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Impacts from groundwater control in urban areas

Impacts de contrôle des eaux souterraines dans les zones urbaines

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ABSTRACT Construction of deep structures, such as basements, road underpasses or metro rail systems often requires significant groundwater control measures. The presence of neighbouring structures and the typically sensitive hydrogeological setting beneath many cities means that impacts on groundwater conditions are often a concern. Potential impacts from groundwater control works can be categorised as: geotechnical impacts; contamination impacts; water dependent feature impacts; water resource impacts; and water discharge impacts. Where impacts are of potential concern a programme of baseline monitoring and operational monitoring should be implemented to allow the magnitude of impacts to be assessed. Possible mitigation measures to reduce or avoid impacts from groundwater control include: artificial recharge; targeted groundwater cut-off walls; temporary cut-off walls; and, measures to protect individual receptors.

RÉSUMÉ Construction de structures profondes, comme les sous-sols, les passages souterrains ou les systèmes ferroviaires de métro ont souvent besoin des mesures de contrôle des eaux souterraines importantes. La présence des structures avoisinantes et la situation hydrogéologique généralement sensible de nombreuses villes signifie que impactes sur les eaux souterraines sont souvent un sujet de préoccupation. Les impacts potentiels de travaux de contrôle des eaux souterraines peuvent être classés de manière suivante: impacts géotechniques; impacts de la contamination; impacts de caractéristiques dépendantes de l'eau; impacts sur les ressources d'eau; et les impacts d'évacuation d'eau. Lorsque les impacts sont une préoccupation potentielle un programme de surveillance de base et opérationnel doit être mis en œuvre pour permettre l'évaluation de l'ampleur des impacts. Les mesures d'atténuation possibles pour réduire ou éviter les impacts de contrôle des eaux souterraines comprennent: la recharge artificielle; murs parafouille hydrogéologiques ciblées; murs parafouille temporaires; et des mesures pour protéger les récepteurs individuels.

1 INTRODUCTION

Groundwater control is an important part of many civil engineering projects where excavation is made below groundwater level, for example for deep basements or for transport infrastructure (e.g. road underpasses or metro rail systems). An extensive range of groundwater control techniques is available to allow excavations to be made in a wide range of ground conditions and hydrogeological settings (Cashman & Preene 2012).

Traditionally, the primary focus of geotechnical engineers and construction managers designing and implementing groundwater control systems has been on providing safe and robust solutions within the constraints of available budget, resources and schedule. In the past, it was not routine to consider the potential environmental impacts of dewatering and groundwater control. In recent decades, discussion and guidance has emerged on potential environmental impacts (such as Powers 1985; Preene & Brassington 2003), and these issues are now routinely considered in most major civil engineering projects. Indeed, in areas such as the Middle East, where there are major infrastructure construction programmes requiring groundwater control, regulatory guidelines stress the importance of avoiding or mininising impacts (Abu Dhabi City Municipality 2014; ASHGHAL 2014).

This paper describes the particular issues and potential environmental impacts associated with groundwater control in urban areas, where the restricted working space and the presence of neighbouring structures will influence the choice of methods, and discusses the requirements for environmental monitoring and mitigation.

2 METHODS OF GROUNDWATER CONTROL

Groundwater control can be achieved via two principal types of methods: pumping methods and exclusion methods. A range of methods can be used to control groundwater as shown in Table 1.

Table 1. Groundwater control methods

Pumping methods	Exclusion methods
Sump pumping	Steel sheet-piling
Vertical wellpoints	Vibrated beam walls
Horizontal wellpoints	Cement-bentonite or soil-bentonite slurry walls
Deep wells with submersible pumps	Concrete diaphragm walls
Ejector wells	Bored pile walls
Passive relief wells	Grout curtains (permeation grouting; rock grouting; jet grouting; mix-in place methods)
Electro-osmosis	Artificial ground freezing

The techniques most commonly associated with groundwater control are the pumping methods. These involve pumping groundwater from an array of wells or sumps (Figure 1) with the aim of temporarily lowering groundwater levels to allow excavations to be made in stable conditions. Pumping methods are also known as groundwater lowering, construction dewatering or simply dewatering. The amount of lowering of the groundwater level is known as drawdown.

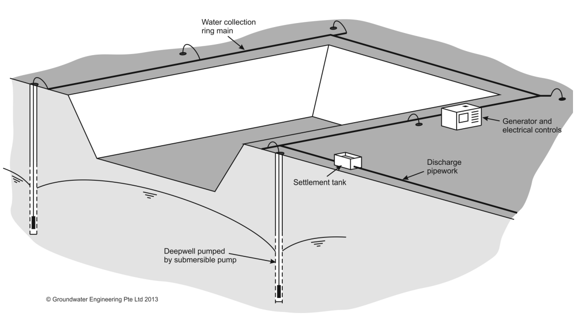

Figure 1: Groundwater control by pumping

In contrast, exclusion methods rely on low permeability cut-off walls around the excavation to exclude groundwater from the excavation (Figure 2). Exclusion methods can significantly reduce, or even eliminate completely, the requirement to pump groundwater.

Each group of methods (pumping and exclusion) has the potential to cause different types of environmental impacts.

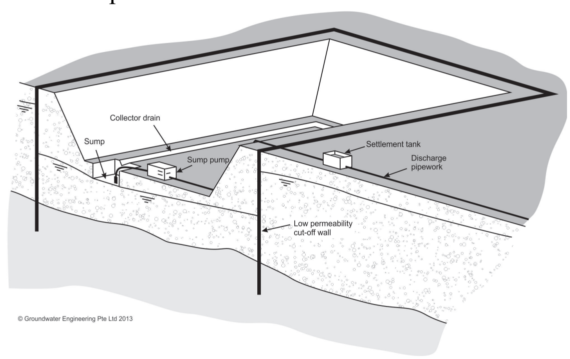

Figure 2: Groundwater control by exclusion

3 INDICATIVE FACTORS FOR IMPACTS

It would be extremely useful to practicing engineers if generic 'key indicators' of potential impacts from groundwater control could be identified. This could allow early screening of projects to determine whether groundwater control works have the potential to cause significant impact, and therefore whether special monitoring and mitigation measures may be required.

Unfortunately, it is difficult to provide general indicators of the risk of potential impacts. This is partly because the potential impacts are largely controlled by the site setting and are dependent on hydrogeological conditions, which are unique to each site. Additionally, the type of groundwater control methods used can also have key influence on the potential impacts.

It is true that the scale and duration of the groundwater control works have some influence – as a general guide, excavations that go deeper below groundwater level and require groundwater control for long periods have the greater potential to create impacts than shallower excavations that are open for shorter time periods. This is particularly the case for groundwater control using pumping, where deeper, long-term excavations will tend to create a larger 'zone of influence' within which groundwater levels are lowered by the effect of pumping.

However, it is important to realise that in the past there have been several cases where significant detrimental impacts have occurred from groundwater control for shallow and short-term excavations.

Where groundwater control is carried out in sparsely developed areas, even where detrimental impacts are expected, the potential consequences may be modest, because there are relatively few buildings or limited infrastructure around that may be affected. One of the particular challenges of working in densely developed urban areas is that the project site is likely to be surrounded by multiple neighbouring sites, which may have different sensitivities and vulnerabilities to impacts from groundwater control.

4 CATEGORIES OF IMPACTS

The potential for impacts will have to be assessed on a site-by-site basis. Ideally such assessments need some structure of framework, and the categories of impacts in Table 2 are suggested as an aid to planning and structuring the assessments.

Table 2. Categories of impacts from groundwater control

Impact category	Types of impact
Geotechnical	Ground settlement – effective stress Ground settlement – loss of ground
Contamination	Mobilisation by pumping Creation of vertical flow pathways
Water feature	Reduction in flow Change in water quality Change in water level
Water resource	Change in water availability Change in water quality
Water discharge	Change in water quality Downstream scour and flooding

The impacts categories in Table 1 are the direct impacts from interference with, or manipulation of, the groundwater regime. There will be additional indirect impacts (such as noise, emissions from plant, etc.) associated with the physical construction activities, such as well drilling or pumping. These indirect impacts are not discussed here.

4.1 Geotechnical impacts

Defined as impacts where the geotechnical properties or state of the ground are changed by groundwater control activities.

The most common type of impact in this category is ground settlement, with the corresponding risk of distortion and damage to structures, services and other sensitive infrastructure. Ground settlement can be caused by two principal mechanisms:

- Increases in effective stress as a result of lowering of groundwater levels, resulting in compression and consolidation of the ground. Such settlements are an unavoidable consequence of lowering of groundwater levels.
- Removal of fine particles from the ground (loss of fines) which can occur when poorly controlled sump pumping draws out soil particles with the pumped water. With good design and implementation, loss of fines (and the associated settlement risk) can be avoided.

Further details on settlement caused by groundwater control works are given in Preene (2000).

Lowering of groundwater levels can potentially cause other geotechnical impacts. One possible impact is negative skin friction loads on piles (where soil is consolidating around the piles). Another possible impact is the degradation of timber piles supporting older structures. This is a particular issue in Scandinavia, where buildings founded on timber piles are commonplace. In many cities in Scandinavia, such as Copenhagen, artificial recharge is commonly used to minimise lowering of groundwater levels outside the site, to reduce impacts on nearby timber-piled structures (Bock & Markussen 2007).

4.2 Contamination impacts

Defined as impacts where pre-existing ground or groundwater contamination is mobilised, transported and/or where transmission pathways are created.

Many urban sites have a legacy of former industrial uses, which may have left behind contamination in soil or groundwater. Groundwater contamination can be mobile under the effect of hydraulic gradients and may migrate away from the original source.

Even in the absence of pumping, natural hydraulic gradients can allow groundwater contamination to slowly spread horizontally to form a 'plume' of contamination away from the original site. Hydraulic gradients created by pumping will typically be much larger than natural gradients, and any nearby groundwater contamination will tend to be drawn toward the pumping system.

The mobility of groundwater contamination is complex to assess, primarily being controlled by the nature and hydraulic conductivity of the ground, and the type and properties of contaminant. In some cases groundwater contamination from a neighbouring site may reach the pumping system (and emerge in the discharge water) within a few hours of pumping, while in other circumstances it may be weeks or months before the contamination emerges at the dewatering system.

Even if the contamination does not reach the pumping system, there may still be potential impacts associated with the migration of the existing contamination to cover a larger area under the influence of pumping.

There can also be impacts from vertical migration of contamination where poorly designed and installed wells or investigation boreholes act as vertical pathways (Figure 3).

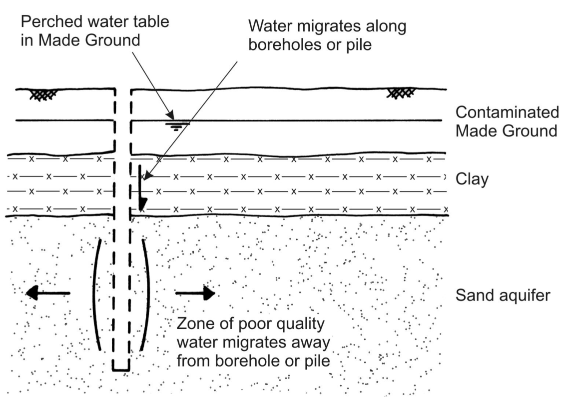

Figure 3: Vertical migration of contamination along a borehole or well

This potential impact is relevant when designing site investigation boreholes, piezometers and dewatering wells. As a general rule, wells and piezometers should 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. In areas with layered ground conditions any site investigation boreholes not completed as piezometers should be adequately sealed on completion.

4.3 Water feature impacts

Defined as impacts where groundwater flows, levels and/or quality are affected in water-dependent features (including both natural and artificial features).

This primarily relates to the consequences of lowering of groundwater levels or changes in groundwater flow pattern as a result of groundwater control works. An obvious example is pumped groundwater control near natural water-dependent features such as wetlands (where water levels may fall due to increased seepage losses) or groundwater springs (where flow rates may be reduced). Artificial features, such as archaeological remains might also be detrimentally affected by lowered groundwater level, and this may need to be considered when assessing impacts.

Even if groundwater pumping is not planned to be significant, low permeability cut-off walls used as part of groundwater exclusion methods can also have impacts. Groundwater levels may rise on the upgradient side and fall on the downgradient side (Figure 4). In many cases the changes in groundwater level will be small but where large structures (such as metro stations or cut and cover tunnels) fully penetrate significant aquifer horizons there is a risk that changes in groundwater levels may affect nearby basements or buried services.

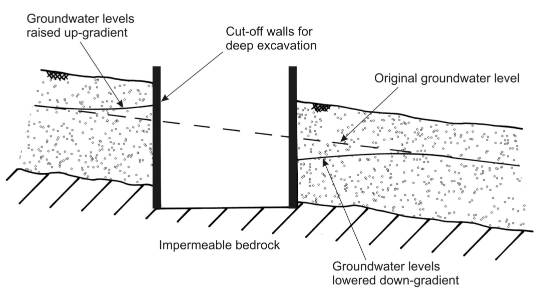

Figure 4: Low permeability cut-off walls acting to block natural groundwater flow

4.4 Water resource impacts

Defined as impacts where water availability or water quality (including saline intrusion) are affected either at defined abstraction points (wells or springs) or in known water resource units (aquifers).

In many cases, groundwater control is deployed at a site to deal with groundwater viewed as a 'problem' by the construction team. Conversely, that same groundwater may be a 'resource' used by others for beneficial purposes such as drinking water, irrigation and agriculture or in industrial processes. For major groundwater control projects it is important that a review of nearby groundwater uses is carried out at an early stage so that the potential impact on water resource use can be assessed if necessary.

Possible impacts on water resources from groundwater control include a reduction in 'quantity' of water resources, due to lowering of groundwater levels or reduction in yield of existing wells and springs. Other impacts may affect water 'quality' (i.e. the chemical make up of the water), for example by drawing in saline water from coastal waters or drawing in poorer quality water from abandoned mine workings.

In arid countries, fresh or brackish water lenses may exist above a generally saline water table, and are exploited by shallow wells for irrigation. In those circumstances even small changes in groundwater levels can cause significant changes in water quality in the shallow wells.

4.5 Discharge impacts

Defined as impacts where the discharge of water from pumping systems impacts on the receiving environment (surface water or groundwater, where recharge wells are used).

Where water is pumped it must be disposed of, potentially creating a range of impacts. The most common impact is where discharge water has a significant sediment load. When discharged to surface watercourses the sediment will to harmful to aquatic life and can build up in ponds and channels, affecting hydraulic capacity. If suspended solids in the pumped water cannot be avoided through the use of well filters then the water should be passed through a sedimentation system prior to discharge. Even if the pumped water has a low sediment load, the aquatic habitats in the receiving watercourse may be affected by differences in chemistry and temperature between the pumped water and the receiving waters.

If groundwater is pumped from or near a contaminated site, the discharge water may be contaminated and require specialist treatment prior to discharge.

5 MONITORING AND MITIGATION

Monitoring and mitigation are closely linked and should be developed based on a solid understanding of the hydrogeological conceptual model for the site and its environs. The aim should be to identify and measure (through monitoring), and then minimise and control (through mitigation) the potential impacts from groundwater control works.

5.1.1 Baseline (pre-construction) monitoring

It is prudent to have pre-construction monitoring of groundwater levels, spring flows, ground levels, etc. to determine baseline conditions against which any impacts can be assessed. This will require early access to site, or sourcing of third party data.

If settlement damage to structures is a concern, pre-construction building condition surveys may be appropriate within the predicted zone of influence.

5.1.2 Operational monitoring

Monitoring of groundwater levels and pumped flow rates is a routine and necessary part of the operation of any groundwater control scheme.

However, where environmental impacts are assessed to be of concern then operational monitoring assumes even greater importance. Additional monitoring parameters for monitoring are given in Table 3.

5.2 Mitigation

The first step in developing a method for mitigation of impacts is to ensure the most appropriate dewatering technology is adopted. For example:

- Exclusion methods could be used to reduce or avoid pumping and hence reduce external drawdown.
- Conversely, the barrier effect when laterally extensive cut-off walls dam groundwater flow may militate against the use of the exclusion technique in some circumstances.

Mitigation measures must be developed on a site-specific basis, but can include:

Artificial recharge: Groundwater from the pumped discharge can be re-injected (via wells) or re-infiltrated (via shallow wells or trenches) back into the ground, either to prevent lowering of groundwater levels and corresponding ground settlement, or to prevent depletion of groundwater resources.

Table 3. Principal monitoring parameters related to impacts from groundwater control works

Monitoring parameter	Comments
Pumped flow rate from groundwater control system	Both instantaneous flow rates and cumulative volumes pumped are relevant to impact assessment.
Groundwater levels	Should be monitored close to the groundwater control system, as well as closer to vulnerable receptors. Piezometers with defined response zones in specific strata are preferred over wells with long screened sections.
Surface water levels	Can be monitored in rivers, ponds and wetlands that may be affected by groundwater control.
Surface water flow rates	Can be monitored in rivers, ponds and wetlands that may be affected by groundwater control.
Discharge water chemistry	Temperature, suspended solids and water chemistry should be monitored.
Groundwater and surface water chemistry	Can be monitored in wells, springs, rivers, ponds and wetlands.
Ground levels	Monitoring of ground levels will allow the magnitude of ground settlement to be assessed.
Condition of structures	Visual inspection and structural monitoring will aid the identification of any structural distortion and damage.
Climate conditions	Monitoring of rainfall and barometric pressure can be useful to identify any natural variations in groundwater conditions to separate such variations from any artificial impacts.

Targeted groundwater cut-off walls: Where there is a specific receptor to be protected, such as a wetland or sensitive structure, it may be possible to install a targeted section of cut-off wall or grout curtain between the dewatering system and the receptor, to reduce the drawdown at the receptor.

Temporary cut-off walls: If there is a concern that permanent cut-off walls will act as a barrier and affect the long term groundwater flow regime, then it may be possible to use temporary cut-off methods. For example, steel sheet-piles that are withdrawn at the end of the project, or artificial ground freezing, which will eventually thaw and allow groundwater flow to pass.

Protection of individual receptors: If there are only a small number of isolated receptors, it may be more cost effective to prevent the problem directly at the receptor, for example by underpinning the foundations of a sensitive structure, or by replacing a residential water supply well with a piped supply where lowering of groundwater levels has reduced the yield.

6 CONCLUSION

A range of environmental impacts can result from groundwater control, even if pumping is not involved. Categories presented in this paper can be useful to classify potential impacts to help identify sites and projects that may be significantly impacted.

Monitoring and mitigation measures can be used and should be based on a sound hydrogeological conceptual model developed from the available site investigation data, ideally including a desk study.

REFERENCES

Abu Dhabi City Municipality. 2014. *Dewatering Guidelines. Geotechnical, Geophysical, and Hydrogeological Investigation Project (GGHIP)*. Report 13-5015, Draft B. Abu Dhabi City Municipality, Abu Dhabi.

ASHGHAL. 2014. *Management of Construction Dewatering – Construction Dewatering Guidelines*. Public Works Authority, Quality and Safety Department, Doha, Qatar.

Bock, M. & Markussen, L.M. 2007. Dewatering control in central Copenhagen. *Geotechnical Engineering in Urban Environments: Proceedings, 14th European Conference on Soil Mechanics and Geotechnical Engineering* **2**, (Eds: Cuéllar, V., Dapena, E., Alonso, E., Echave, J.M., Gens, A., De Justo, J.L., Oteo, C., Rodríguez-Ortiz, J.M., Sagaseta, C., Sola, P. & Soriano, A) 715–720. IOS Press, Amsterdam.

Cashman, P.M. & Preene M. 2012. *Groundwater Lowering in Construction: A Practical Guide to Dewatering*, 2nd edition. CRC Press, Boca Raton.

Powers, J.P. 1985. *Dewatering – Avoiding its Unwanted Side Effects*. American Society of Civil Engineers, New York.

Preene, M. 2000. Assessment of settlements caused by groundwater control. *Proceedings of the Institution of Civil Engineers, Geotechnical Engineering* **143**, 177–190.

Preene, M. & Brassington, F.C. 2003. Potential groundwater impacts from civil engineering works. *Water and Environmental Management Journal* **17**, 59–64.