

'Model' water safety plan for mechanised boreholes

Hazard event	Cause	Risk	Control measure	Critical limits		Monitoring			Corrective action	Verification
				Target	Action	What	When	Who		
Ingress of contaminated surface water directly into borehole	Poor wellhead completion	Unlikely/ Major	Proper wellhead completion measures	1m concrete apron around wellhead; lining extends 30cm above the apron; drainage ditches in place	Lining stops at ground level. Apron damaged or cracked. Ditches full, faulty or absent	Sanitary inspection	Monthly	Operator	Extend lining Repair apron Clean and repair drainage ditches	Sanitary inspection. <i>E.coli</i> Faecal streptococci Bacteriophage
Ingress of contaminants due to poor construction or damage to the lining	Poorly maintained wellhead completion	Moderate/ Major	Proper wellhead completion	Top 5 metres of the annulus sealed Rising main in good condition	Annulus sealed for less than 3 metres. Colour changes Increased pumping required to raise water	Sanitary inspection Water clarity CCTV	Monthly	Operator	Insert seal around annulus. Replace worn and corroded rising mains. Use materials less likely to corrode (e.g. plastics)	Sanitary inspection; analysis of colour, iron and turbidity, CCTV
Borehole area is inundated with contaminated surface water	Lack of diversion ditches	Unlikely/ Major	Good drainage around wellhead	Diversion ditches of adequate size, in good condition and clear of rubbish	Ditch has rubbish or shows signs of wear	Sanitary inspection	Weekly	Operator	Repair and clean ditch Increase size of ditch using	Sanitary inspection
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifers allowing draw-down into deeper aquifer	Almost certain/ Moderate	Control pumping regimes Set intake at depth	No evidence on induced leakage	Evidence of shallow water drawdown (e.g. shallow wells start to dry up)	Colour (appearance) Taste Odour Electric conductivity	Weekly	Operator	Set intake deeper (microbes) Water treatment (microbiol) or blending (chemicals)	<i>E.coli</i> Faecal streptococci Bacteriophages Nitrate Tracer studies Hydrological models
Rapid recharge by rivers, streams and ponds	Hydraulic connection exists between surface water and aquifers	Unlikely/ Major to Catastrophic	Set intake at greater depth	Rapid recharge does not occur or cannot reach intake	Evidence of rapid recharge from surface water bodies	Surface water levels Colour Electric conductivity	Daily	Operator	Set intakes at greater depth or modify pumping regimes	<i>E.coli</i> Faecal streptococci Bacteriophages Pathogen assessments Nitrate
Pumping leads to increased leaching of contaminants	Pumping induces increased leaching of chemicals	Unlikely/ Moderate	Pumping regime	Leaching of contaminants is within predicted range	Evidence of increased leaching of contaminants	Monitoring of key contaminants of concern Hydro-chemical models	Monthly	Operator	Modify pumping regime Treatment	Hydrochemical models Monitoring of contaminants of concern

Pumping increases safe distances beyond current protection zone boundaries	Pumping increases cone of depression extends minimum travel time distance beyond protection zone	Unlikely/ Moderate	Protection zones	Protection zones include influence of drawdown on groundwater flow	Drawdown increases distance equivalent to travel time set	Water table levels surrounding borehole when pumping	Annual	Operator	Extend groundwater protection zone to account of the change in distance	Tracer tests Hydrogeological modelling Tracer tests Analysis of key microbiol and chemical contaminants controlled in protection zones
Back-siphonage from pipe into borehole	No backflow preventer installed	Likely/ Minor	Backflow preventer on mains	Backflow preventer installed	Lack of backflow preventer	Inspect pumping works	Installations Periodic checks	Constructor Operator	Backflow preventer installed	Audit of wellhead and pumping works
Failure in disinfection process	Disinfection process fails	Unlikely/ Major catastrophic	Effective chlorination with contact time	Ct value adequate and residual produced	Lack of residual	Monitoring chlorine dosing and residual	Daily/hourly	Operator	Take pump off-line and repair disinfection unit	Audit of results E.coli Faecal streptococci Bacteriophages
Mobilisation of toxic chemicals and elution of viruses	Changes in land-use and increased recharge through irrigation leads to mobilisation and elution	Rare/ Minor to moderate	Land-use control, in particular managing irrigation	Little artificial recharge through irrigation, pH and Eh of water stable	Significant changes in land-use Increased use of irrigation	Land-use; pH of groundwater Redox (Eh)	Weekly	Operator	Reduce artificial recharge	E.coli Faecal streptococci Bacteriophages Chemicals of concern
Leaching of microbiol contaminants into aquifer	Leaching of faecal material from sanitation, solid waste, drains	Moderate/ Moderate	Protection zones and set-back distances	Lateral separation defined on basis of travel times and hydrogeology	Latrines/sewers built or solid waste dumps within separation distance	Sanitary inspection; inspection of protection zone, electric conductivity, sewer leakage	Monthly	Operator	Remove pollutant sources, improve sanitation design, reduce sewer leakage, insert cut-off walls around sewers	Inspection <i>E.coli</i> Faecal streptococci Bacteriophages Nitrate Chloride Tracer tests
Groundwater contains naturally occurring chemicals	Geological setting means chemicals present at toxic levels	Moderate/ Moderate	Source selection	Use of groundwater with no natural chemical at harmful levels	Evidence of natural contaminants	Risk assessment of geological setting Initial assessment of water quality	Before installation	Constructor	Use alternative source Treatment	Risk assessment Water quality assessment Monitoring of chemicals of concern

Agricultural pollution: nitrate	Use of inorganic or organic fertilisers, stock density	Unlikely/Minor	Protection zone	Nitrate vulnerable zones defined for aquifer prevent excessive leaching	Evidence of increasing nitrate levels	Monitoring of nitrate in groundwater Monitor fertiliser applications Monitor stock densities	Monthly	Supplier Environment agency	Control of fertiliser applications Blending of drinking water	Nitrate levels in groundwater Audit fertiliser applications Audit stock densities
Agricultural pollution: pesticides	Pesticides leached into the groundwater	Unlikely/Minor	Protection zone	Pesticide applications controlled in recharge area	Evidence of increasing pesticides in water Evidence of pesticide application at high-risk locations and times	Monitor pesticide applications	Monthly	Supplier Environment agency	Control of pesticide applications	Pesticide levels in groundwater Audit pesticide applications
Leaching of chemicals from landfill sites into groundwater	Leaching of chemicals from landfills, waste dumps, industrial discharges to ground	Moderate/Minor	Protection zone	Landfills are sanitary and properly sealed Landfill presence controlled on basis of travel times and hydrogeology	Monitoring around pollutant sources indicate increasing pollution migration	Monitor for key contaminants around pollutant sources Monitoring bills of lading	Weekly/daily	Waste Managers Environment agency Supplier	Move pollutant sources, improve pollution containment, monitoring network around pollutant sources	Inspection Analysis of chemical composition of pollution Analysis of water quality Audit bills of lading for composition of waste
Pathogens from hospital wastes contaminate groundwater	Poor disposal of hospital wastes allows direct ingress of leaching into groundwater	Unlikely/Catastrophic	Proper hospital waste disposal	Hospital wastes with pathogenic material incinerated	Hospital waste disposal in dumps or ground containers	Monitor hospital waste disposal methods	Daily	Water supplier Health authorities	Ensure all pathogenic material incinerated or sterilised	Audit of hospital waste disposal
Pollution from urban areas contaminates groundwater	Poorly sealed drains cause recharge of groundwater	Moderate/Minor	Protection zones	Drainage water unable to recharge groundwater	Poorly constructed drains increase potential for recharge	Inspection	Operator	Weekly	Ensure all drains properly sealed in recharge or vulnerable areas	Audit of drainage channel design, construction and maintenance
Industrial discharges contaminated groundwater	Poorly disposed of industrial waste can inundate groundwater source or leach into aquifer	Moderate/Minor	Waste containment and treatment	Effective disposal methods prevent spills and leaching	Waste disposal methods do not provide security against inundation and leaching	Monitor containment methods at industrial sites	Supplier Environment agency	Monthly	Ensure all industrial waste is properly contained and treated at the site	Audit of industrial wastewater treatment plants