PROTOCOL

DELINEATION OF
WELLHEAD PROTECTION AREAS FOR
MUNICIPAL GROUNDWATER SUPPLY WELLS
UNDER DIRECT INFLUENCE OF
SURFACE WATER

Date: October 2001

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for
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for
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I PURPOSE

The purpose of this Protocol is to identify the Ontario Ministry of the Environment requirements regarding delineation of wellhead protection areas around municipal groundwater supply wells where there may be a need for restrictions on certain types of land use and/or introduction of other measures to prevent and manage risks from human activities relating to the use, manufacture, production, storage, and release of biological or chemical contaminants.

II APPLICABILITY

This Protocol only applies to municipal groundwater supply systems where the delineation of wellhead protection areas is a requirement of a condition of a consolidated Certificate of Approval for the water works issued by the Ministry on the basis of the review of the Engineer's Report submitted in accordance with the Drinking Water Protection Regulation (O.Reg. 459/00).

Note: Where on the basis of the review of the Engineer's Report submitted for the groundwater supply system the Ministry suspects that the groundwater supply is under the direct influence of surface water, the conditions of the consolidated Certificates of Approval issued by the Ministry on the basis of the review may include a requirement to undertake a hydrogeological study in accordance with the Ministry document "***Terms of Reference for Hydrogeological Study to Examine Groundwater Sources Potentially under the Direct Influence of Surface Water***".

In all cases where the undertaking of such a hydrogeological study is required by the consolidated Certificate of Approval, the certificate would also require submission of a delineation of the wellhead protection areas prepared in accordance with this Protocol, if the required hydrogeological study concludes that there is a direct influence of surface waters on the groundwater source and further concludes that, despite the direct influence, a requirement for chemically assisted filtration is not warranted, and based on the study's conclusions, the Owner of the works does not wish to provide chemically assisted filtration as part of the necessary improvements to the works.

III GENERAL REQUIREMENTS

1. Delineation of Wellhead Protection Areas - Well Capture Zones

A wellhead protection area (WHPA) must be delineated (mapped) separately for each municipal well and well-field to which the requirement to delineate this area applies. The WHPA represents a surface projection of the entire 3-dimensional capture area from which the water that is pumped from the well or well-field originates.

Each WHPA should be sub-divided into ***well capture zones*** to distinguish among the areas of different potential risks posed to well water quality from various types of microbiological and chemical contaminants that could enter the water table and/or move with the groundwater flow to the well, and to facilitate effective and economical management of those risks.

This variation in the risk potential throughout the WHPA results from the fact that bacteria have a limited life span and an adequate travel time from the point of entrance to the well may effectively inactivate these organisms. Similarly, over time, some chemical contaminants degrade into lower risk compounds or are adsorbed by the geological materials encountered along the flow path. On the other hand, other chemicals are stable in a groundwater setting and the risk from their presence may only be attenuated through dilution along the flow path.

At a minimum, three well capture zones should be delineated for each municipal production well/well field:

1) **Zone 1** : 0 to 2 year saturated travel time (TOT). Land uses in this zone need to be managed to avoid all possible risks, including those from bacteria and viruses.

2) **Zone 2** : 2 to 10 year TOT. The main focus of the land use management in this zone should be to minimize risks from all chemical contaminants, however, the bacterial and viral risks may still be a concern.

3) **Zone 3** : 10 to 25 year TOT / Zone of Contribution. The land use management in this zone needs to address risks from persistent and hazardous contaminants.

In addition, within Zone 1, a 50-day TOT area should be identified to recognize potential risks from day-to-day activities of the water utility itself or other contaminant sources.

The size of well capture zones is influenced by the well pumping rate, aquifer porosity, and hydraulic conductivity. The size and shape of the zones are influenced by hydraulic gradient and flow direction, the orientation and density of fractures/faults and by dissolution features such as in karst geology. The identified capture zones need not extend beyond aquifer flow boundaries. However, they may do so where the existing topographic features or geologic structure can funnel contaminants towards the aquifer flow zone because of the combination of a relatively impermeable geology and a surface slope which is directed towards the aquifer flow zone.

Note: Capture zones in rock aquifers often extend for many kilometres. In such situations, checking residence times by means of water chemistry and isotope analysis can help ensure that time of travel estimates are not excessive (e.g. where the water is thousands of years old, the defined zone of contribution may be overly large).

2. Capture Zone Delineation Methodology

Preferred Method – In the majority of cases, three-dimensional, steady-state computer models should be used to delineate capture zones. When properly set-up and calibrated, these models produce the most realistic time of travel boundaries. It is anticipated that the numerical code that will most frequently be used is MODFLOW. It is necessary to have data regarding well production rate, the aquifer's lateral extent, thickness, hydraulic conductivity and flow gradients. Assumptions made in developing the model and details of model sensitivity analyses must be provided in the final report. It is the only method for accurately delineating capture zones where there is a significant presence of: (1) discrete fractures, (2) anisotropy, (3) spatial variations in hydrogeologic parameters, (4) vertical movement of water and variation in total hydraulic head with depth, and/or (5) changes in water levels seasonally or through time.

Exceptions to the requirement for applying three-dimensional models should only be considered where site-specific conditions suggest that any of the other methods described below is/are more appropriate and justified from a technical standpoint.

Analytical method – Analytical methods use equations to define groundwater flow, and require site-specific estimates of transmissivity, porosity, hydraulic gradient, hydraulic conductivity and saturated aquifer thickness. Flow system mapping using analytical models to estimate time of travel may be sufficient for conservative estimates of capture zones. Two-dimensional wellhead delineation models, such as WHPA and WhAEM, are available free of charge from the U.S. EPA.

Note: Flow system boundaries may include both, physical boundaries (limits of the aquifer and structural features such as fault-block walls, zones of fracturing, and topography), and hydrologic features (rivers, canals, lakes). This method requires detailed mapping of the water table on which flow lines are drawn perpendicular to the water-table elevation lines. Flow system boundaries can also be used with TOT calculations to help ensure that the zone of contribution is not unacceptably large. However, in a fractured-rock aquifer, this is only appropriate if the aquifer acts like a uniform porous medium.

Uniform Flow Method — This method uses the following group of analytical expressions to delineate capture zones:

1) Distance to down-gradient null point:

$$X_L = \mathbf{Q / (2 * \pi * K * b * i)}$$

2) Shape of outer streamline:

$$X = \mathbf{- Y / tan\ [(2 * \pi * K * b * i) / Q * Y\ ]}$$

Where the boundary limit (asymptotic width) of the capture zone:
$Y_L = \pm \mathbf{Q / (2 * K * b * i)}$

Note: The width of the capture zone is extended to the ultimate recharge area and can be made to conform to variability in mapped flow direction.

3) Upgradient distance as a function of time:
$X_t = \mathbf{K * i * (t / n)}$

__Where__:
X = distance along length of capture zone
Y = width of capture zone as a function of "X"
Q = maximum approved pumping rate of the well
K = hydraulic conductivity
b = saturated thickness of screened interval
i = hydraulic gradient
t = saturated travel times for each well capture zone
n = porosity
π = 3.14156....

These formulas can be calculated in a standard spreadsheet and this method is more flexible than standard analytical models since it can conform to variability in flow direction. The disadvantage is that this method generally does not take into account hydrologic boundaries (streams, lakes, etc.), aquifer heterogeneities, and it assumes no recharge. Also, it is limited to two-dimensional analyses of flow systems and capture zone delineation.

Calculated Fixed Radius method – This method, also known as the "cylinder method", is easy to use and is based on simple hydrogeological principles that require limited technical expertise. However, this method tends to overprotect down-gradient and under protect up-gradient areas because it does not account for regional gradients. Unless combined with flow system mapping, this method should not be used for unconfined aquifers or for confined aquifers with a sloping potentiometric surface. Calculated fixed radius capture zones are circular areas whose radius is determined using the formula:

$$\mathbf{r = square\ root\ [(Q * t) / (\pi * b * n)]}$$

__where__: r = radius (distance from well) in metres
Q = maximum approved pumping rate of the well

t = saturated travel times for each well capture zone
b = saturated thickness of screened interval
n = porosity
π = 3.14156...

Note: Where an aquifer characterization study is not being undertaken, the intrinsic susceptibility to contamination of the aquifer(s) supplying water to municipal wells should be assessed to at least 500 metres beyond the limit of capture Zone 3. Intrinsic susceptibility to contamination is to be evaluated by considering the thickness and permeability of the material above the water supply aquifer. The thickness of the overlying formation(s) is important, since any contaminants that are applied, deposited or spilled on or near the ground surface will be less attenuated and will reach an aquifer more quickly where formations are thin. Low permeability surficial soils, composed largely of clay and silt, are generally less likely to transmit significant quantities of contaminants than high permeability soils such as sand and gravel. However, fractures or other openings in an aquitard overlying the aquifer could negate natural protection. Where bedrock is exposed at surface, the ground surface will be considered to be the top of the aquifer since the intrinsic susceptibility to contamination will be highly dependent upon the degree and inter-connectivity of fracturing.

IV PREPARATION OF A REPORT

1. The results of each WHPA delineation analysis shall be compiled in a report which includes a map drawn to scale and showing the groundwater Time-of-Travel (TOT) capture zones. The report should also include the attribute data and documentation regarding the model and assumptions used in the analysis.

2. The report shall be prepared and signed by a qualified hydrogeologist.

3. Questions regarding this Protocol, appropriateness of the planned scope of work, the methods intended to be used in the analysis, and any other pre-submission consultation issues should be directed to an MOE hydrogeologist at the appropriate MOE Regional Office.