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POTENTIAL GROUNDWATER IMPACTS FROM CIVIL ENGINEERING WORKS

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ABSTRACT

Civil engineering construction works often have significant impacts on groundwater conditions. Such impacts range from the derogation of water sources by dewatering works, to the creation of barriers and pathways for groundwater flow, formed by foundations or ground improvement processes. In some cases, not all these impacts are identified sufficiently early during the planning and design process.

This paper describes the full range of potential groundwater impacts that may result from construction activities. The effects are grouped into five rational categories as an aid to initial assessment. The need for accurate baseline groundwater environmental data is set out, and recommendations are made for planning of monitoring programmes.

INTRODUCTION

It is well established that civil engineering projects can impact on the groundwater environment, both during construction and in the longer-term. The potential for some effects, such as the derogation of existing groundwater sources during construction dewatering abstractions, are commonly considered. Other changes, such as the creation of flow pathways by pipeline or foundation construction, are often not identified sufficiently early in the planning process (Brassington(1)).

Groundwater can be viewed either as a *resource*, worth protecting and managing, or as a *problem* requiring a solution during construction of below-ground works. Water resource managers and hydrogeologists approach groundwater primarily from the resource point of view, while construction engineers have traditionally viewed the presence of groundwater as an inconvenience or problem, to be solved by suitable construction expedients.

When water is abstracted water for beneficial use, hydrogeologists would ideally like to abstract large volumes of groundwater, while lowering groundwater levels in the aquifer by only a small amount. In contrast, where works are constructed below groundwater levels, the construction engineer's aim is to deliberately lower groundwater levels on a local basis, ideally by abstracting relatively small volumes of water. Engineers will adopt methods to mitigate the effect of groundwater on construction; this might include temporary dewatering pumping or the construction of physical cut-off walls into the aquifer (Cashman and Preene(2)). Some large structures (such as basements, road or rail cuttings) below the water table may be equipped with permanent groundwater drainage systems, to prevent flooding, and lower the water table in the immediate vicinity with consequential impacts on groundwater resources that have not always been fully appreciated.

GROUNDWATER AS A RESOURCE

Groundwater is an important resource in the United Kingdom, in terms of both its potential for abstraction for beneficial use and for its interaction with the wider environment. In England 33 per cent of public water supply is obtained from groundwater, compared with 8 per cent in Wales, 5 per cent in Scotland and 8 per cent in Northern Ireland (Robins *et al.*(3)). These figures hide considerable local variations. In addition to abstractions for public supply, groundwater is relied upon by many for domestic water supplies from private springs or boreholes even in regions with an overall low groundwater usage.

Groundwater has a strong interaction with many surface water features such as rivers and wetlands. As a consequence, changes in groundwater levels or quality can have detrimental environmental impacts. In the UK groundwater protection policies, such as Environment Agency[(4)] and Scottish Environment Protection Agency[(5)], have been adopted to prevent:

i. Over-abstraction of aquifers.
ii. Derogation of individual sources.
iii. Damage to environmental features dependent on groundwater levels (e.g. river baseflows).
iv. Unacceptable risk of pollution of groundwater from point and diffuse sources. This includes delineation of source protection zones (SPZs) around individual groundwater abstraction sources, within which various potentially polluting activities are either strictly controlled or prohibited.

GROUNDWATER IMPACTS FROM CONSTRUCTION WORKS

A range of temporary and permanent impacts on the groundwater environment may result from civil engineering works. No comprehensive summary of these potential effects exists in the literature, although Powers[(6)] described so-called 'unwanted side effects' of temporary dewatering and (Thompson *et al*.[(7)]) reviewed groundwater impacts from mineral extraction. Brassington[(1)] also discussed the derogation private water supplies resulting by temporary dewatering or permanent disruption of groundwater flow by engineering works.

The major potential groundwater impacts from civil engineering works were categorised by Preene and Brassington[(8)], summarised in 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.

As with any study, 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.

CATEGORY 1: ABSTRACTION FROM AQUIFERS – TEMPORARY

Construction in permeable strata below groundwater level will require temporary groundwater control to allow the works to be completed in dry and stable conditions. The methods available include pumping from sumps, wells or wellpoints (Cashman and Preene[(2)]). Under current UK practice these are unregulated abstractions, with no mechanism for formal consenting by the environmental regulators.

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 the UK 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 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 (Cunningham[(9)]). However, Acreman *et al*.[(10)] noted that in some cases impacts 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. Archaeological remains may also be dependent on stable groundwater levels, and there have been cases of degradation associated with large-scale dewatering works (French and Taylor[(11)]).

For most construction projects, it is likely that 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 (Figure 1):

i. Installation of a groundwater cut-off barrier (although the cut-off wall may itself detrimentally affect groundwater flow – see impact category 2).
ii. Artificial recharge of groundwater or surface water (Cliff and Smart[(12)]). 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 large long-term temporary dewatering systems are likely to have a significant effect on regional groundwater resources. As many dewatering operations are carried out in low to moderate permeability strata, classified as non-aquifers in terms of their potential for supply, such regional effects are rare. Examples include effects on public supply sources – in coastal areas vulnerable to saline intrusion (Luniss[(13)]).

There have also been concerns 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 water supply boreholes will fall within the SPZs, and the regulator can be expected to recognize the risk of derogation at planning stage. In contrast, small private borehole or spring sources (including domestic abstractions exempt from licencing), do not have SPZs defined and may be overlooked during investigation and planning. Many such sources exploit shallow drift aquifers and are likely to be vulnerable to yield reduction caused by lowered groundwater levels for the duration of dewatering works (Figure 2). Impacted sources may require temporary replacement by tanker or bottled water or modifications to the borehole or spring source.

CATEGORY 1: ABSTRACTION FROM AQUIFERS – PERMANENT

It is not universally realised that many structures and engineered features that extend below groundwater level involve some form of permanent drainage system that are effectively long-term abstractions. For basements and tunnels a pumping system may be involved, or for road and rail cuttings discharge may be by gravity flow where the topography allows.

Drainage systems for discrete structures such as basements are unlikely to have more than a local effect on groundwater levels. In contrast, more extensive structures such as tunnels, pipelines and deep road and rail cuttings with associated drainage may cause greater impacts (Brassington [(1)]). Their linear extent can allow them to intercept and discharge considerable groundwater flow (Figure 3) that may derogate borehole and spring supplies or impact groundwater dependent features. These effects are usually slow and many may go unrecognised as the consequences of poorly designed drainage works. Such effects may be avoided 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.

CATEGORY 2: PHYSICAL DISTURBANCE OF AQUIFERS – PATHWAYS FOR GROUNDWATER FLOW

Some types of engineering construction form informal groundwater flow paths. Some of these pathways may be temporary (such as investigation and dewatering boreholes) and can be sealed on completion, while others form a permanent part of a structure. 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 with their associated drainage works may themselves form flowpaths to divert groundwater.

The consequential impacts of these pathways include (Figure 4):

1. Loss of yield when horizontal pathways act to divert water away from springs or supply boreholes.
2. Increased risk of aquifer pollution from surface activities when for example, the confining bed above an aquifer is punctured by the works, and the near surface strata have been contaminated by historic or ongoing polluting industries.
3. Changes in groundwater quality if conduits 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 such potential impacts is important when designing site investigations or dewatering schemes. 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 may puncture low permeability layers (Westcott *et al.*[14]).

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

CATEGORY 3: PHYSICAL DISTURBANCE OF AQUIFERS – BARRIERS TO GROUNDWATER FLOW

Where extensive heavy-duty foundations are installed into aquifers that are shallow or of limited thickness, the concrete walls or groups of piles that are commonly used may interrupt horizontal groundwater flow, causing a damming effect (Figure 5). 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. It is rare that sufficient groundwater monitoring is carried out to allow these effects to be quantified; Barton [15] recorded groundwater level rises of 0.2–0.8 m upstream of a structure that fully penetrates a valley gravel aquifer. Such barriers will divert the groundwater flow around the sides of the structure and may reduce the supply to nearby groundwater sources, or cause flooding of adjacent basements.

Appreciation of these impacts allows the designer to 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.

CATEGORY 4: DISCHARGES TO GROUNDWATERS

Construction activities can create the potential for discharges to groundwaters, with the consequent risk of pollution and degradation of groundwater quality. Common examples include: 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. The pollution risk can be reduced by the adoption of good practices, following guidance from the environmental regulators.

The risk of pollution is increased if groundwater pathways (impact category 2) are associated with the works (Figure 6). Open excavations often 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 a long-term potential for discharges into aquifers. If the structures are not watertight and penetrate confining beds, 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 regional groundwater contamination.

CATEGORY 5: DISCHARGES TO SURFACE WATERS
Abstraction for temporary dewatering or from longer-term drainage schemes will generate a discharge need. Potential detrimental impacts on the receiving water body, include:

i. Erosion of the banks to water courses by poorly arranged discharges, which may also 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 in the discharge water are a highly visible aesthetic problem and are also harmful to aquatic plant, fish and insect life. Any abstraction system should have adequate filters 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 appear 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. Water abstracting from or near a contaminated site may be contaminated and may require appropriate treatment prior to discharge **(**Nyer [16]). The cost of long-term treatment may be a major constraint on the feasibility of a construction project.

MONITORING OF IMPACTS
Monitoring is an essential part of managing groundwater impacts from construction projects and may include:

i. Groundwater levels in wells and boreholes.
ii. Surface water levels in wetlands, streams, etc.
iii. Flow from springs and watercourses.
iv. Water quality parameters in springs or boreholes.

The availability of simple, cheap and reliable datalogging systems enable a continuous records of these parameters to be obtained and has almost done away with the need for manual measurements.

Streetly [17] has pointed out the difficulties of establishing a true baseline against which to assess impacts such as changes in groundwater level. Typically, groundwater levels vary in the short term (due to barometric changes, rainfall, abstraction, etc.) and in the longer term due to variations in recharge and, ultimately perhaps, climate change – this creates problems of data interpretation. Possible solutions include the installation of 'control' monitoring points, beyond the area influenced by the project. Alternatively, records from bodies such as the Environment Agency may perform this function and may also provide historic data and extend the records for the site.

The monitoring system should be designed to measure anticipated effects, with observations also taken in areas where no impacts are expected, to verify the conceptual understanding of the site hydrogeology.

CONCLUSION

1. Civil engineering works penetrating aquifers may create significant impacts on the groundwater environment. In the majority of cases simple mitigation measures are possible. However, the design of such measures require the potential impacts to be identified at an early stage in the project, which in many instances is not carried out

2. The principal groundwater impacts from civil engineering works can be categorised as:
   i) Abstraction from aquifers.
   ii) Physical disturbance of aquifers creating pathways for groundwater flow.
   iii) Physical disturbance of aquifers creating barriers to groundwater flow.
   iv) Discharges to groundwaters.
   v) Discharges to surface waters.

3. Ideally, potential impacts need to be assessed at an early stage of a scheme. The assessment should take into account the nature of the works, the presence and vulnerability of aquifers, and the proximity and sensitivity of nearby water sources, etc. Once this has been done the project design can be varied, and mitigation measures adopted if necessary.

4. Monitoring appropriate parameters such as groundwater levels is an essential part of managing potential impacts. Natural variations in groundwater levels can make it difficult to establish notionally 'undisturbed' baseline conditions against which to assess impacts. Monitoring programmes should be designed to determine baseline conditions pertaining in areas unaffected by anticipated impacts and for time periods before the impacts began.

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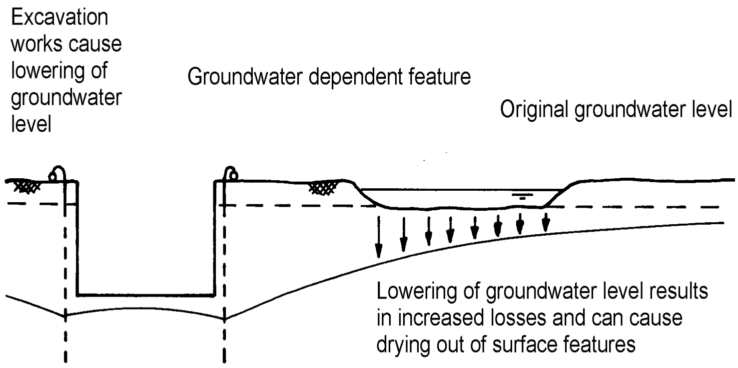
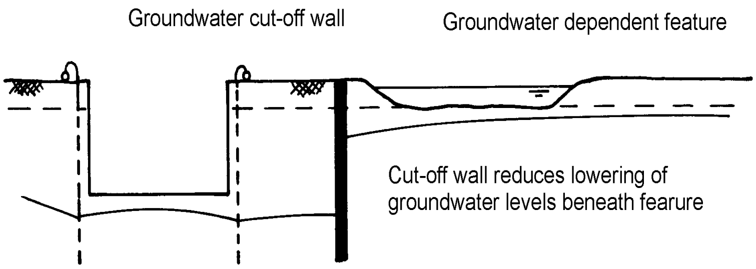
Table 1: Impacts on groundwater conditions from civil engineering works

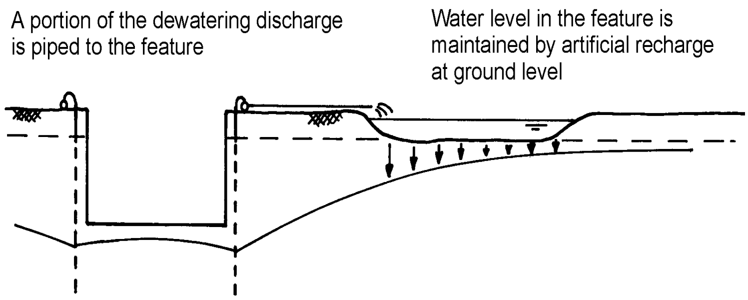
	Category	Potential impacts	Duration	Relevant construction activities
1	Abstraction	Ground settlement Derogation of individual sources Effect on aquifer – groundwater levels Effect on aquifer – groundwater quality Depletion of groundwater dependent features	Temporary	Dewatering of excavations and tunnels 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



a) Depletion due to lowering of groundwater levels

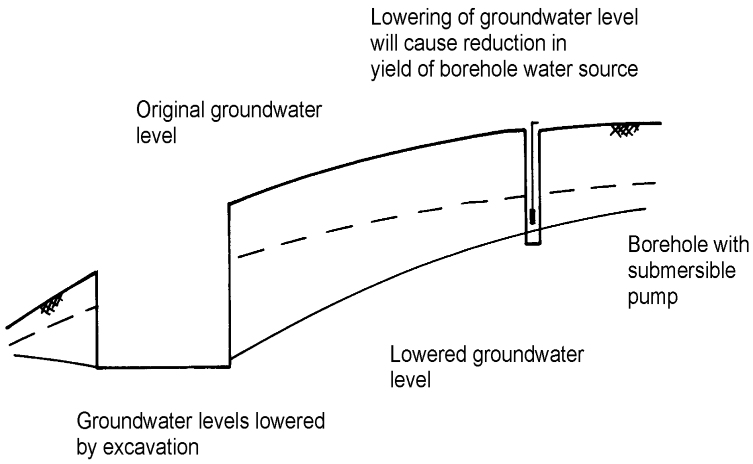


b) Cut-off wall used to mitigate impact

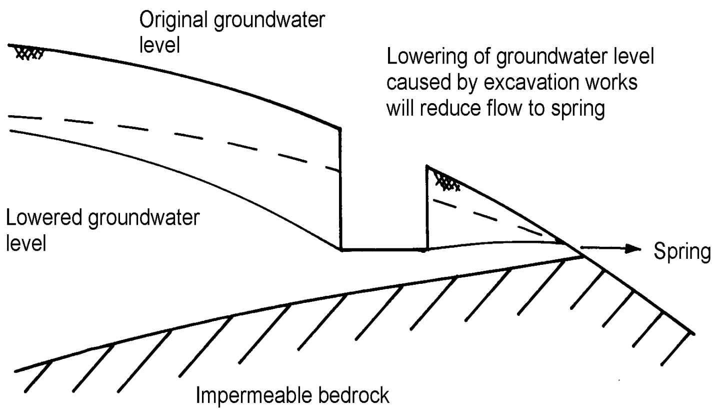


c) Artificial recharge used to mitigate impact

Figure 1: Depletion of groundwater dependent features

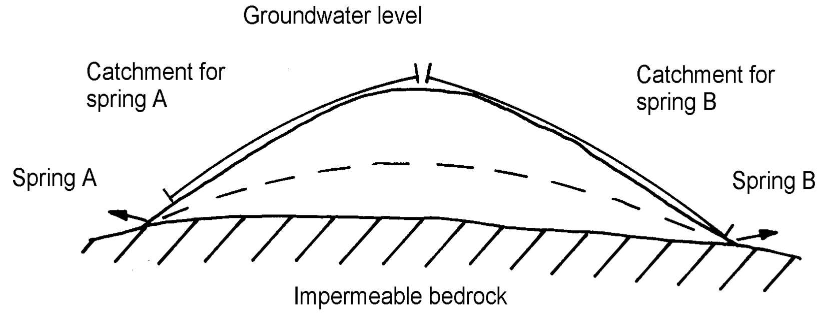


a) Effect on borehole



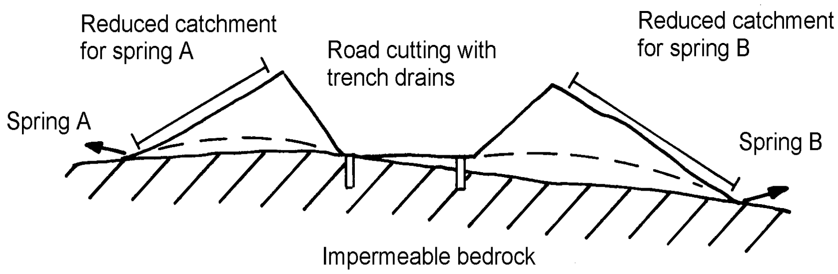
b) Effect on spring

Figure 2: Derogation of groundwater sources



The hill forms an aquifer from which groundwter issues at springs A and B

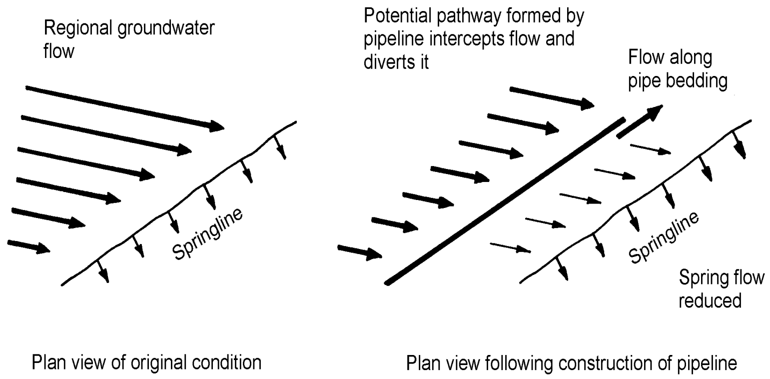
a) Flow to springs prior to construction



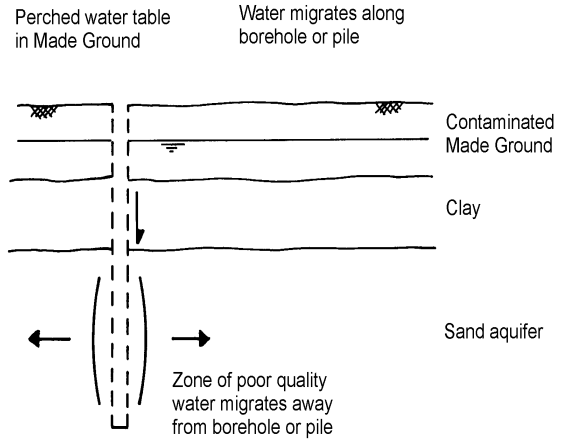
Trench drains installed to keep the road cutting dry form additional discharge points for groundwater. This causes a lowering of groundwater level and reduced flow from springs

b) Reduced flow to springs following construction

Figure 3: Groundwater abstraction from road cutting

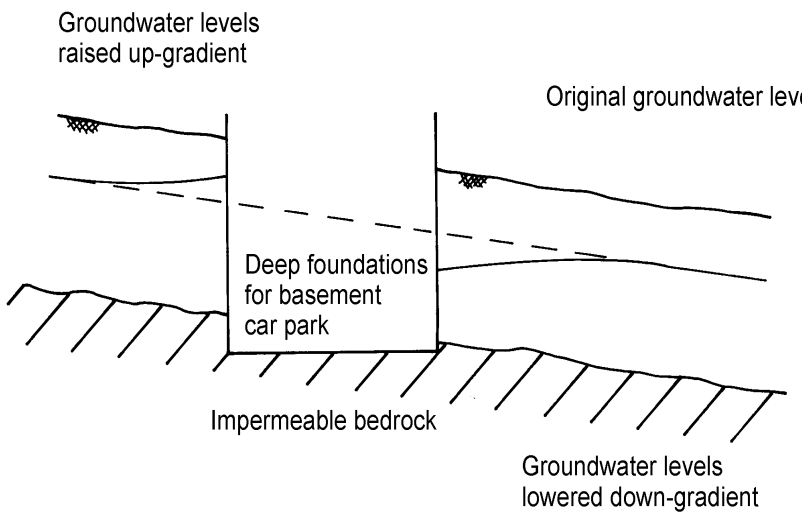


a) Diversion of flow from groundwater source

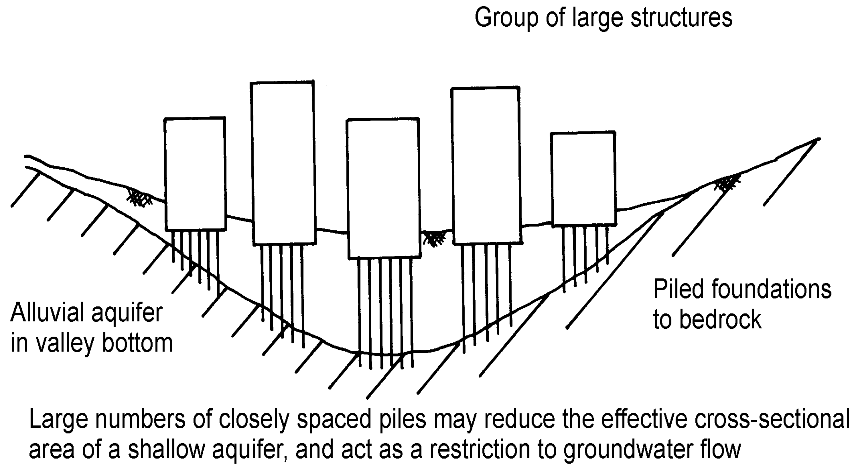


b) Vertical pathways leading to change in groundwater quality

Figure 4: Pathways for groundwater flow



a) Deep foundations



b) Groups of piles

Figure 5: Barriers to groundwater flow created by cut-off walls and piles

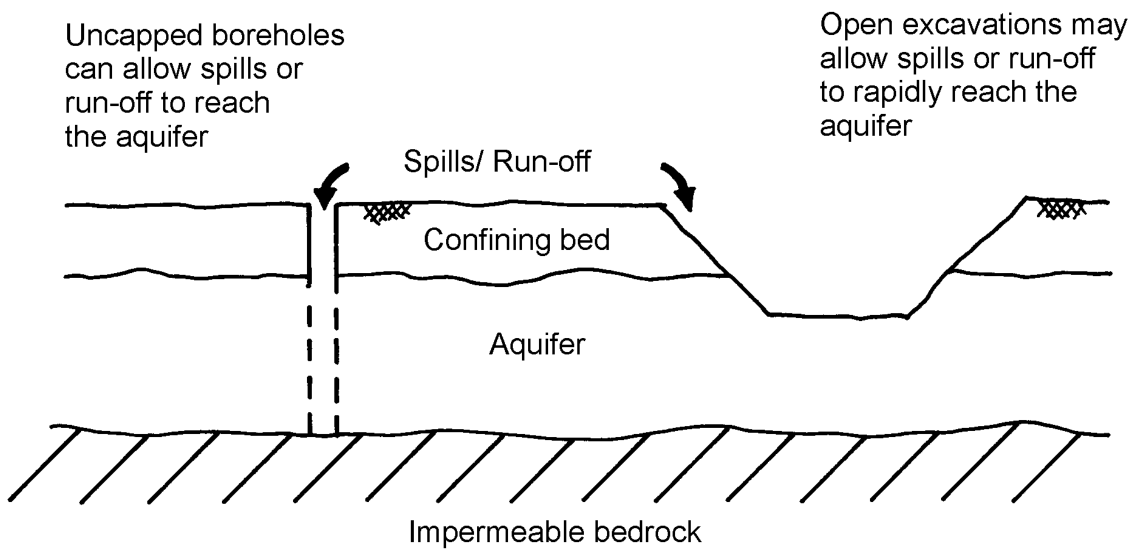


Figure 6: Potentially polluting discharges to groundwater