groundwater contamination.

DISCHARGES TO SURFACE WATERS

Groundwater flows from temporary dewatering or longer-term drainage must be disposed of. There may be detrimental impacts on the receiving water body, including:

i. Erosion of river banks or water courses by poorly arranged discharges. This can block or change flow as scoured material is re-deposited downstream. Impacts can be reduced by the use of gabion baskets, geotextile mattresses or straw bales to dissipate the energy of the water at the point of discharge.

ii. Suspended solids (clay, silt and sand sized particles) in the discharge water are a highly visible aesthetic problem, but are also harmful to aquatic plant, fish and insect life in surface waters. Any abstraction system should have adequate treatment to avoid suspended solids in the discharge water.

iii. Oil and petroleum products may appear in discharge water as a result of spills or leaks from plant, vehicles or storage areas. These are often light non-aqueous phase liquids (LNAPLs) and will not mix easily with water, appearing as floating films or layers on the surface of lagoons or watercourses and may be present in solution. Water may have to be passed through proprietary 'petrol interceptors'; collecting the oil products for separate disposal.

iv. Contaminated groundwater. When abstracting from or near a contaminated site, the discharge water may be contaminated. Unless discharged via sewers to a wastewater treatment works capable of dealing with the contaminants, the flow will require treatment prior to discharge. The scale of treatment can vary greatly. If the abstraction and discharge are to continue in the long term, the ongoing need for treatment can be a major constraint on the feasibility of a construction project.

MONITORING

Monitoring is an essential part of managing groundwater impacts from engineering projects. Typical parameters to be monitored could include:

i. Groundwater levels in wells and boreholes.
ii. Surface water levels in wetlands, streams, etc.
iii. Flow from springs and in associated watercourses.
iv. Water quality parameters at springs or boreholes, including the use of geophysical fluid logging in boreholes with stratified water quality.

The natural variability of the groundwater regime can make it difficult to establish baseline conditions against which to assess impacts such as changes in groundwater level. For major or sensitive projects it may be appropriate to install 'control' monitoring points, beyond the area influenced by the project.

Location of monitoring points should be determined by the conceptual model of the anticipated impacts. The majority of monitoring points should be located in aquifer units where impacts are expected. However, it is also prudent to carry out monitoring in aquifer units where no impacts are expected (e.g. horizons that are hydraulically isolated from the works by very low permeability strata).

CONCLUSION

Engineering projects have the potential to cause significant impacts on the groundwater environment. Provided the potential impacts are identified early enough in a project, mitigation measures and associated monitoring can often be adopted to control these impacts. However, it is important that the full range of impacts is addressed, not merely those impacts directly associated with dewatering pumping.

The principal groundwater impacts from engineering projects can be categorised as:

1. Abstraction from aquifers.
2. Physical disturbance of aquifers creating pathways for groundwater flow.
3. Physical disturbance of aquifers creating barriers to groundwater flow.
4. Discharges to groundwaters.
5. Discharges to surface waters.

The risk and significance of impacts on each site and project must be assessed individually, taking into account, for example, the nature of the works, the presence and vulnerability of aquifers, and the proximity and sensitivity of nearby water sources, etc.

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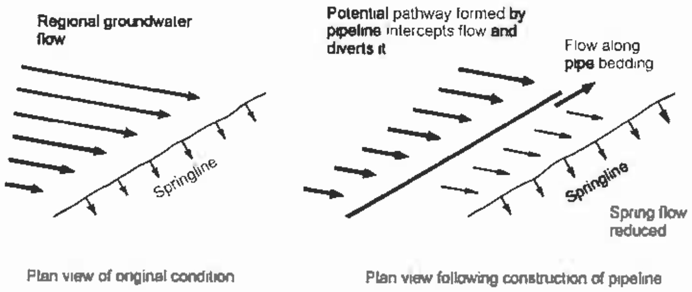

Figure 1: Pathways for groundwater flow

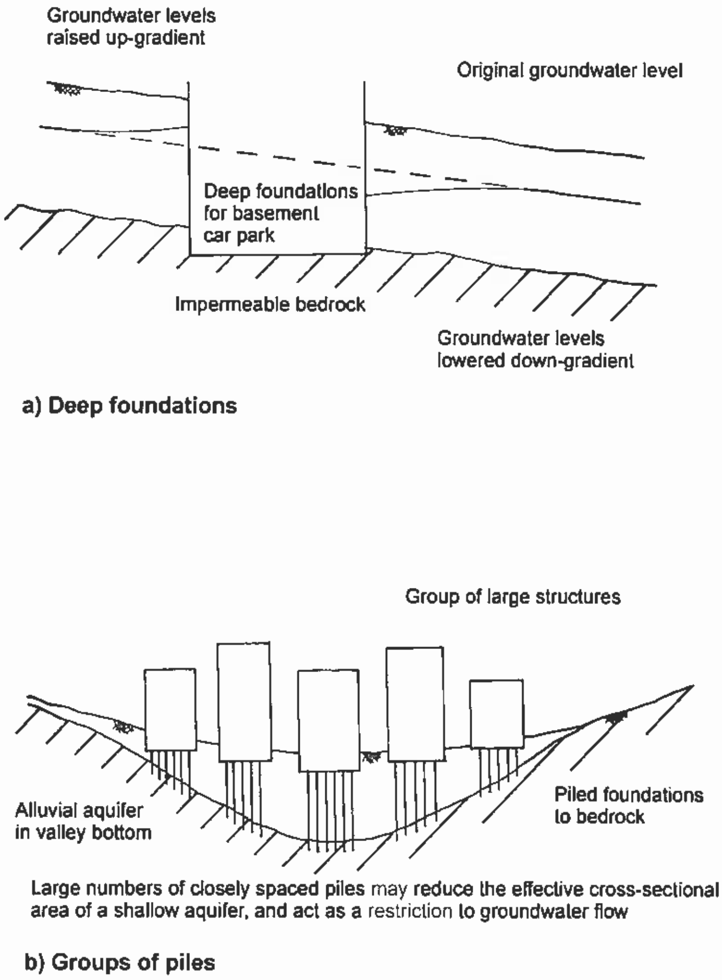

Figure 2: Barriers to groundwater flow

Table 1: Impacts on groundwater conditions from civil engineering works (from Preene and Brassington, 2003)

	Category	Potential impacts	Duration	Relevant construction activities
1	Abstraction	Ground settlement Derogation of individual sources Effect on aquifer – groundwater levels Effect on aquifer – groundwater quality Depletion of groundwater dependent features	Temporary	Dewatering of excavations and tunnels using wells, wellpoints and sumps Drainage of shallow excavations or waterlogged land by gravity flow
			Permanent	Permanent drainage of basements, tunnels, road and rail cuttings, both from pumping and from gravity flow
2	Pathways for groundwater flow	Risk of pollution from near surface activities Change in groundwater levels and quality	Temporary	Vertical pathways created by site investigation and dewatering boreholes, open excavations, trench drains, etc. Horizontal pathways created by trenches, tunnels and excavations
			Permanent	Vertical pathways created by inadequate backfilling and sealing of site investigation and dewatering boreholes and excavations and by permanent foundations, piles and ground improvement processes Horizontal pathways created by trenches, tunnels and excavations
3	Barriers to groundwater flow	Change in groundwater levels and quality	Temporary	Barriers created by temporary or removable physical cut-off walls such as sheet-piles or artificial ground freezing
			Permanent	Barriers created by permanent physical cut-off walls or groups of piles forming part of the foundation or structure or by linear constructions such as tunnels and pipelines Barriers created by reduction in aquifer hydraulic conductivity (e.g. by grouting or compaction)
4	Discharge to groundwaters	Discharge of polluting substances from construction activities	Temporary	Leakage and run-off from construction activities (e.g. fuelling of plant) Artificial recharge (if used as part of the dewatering works)
			Permanent	Leakage and run-off from permanent structures Discharge via drainage soakaways
5	Discharge to surface waters	Effect on surface waters due to discharge water chemistry, temperature or sediment load	Temporary	Discharge from dewatering systems
			Permanent	Discharge from permanent drainage systems