Commonwealth of Massachusetts
Executive Office of Environmental Affairs
Department of Environmental Protection

Daniel S. Greenbaum
Commissioner

April 19, 1991

Dear Reader:

These *Standard References for Monitoring Wells*, WSC-310-91, describe the technical requirements for locating, drilling, installing, sampling and decommissioning monitoring wells. *Standard References for Monitoring Wells* was developed to help ensure data used for environmental monitoring purposes is valid and can be interpreted consistently by anyone assessing groundwater, including Department staff, consultants, drillers and firms performing these assessments.

Many people, from within and outside the Department, were involved in developing this technical document. These References represent the Department's current understanding of the art of groundwater monitoring. We welcome any information on innovative field techniques, suggestions for updates, or comments. This document will be updated to reflect new information about emerging technologies as our resources permit.

These References are one of several initiatives the Department is undertaking to provide clear, practical guidance for those affected by Massachusetts environmental regulations. We hope that you find this document a valuable tool.

Very truly Yours,

Daniel S. Greenbaum
Commissioner

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS
WSC–310-91

DEDICATION

This document is dedicated with great affection to Dodie Brownlee. She pioneered hydrogeology in the Department of Environmental Protection. Dodie worked tirelessly to protect and improve our environment.

Dodie Brownlee conceived and developed these ***Standard References for Monitoring Wells****. She worked on them until her death in the spring of 1990.*

May her spirit of commitment and drive for excellence live on through all of us.

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 1.1 FOREWORD

SECTION 1.1 FOREWORD

TABLE OF CONTENTS

SECTION 1.1 FOREWORD

1.1-1 PURPOSE

These Standard References (SRs) covering the technical aspects of locating, drilling, installing, sampling, and decommissioning of monitoring wells have been prepared by the Department of Environmental Protection (DEP) to provide guidance to employees of the Department, consultants, drillers, and members of the regulated community. Monitoring wells may be installed for a variety of reasons including observation of drawdown during a pumping test, determination of groundwater quality, estimation of hydraulic conductivity using permeability tests, determination of ground water flow directions and rates of flow, and monitoring impacts of various activities on the hydraulic head. Some monitoring wells are installed primarily for geochemical monitoring of uncontaminated ground water to serve as baseline data, as well as providing background values against which potential impacts on ground water can be measured. In some cases, chemical sampling is not part of a monitoring program. If ground water chemistry and contaminant characteristics are not matters of concern, then the monitoring well network may be designed with a minimum amount of information, primarily the site geology and hydrology. An in-depth discussion of monitoring well network design can be found in Section 4.1 of these Standard References.

The impetus for writing these SRs came from frequent observations of improperly sited, improperly constructed, and improperly sampled monitoring wells. Such wells do not produce valid data for environmental monitoring purposes. In order to improve the quality of the data collection and of the Department's interpretation of environmental monitoring reports, the writing of these SRs was undertaken.

1.1-2 ORDER OF PRESENTATION

This introductory section contains the full Table of Contents (Section 1.2) and Definitions (Section 1.3). The sections and subsections in the Table of Contents have been assembled in the order in which one typically proceeds when undertaking a hydrogeologic investigation: from site reconnaissance to drilling, to well installation, to ground water sampling. Geophysical techniques, which may be employed during any phase of a site assessment, can be found in a separate section at the end of the document.

It was the authors' decision that each section should be able to stand alone as a reference on a given topic. For that reason, the user will find that this document contains some deliberate redundancies. Cross-references are provided to other sections where a similar subject is discussed.

Most subsections started from a predetermined format: Purpose, Methodology, Problems and Solutions, and References. For editorial simplicity, the figures and tables for each section follow the text rather than being inserted into it. The section on Purpose is designed to present a set of standards to be achieved (i.e., performance standards). The section on Methodology contains some examples of current, acceptable methods for attaining these standards. The methodology does not attempt to be all-encompassing; it seeks to be illustrative. Other techniques which achieve an equivalent degree of compliance with the standard should be equally acceptable.

Each subsection has been assigned its own unique number. Each page within a subsection contains the subsection number, page number, and date. It is anticipated

that this document will be expanded and updated in the future by the addition of new subsection pages with new dates. The figures and tables all carry the subsection designation number plus a figure or table number. They also display a consecutive page number. Perhaps an example will clarify this point: the second figure in Section 7.1 would be numbered Figure 7.1-2; the page number might be 24, and the date January 1991.

A loose-leaf format has been chosen to facilitate updating these SRs. The old page should be removed and discarded. The new insert should replace it. It is anticipated that this system may require the use of pages with suffixes such as 4(a), 4(b), etc., so that the original pagination will not be affected.

1.1-3 DEPARTMENTAL USE OF STANDARD REFERENCES

1.1-3.1 Statement by Division of Water Pollution Control (DWPC)

These SRs can serve as a general reference for hydrogeologic investigation techniques. For more specific guidance on submitting hydrogeologic reports, siting discharge points, and designing monitoring well networks in connection with ground water discharge permits, the reader is directed to the following:

- DWPC Policy Memorandum #GW88-1, "Guidelines for siting disposal areas for wastewater treatment plants," 12/1/88.
- DWPC Policy Memorandum #GW88-2, "Monitoring well plan guidelines," 12/1/88.
- "Guidelines for the design, location, operation and maintenance of small sewage treatment plant facilities with land disposal," second draft, January 1988.

Information concerning these publications or other Divisional policies and issues is available from the Ground Water Section at the Division's Boston Office, 1 Winter Street, Boston, MA 02108.

1.1-3.2 Statement by Division of Water Supply (DWS)

Several programs administered by the Division of Water Supply may utilize observation wells or monitoring wells as a means of obtaining information related to the quantity and/or quality of drinking water supplies within the State. These programs include, but are not limited to, Aquifer Land Acquisition, New Source Approval, Water Management Act Permitting, and Water Supply Contamination Correction. For such programs, the Standard References are applicable as general guidance.

To obtain information regarding specific policies and guidance documents, contact the Division of Water Supply at the Department's Boston office.

1.1-3.3 Statement by Division of Hazardous Waste (DHW)

In 1979, Massachusetts enacted M.G.L. c. 21C, the Hazardous Waste Management Act. This act was intended to be equivalent to Subtitle C of the Resource Conservation and Recovery Act (RCRA) passed by the United States Congress in 1976. In 1982, the DEP promulgated regulations (310 CMR 30.000) to enforce the M.G.L. c. 21C statute. This

enabled the state to obtain from EPA authorization to implement the RCRA hazardous waste management program in the state.

Ground water protection is a key component of RCRA and M.G.L. c. 21C. Under 310 CMR 30.000, ground water monitoring is required at all hazardous waste disposal facilities and may be required at treatment and storage facilities, if there is a threat to the environment. Ground water monitoring, according to the regulations, can be broken down into two main components:

- Detection monitoring (i.e., detecting a release)
- Compliance monitoring (i.e., assessment and corrective action)

The ground water monitoring requirements of 310 CMR 30.663 are equivalent to the federal RCRA requirements of 40 CFR Part 264, Subpart F. Guidance is available from the U.S. EPA on implementing both detection and compliance monitoring programs under 40 CFR Part 264, Subpart F. The RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD, 1986) discusses site characterization, data collection, well construction, and well system design for detecting a release and assessing the rate and extent of its migration.

The RCRA Corrective Action Plan (June 1988) guidance document published by EPA provides a technical framework for implementing a Compliance monitoring program at RCRA-permitted facilities where a release has occurred. It consists of three phases:

(1) RFI - RCRA Facility Investigation (i.e., assessment; data gathering)

(2) CMS - Corrective Measures Study (i.e., selection of remediation alternatives)

(3) CMI - Corrective Measures Implementation (i.e., implementation of the preferred alternative)

The RCRA Corrective Action Interim Measures Guidance (June 1988) supplements the Corrective Action Plan.

EPA REFERENCES

RCRA Ground Water Monitoring Technical Enforcement Guidance Document Final; EPA/OWPE; September 1986.

RCRA Corrective Action Plan; Interim Final; EPA/530 SW-88-029, June 1988.

RCRA Corrective Action Interim Measures Guidance, Interim Final; EPA/530-SW-88-029; June 1988.

1.1-3.4 Statement by Bureau of Waste Site Cleanup (BWSC)

The Bureau of Waste Site Cleanup is responsible for overseeing the assessment and remediation at oil and hazardous material disposal sites. Subsurface exploration is an integral component of such site assessments and for the evaluation of remedial actions.

1.1-3.4.1 The Massachusetts Contingency Plan (310 CMR 40.000)

In site assessment investigations involving disposal sites, the Massachusetts Contingency Plan (MCP) requires that assessments be performed in phases, incorporating an increasing degree of complexity in each phase as more information is collected and analyzed about the specific site condition. It describes the following investigative phases at a site where hazardous materials may be the constituents of concern to public health and the environment:

- Preliminary Assessment (see MCP 40.541).
- Phase I - Limited Site Investigation (see MCP 40.543).
- Phase II - Comprehensive Site Assessment (see MCP 40.545).
- Phase III - Development of Remedial Response Alternatives and the Final Remedial Response Plan (see MCP 40.546).
- Phase IV - Implementation of the Approved Remedial Response Alternative (see MCP 40.547).
- Phase V - Reserved (see MCP 40.548).

1.1-3.4.2 Long-term Monitoring

It is quite probable that long-term monitoring will be required following the termination of remedial actions or upon the closure of a treatment or disposal facility that might have had an adverse effect upon ground water. Monitoring wells will be needed to detect changes in contaminant levels at a site. It is important that both the site hydrogeology and the contaminant chemistry be understood so that the monitoring well network is effective. For some long-term monitoring, where not all of the preliminary steps have been undertaken, it is important that the monitoring wells are installed properly an that the appropriate construction materials are used.

1.1-4 REVISION AND SUGGESTIONS

This document represents Department of Environmental Protection's current understanding of the art of ground water monitoring. These References will be periodically reviewed by the DEP, and as new techniques are developed and new theories proposed, they will be updated in the light of emerging technologies and revised as appropriate.

The agency invites comments and suggestions related to format, usefulness, and substance. Information on innovative field techniques and suggested updates may be submitted at any time. This information should be sent to:

Department of Environmental Protection
Bureau of Waste Site Cleanup; Policy Branch
One Winter Street, 7th Floor
Boston, MA 02108

ADDITIONAL REFERENCES

Driscoll, F.F., 1986, Groundwater and wells, 2nd edition: St. Paul, MN, Johnson Division, 1089 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, NJ, Prentice-Hall, Inc., 604 p.

Journals

Ground Water Monitoring Review: published quarterly by the National Water Well Association, 6375 Riverside Drive, Dublin, Ohio 43107.

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 1.2 TABLE OF CONTENTS

SECTION 1.2 TABLE OF CONTENTS

SECTION 1.1 FOREWORD

TABLE OF CONTENTS

SECTION 2.1
RECONNAISSANCE SURVEYS

TABLE OF CONTENTS

SECTION 2.1
RECONNAISSANCE SURVEYS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

SECTION 2.2
WORK AND COST PLANS (RESERVED)

SECTION 2.3
HEALTH AND SAFETY PLANS

TABLE OF CONTENTS

SECTION 2.3
HEALTH AND SAFETY PLANS

APPENDICES

SECTION 2.3
HEALTH AND SAFETY PLANS

LIST OF FIGURES

LIST OF TABLES

SECTION 3.1
EXPLORATORY TEST PITS

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 3.2
DRILLING TECHNIQUES

TABLE OF CONTENTS

SECTION 3.2
DRILLING TECHNIQUES

LIST OF FIGURES

SECTION 3.2
DRILLING TECHNIQUES

LIST OF TABLES

APPENDICES

SECTION 3.3
BORINGS IN CONTAMINATED AREAS

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 3.4
IN-SITU SAMPLING OF SOIL

TABLE OF CONTENTS

SECTION 3.4
IN-SITU SAMPLING OF SOIL

TABLE OF CONTENTS
(continued)

SECTION 3.4
IN-SITU SAMPLING OF SOIL

TABLE OF CONTENTS
(continued)

SECTION 3.4
IN-SITU SAMPLING OF SOIL

LIST OF FIGURES

LIST OF TABLES

SECTION 3.5
SOIL CLASSIFICATION

TABLE OF CONTENTS

SECTION 3.5
SOIL CLASSIFICATION

LIST OF FIGURES

LIST OF TABLES

SECTION 3.6
IN-SITU SAMPLING OF ROCK

TABLE OF CONTENTS

SECTION 3.6
IN-SITU SAMPLING OF ROCK

LIST OF FIGURES

LIST OF TABLES

SECTION 3.7
ROCK CLASSIFICATION

TABLE OF CONTENTS

SECTION 3.7
ROCK CLASSIFICATION

TABLE OF CONTENTS
(continued)

LIST OF FIGURES

LIST OF APPENDICES

SECTION 3.8
LABORATORY TESTS FOR SOIL

TABLE OF CONTENTS

SECTION 3.8
LABORATORY TESTS FOR SOIL AND ROCK
(continued)

TABLE OF CONTENTS

SECTION 3.8
LABORATORY TESTS FOR SOIL AND ROCK

LIST OF TABLES

SECTION 3.9
PLUGGING BOREHOLES

TABLE OF CONTENTS

SECTION 4.1
MONITORING WELL NETWORK DESIGN

TABLE OF CONTENTS

SECTION 4.1
MONITORING WELL NETWORK DESIGN

TABLE OF CONTENTS
(continued)

SECTION 4.1
MONITERING WELL NETWORK DESIGN

LIST OF FIGURES

SECTION 4.2
SELECTION OF WELL CONSTRUCTION MATERIALS

TABLE OF CONTENTS

SECTION 4.2
SELECTION OF WELL CONSTRUCTION MATERIALS

TABLE OF CONTENTS
(continued)

SECTION 4.2
SELECTION OF WELL CONSTRUCTION MATERIALS

LIST OF FIGURES

LIST OF TABLES

SECTION 4.3
WELL INSTALLATION PROCEDURES

TABLE OF CONTENTS

SECTION 4.3
WELL INSTALLATION PROCEDURES

TABLE OF CONTENTS
(continued)

SECTION 4.3
WELL INSTALLATION PROCEDURES

LIST OF FIGURES

LIST OF TABLES

SECTION 4.4
AS-BUILT NOTES AND RECORDS

TABLE OF CONTENTS

SECTION 4.4
AS-BUILT RECORDS AND NOTES

LIST OF FIGURES

APPENDICES

SECTION 4.5
WELL DEVELOPMENT

TABLE OF CONTENTS

SECTION 4.5
WELL DEVELOPMENT

LIST OF FIGURES

SECTION 4.6
DECOMMISSIONING OF MONITORING WELLS

TABLE OF CONTENTS

SECTION 4.6
DECOMMISSIONING OF MONITORING WELLS

LIST OF FIGURES

SECTION 5.1
WATER-LEVEL MEASUREMENTS

TABLE OF CONTENTS

SECTION 5.1
WATER-LEVEL MEASUREMENTS

LIST OF FIGURES

SECTION 5.2
IN-SITU HYDRAULIC CONDUCTIVITY TESTS

TABLE OF CONTENTS

SECTION 5.2
IN-SITU HYDRAULIC CONDUCTIVITY TESTS

TABLE OF CONTENTS
(continued)

SECTION 5.2
IN-SITU HYDRAULIC CONDUCTIVITY TESTS

LIST OF FIGURES

LIST OF TABLES

SECTION 5.3 PUMPING TESTS

TABLE OF CONTENTS

SECTION 5.3 PUMPING TESTS

TABLE OF CONTENTS
(continued)

SECTION 5.3 PUMPING TESTS

LIST OF FIGURES

SECTION 5.3 PUMPING TESTS

LIST OF TABLES

APPENDICES

LIST OF APPENDICES FIGURES

SECTION 5.4 PACKER TESTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 5.5
SURVEYING AND DATUM PLANES

TABLE OF CONTENTS

SECTION 6.1
QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

TABLE OF CONTENTS

APPENDIX

SECTION 6.2
SAMPLING TECHNIQUES

TABLE OF CONTENTS

SECTION 6.2
SAMPLING TECHNIQUES

LIST OF FIGURES

SECTION 6.3
SAMPLE HANDLING

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 6.3
SAMPLE HANDLING

LIST OF TABLES

SECTION 6.4
CHAIN-OF-CUSTODY

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 6.5
DECONTAMINATION OF SAMPLING EQUIPMENT

TABLE OF CONTENTS

SECTION 7.0
GROUNDWATER MODELING
TABLE OF CONTENTS

SECTION 7.0
GROUNDWATER MODELING

TABLE OF CONTENTS (continued)

SECTION 7.0
GROUNDWATER MODELING

LIST OF FIGURES

LIST OF TABLES

SECTION 8.1
INTRODUCTION

TABLE OF CONTENTS

SECTION 8.2
SYNOPSIS OF GEOPHYSICAL INVESTIGATION METHODS

TABLE OF CONTENTS

SECTION 8.2
SYNOPSIS OF GEOPHYSICAL INVESTIGATION METHODS

TABLE OF CONTENTS
(continued)

LIST OF FIGURES

SECTION 8.3
BOREHOLE GEOPHYSICAL METHODS

TABLE OF CONTENTS

SECTION 8.3
BOREHOLE GEOPHYSICAL METHODS

TABLE OF CONTENTS (continued)

SECTION 8.3
BOREHOLE GEOPHYSICAL METHODS

TABLE OF CONTENTS (continued)

SECTION 8.3
BOREHOLE GEOPHYSICAL METHODS

LIST OF FIGURES

SECTION 8.3
BOREHOLE GEOPHYSICS

LIST OF TABLES

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 1.3 DEFINITIONS

SECTION 1.3 DEFINITIONS

Abandoned well - a well whose use has been permanently discontinued; as used in these References it includes a monitoring well, piezometer, or observation well that is no longer suitable for use either for water-level measurements or water quality sampling.

Annular space - see Annulus.

Annulus - the open space between the exterior or the outermost well casing and/or well screen and the wall of the drilled hole, or the space between two or more concentric casings; also, Annular space.

Aquifer - a geologic formation, group of formations, or part of a formation (consolidated or unconsolidated) that contains sufficient saturated permeable material to yield significant quantities of water to wells or springs.

Aquifer, artesian - see Aquifer, confined.

Aquifer, confined - an aquifer saturated with water and bounded above and below by material having a distinctly lower hydraulic conductivity than the aquifer itself.

Aquifer, unconfined - an aquifer partially saturated with water that has no upper confining layer and where the water table is free to rise and fall.

Aquifer test - a test involving the withdrawal or addition of measured quantities of water from or to a well and the measurement of resulting changes in head in the aquifer, both during and after the period of withdrawal or addition. These tests include pumping tests and in-situ permeability tests.

Area of diversion - see Contributing area.

Area of influence - the land that directly overlies and has the same horizontal extent as the part of the water table or other potentiometric surface that is perceptibly lowered or raised by the withdrawal or addition of water. Under pumping conditions, the water in a fully penetrating well ideally flows in from all directions, forming an imaginary cylinder centered about the well and extending throughout the aquifer thickness. This flow pattern applies to both confined and unconfined aquifers. The area of influence, however, is rarely circular in plan view. The size and shape of the area of influence is affected by the slope of the pre-pumping water table or potentiometric surface, by the pumping rate, and by the hydraulic conductivity of the aquifer.

Artesian - synonymous with Confined.

Bentonite - a naturally occurring highly plastic, expansive clay. It is composed largely of the mineral sodium montmorillonite.

Bit - a cutting tool attached to the bottom of the drill stem.

Bridge - an obstruction in the drill hole or annulus, usually formed by caving of the wall of the well bore, by the intrusion of a large boulder, or by improperly placed seals or filter pack materials during well installation. Bridging can also occur in the formation during well development.

Capillary fringe - the zone immediately above the water table where the pressure is less than atmospheric and where all or some of the pore spaces are filled with water.

Capture - the combination of artificially decreasing or increasing water derived from an aquifer that results in a decrease from an aquifer that results in a decrease in the storage of that aquifer.

Capture zone - see Zone of contribution.

Casing - an impervious durable pipe, generally of plastic or metal, installed in a borehole to maintain an opening for the well and to prevent the borehole walls from caving in and closing off the well. Casing may be either temporary or permanent.

Casing, inner - any of the casing rings installed within the outermost casing where casing has been installed as a series of concentric rings.

Casing, outer - the outermost ring adjacent to the borehole wall where casing has been installed as a series of concentric rings.

Cone of depression - the geometric solid that fills the space between the position of the water table or other potentiometric surface after a well has begun discharging and the hypothetical position that the water table or other potentiometric surface would have had if there had been no discharge by the well. For a given aquifer, the cone of depression increases in depth and extent with increasing time until a steady state condition is reached.

Confined aquifer - see Aquifer, confined.

Confining bed - a body of material stratigraphically adjacent to one or more aquifers that has a distinctly lower hydraulic conductivity than the aquifer material.

Contributing area - the land area that has the same horizontal extent as that part of an aquifer, or adjacent areas, from which ground water flow is diverted to the pumping well. The contributing area for a pumping well can be visualized as a two-dimensional area on the land surface. The contributing area and area of influence are not necessarily identical; these areas can be the same only under the hypothetical circumstances where the pre-pumping water table is perfectly flat and all aquifer properties are uniform within the area of influence. When the pre-pumping water table has a hydraulic gradient, as it does under most natural conditions, the contributing area to the well will be distorted to extend to a greater distance on the upgradient side and to a lesser distance on the downgradient side; also, Area of diversion.

Decommission - to plug an abandoned well so that it will not serve as a conduit for movement of water to or from the well or between water-bearing zones; often preceded by cleaning a well, ripping or removing well casing if necessary and/or practical. See plug, plugging

Department - the Massachusetts Department of Environmental Protection (DEP).

Development - see Well development.

Dig-Safe - a company set up by gas and electric utilities that should be contacted to determine the location of underground utilities in public right-of-way (in MA: 1-800-322-4844, in ME, NH, VT: 1-800-225-4977). Dig-safe requires at least three days notice and may or may not trace lines across private property.

Drawdown - the effect of lowering a water table or other potentiometric surface a vertical distance with respect to its initial position; it is caused by pumping water from an aquifer.

Drilling fluid - a water- or air-based fluid used in the well drilling operation to remove cuttings from the hole, clean and cool the bit, reduce friction between the drill string and the sides of the hole, or seal the sides of an uncased borehole.

Filter pack - the smooth, uniform, silt-free, well-rounded, and usually siliceous sand or gravel placed in the annulus of a well between the borehole wall and the well screen or intake zone in order to facilitate flow toward the well intake and to prevent formation material from entering or clogging the screen; also, Gravel pack or Formation stabilizer.

Formation - a unit of consolidated or unconsolidated material that has distinct lithological characteristics.

Formation stabilizer - see Filter pack.

Gravel pack - see Filter pack.

Ground water - water occurring beneath the ground surface in the saturated zone.

Ground water divide - a hypothetical vertical boundary across which ground water flow does not occur; ground water gradients on both sides of the boundary result in ground water flow away from the divide.

Ground water contour - a line connecting points of equal hydraulic head, based on the elevation of the water surface in wells screened at approximately the same elevation (mean sea level) with screens approximately the same length.

Grout - a thick fluid mixture of neat cement and water of a consistency that can be forced through a pipe and placed at a required depth or zone in a monitoring well. Various additives, such as sand, bentonite, and hydrated lime, may be in the mixture to meet certain requirements.

Grouting - the operation by which grout is placed as a permanent seal between the outer casing and the sides of the borehole or in the openings between concentric rings of inner casing or in the opening between an inner and outer casing; also, as used in these References, the act of sealing, or plugging, a decommissioned monitoring well, observation well, or piezometer.

Head, hydraulic (h) - the height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point. The hydraulic head is the sum of the elevation head (h_e) and the pressure head (h_p); that is, $h = h_e + h_p$. Head, when used alone, is understood to mean hydraulic head. The head is proportional to the fluid potential; therefore the head is a measure of the potential. Head has the units of length.

Hydraulic conductivity (K) - the rate at which a homogeneous fluid at the existing kinematic viscosity will move in a unit of time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow through an isotropic, porous medium. Hydraulic conductivity has the units of length/time (L/T).

Hydraulic gradient - the change in hydraulic head per unit of distance in a given direction. It provides the driving force for groundwater movement and it has horizontal and vertical components. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head. Hydraulic gradient has the units of length/length (L/L). It is estimated by taking the difference between two points (along the flow path) and dividing by the distance between the points.

Infiltration - the flow of water or other fluids downward from the ground surface through the unsaturated zone.

Monitoring well - see Well, monitoring.

Observation well - see Well, observation.

Organic vapor analyzer - a portable instrument designed to determine the presence and relative concentration of volatile organic vapors. Common detection methods include photoionization (PID) and flame ionization (FID). NOTE: The use of this terminology refers to a generic class of portable instrumentation and should not be construed as an endorsement of specific brands or trade names of equipment.

Overburden - the unconsolidated material overlying bedrock, such as clay, silt, sand and gravel, either transported or formed in place. Overburden can be either native, imported fill, or material that has been reworked in place; also, Unconsolidated formation.

Phreatic zone - see Zone, saturated.

Permeability (intrinsic permeability) (k) - a measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient. It is a property of the medium alone that is dependent upon the size and shape of its pores and is independent

of the nature of the liquid and of the force field causing movement. Permeability has the units of length squared (L).

Piezometer - a small-diameter well designed to measure the hydraulic head (water level elevation) at a specific point in the saturated zone beneath the ground surface. A piezometer has a short screen that is positioned entirely within the saturated zone of an unconfined or confined aquifer.

Plug, plugging - the proper closure of an abandoned well or boring by procedures that will permanently seal the well from the aquifer and from contamination by surface drainage; where the well penetrates multiple or confined aquifers, it will permanently seal off and prevent flow between aquifers.

Pollution - alteration of the chemical, physical, biological, or radiological integrity of the environment.

Porosity (n) - the ratio of the volume of total void space to the total volume of a rock or unconsolidated deposit. It may be expressed as a decimal fraction or as a percentage. The units of porosity are dimensionless.

Porosity, effective (n_e) - the amount of interconnected pore space available for fluid transmission in a rock or unconsolidated deposit, expressed as a percentage of the total volume occupied by the interconnecting interstices. When used alone in this document, porosity refers to effective porosity.

Potentiometric surface - as used in this document, a hypothetical surface representing the hydraulic head of ground water in either a confined or an unconfined aquifer at a particular elevation in the aquifer; synonymous with piezometric surface.

Private water supply well - see Well, domestic water.

Pump test (pumping test) - a test conducted to determine aquifer or well characteristics and properties; see Aquifer test.

Quick condition - a condition of soil in which an increase in pore-water pressure decreases particle-to-particle attraction and reduces significantly the soil's shear strength; also, Liquefaction.

Radius of influence - the horizontal distance between a pumping well and the outer limit of the cone of depression.

Refusal - a condition that occurs when drilling or excavating equipment is unable to penetrate the ground a substantial distance in a reasonable period of time. In glaciated regions, unless there is supporting visual or geophysical evidence, it is often difficult to determine whether refusal has taken place at the bedrock interface or at a glacial erratic. Refusal is dependent upon the size and strength of the equipment used.

Saturated zone - see Zone, saturated.

Screen - see Well Screen

Seal, annular - the watertight materials placed in the drill hole between an outer casing and the borehole wall, between an inner casing and an outer casing, or between two or more inner casings, to prevent the inflow and movement of surface water or ground water into the annulus, or to prevent the outflow or movement of water under artesian or hydrostatic pressures through the annulus.

Seal, divider - a layer of bentonite or other impervious material placed on top of the filter pack and below the annular seal.

Seal, surface - the materials placed in the top four feet of the annular space that are designed to prevent the infiltration of surface water into the annular space. If an above-ground protective casing is installed, the surface seal is mounded at the land surface to conduct surface water runoff away from the well.

Sieve analysis - the determination of the dry particle-size distribution of a soil, sediment, or rock by measuring the percentage (by weight) of the particles that will pass through or be retained on standard sieves with openings of various sizes.

Specific discharge (q) - the rate of discharge of ground water per unit area measured at right angles to the direction of flow. Specific discharge has the dimensions of velocity (L/T), as follows:

$$q = \frac{Q}{A}$$

where Q equals total discharge, or total flux, through area A. Specific discharge is a precise term and is preferred to terms involving "velocity" because of possible confusion with actual fluid velocity through the pore space.

Specific Retention - is the ratio of the volume of water which the rock or soil, after being saturated, will retain against the pull of gravity to the volume of the rock or soil.

Specific yield (S_y) - a change in storage per unit area of unconfined aquifer as the result of a unit change in head. It is equal to porosity minus specific retention. The units of specific yield are dimensionless.

Static water level - the level of water in a well that is not being influenced by the addition or withdrawal of water into the aquifer.

Storage coefficient (S) - the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In a confined water body, the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer. In an unconfined water body, the amount of water derived from or added to the aquifer by

the processes of expansion and contraction is negligible compared to that involved in gravity drainage or filling of pores; hence, in an unconfined water body, the storage coefficient is virtually equal to the specific yield.

Test hole - a drilled borehole used solely for geotechnical or geological purposes; also, Test boring.

Test pit - any excavation made with a shovel or a backhoe for the purpose of visually examining the characteristics of subsurface formations; due to the large volume of disturbed soil in a test pit, it should not be used as a location for a monitoring well.

Transmissivity (T) - the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths. The units of transmissivity are length squared divided by time (L/T).

Tremie pipe - a device, usually a small diameter pipe, that carries grout, bentonite pellets or gravel pack materials to the bottom of a borehole and allows pressure grouting or gravel packing from the bottom up without introduction of appreciable air pockets or bridging.

Uncased test hole - a test hole from which casing has been removed or in which casing has not been installed.

Unconfined aquifer - see Aquifer, unconfined.

Unconsolidated formation - the unlithified geologic materials or deposits such as sand, gravel, clay, and till overlying bedrock, either transported or formed in place; also, Overburden.

Unsaturated zone - see Zone, unsaturated.

Vadose zone - see Zone, unsaturated.

Velocity, average interstitial - (Av. v_i) - the average volume rate of flow of a fluid through the pore spaces. Average interstitial velocity has the units of length/time (L/T).

Water table - the upper surface of an unconfined aquifer at atmospheric pressure. It is defined by the levels at which water stands in wells that penetrate the saturated zone just far enough to hold standing water. In wells which penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of ground water flow exists; also, Potentiometric surface.

Water table aquifer - see Aquifer, unconfined.

Well - a hole drilled or driven into the ground, capable of withdrawing water from the aquifer (1) to provide water for human consumption or other beneficial uses, (2) to obtain geologic information about an aquifer, (3) to monitor the quality or quantity of water, (4) to obtain ground water samples, or (5) to utilize the geothermal properties of earth formations.

Well, abandoned - see Abandoned well.

Well, artesian - a well deriving its water from a confined aquifer. The water level in the well stands above the top of the confined aquifer it taps. This term applies to both flowing and non-flowing wells. (In this document the term is not given a second meaning, used by well drillers, referring to any well terminating in bedrock.)

Well, dewatering - a well constructed for the purpose of lowering the ground water surface, either temporarily or permanently.

Well, domestic water - a water well providing water for human use from other than a public water supply system; a well for the watering of livestock, poultry, farm and domestic animals used in operating a farm; a well for the irrigation of small gardens or farms.

Well, monitoring - a cased well installed for the purpose of obtaining representative samples of ground water for water quality analysis, monitoring for the possible presence of contaminants, or taking water level measurements.

Well, observation - a cased well installed for the purpose of monitoring water levels.

Well, open hole - a well formed by drilling a hole into consolidated rock formations, such as granite or sandstone, and finished with no casing or screen opposite the water-yielding portion of the aquifer.

Well, public water supply - a well that is part of a system for the provision to the public of piped water for human consumption, that has at least fifteen (15) service connections or regularly serves an average of at least twenty-five (25) individuals daily at least sixty (60) days of the year (310 CMR 22.00).

Well, recovery - a well designed to control and hydraulically capture separate phase liquids or ground water containing dissolved contaminants.

Well development - the act of mitigating the effects of alteration to the geologic formation caused by drilling and well installation procedures (e.g., smearing or skim coating the borehole walls, bridging of the natural formation or filter pack, or introduction of water or other fluids not originally derived from the aquifer being developed), and increasing the porosity and permeability of the materials surrounding the intake portion of the monitoring well to ensure hydraulic communication with the aquifer.

Well driller - a person engaged in the business of drilling or driving wells; said driller must be currently registered with the Water Resources Division, Department of Environmental Management, Executive Office of Environmental Affairs, Commonwealth of Massachusetts.

Well operator - a person who undertakes to maintain, use, and/or monitor a well; the term describes a person who does not own the land on which a specific well has been installed.

Well owner - a person who owns the land used for any purpose on which a well has been installed. The well owner is responsible for maintaining the well in good condition and decommissioning it when it is no longer used (i.e., becomes an abandoned well). A well owner may also be the well operator of a different or another well located on land that he does not own.

Well point - a well screen device, equipped with a point at one end, that is meant to be driven into the ground until it reaches the saturated zone.

Well screen - the intake section of a well that obtains water from an aquifer and serves as a filtering device to keep sediment from entering a water well.

Zone, saturated - that part of the water-bearing material in which ideally all voids, large and small, are filled with water under pressure greater than atmospheric; also, Phreatic zone.

Zone, unsaturated - the zone between the land surface and the water table. It includes the capillary fringe. Characteristically, this zone contains liquid water under less than atmospheric pressure, and water vapor and air or other gases generally at atmospheric pressure. Perched water bodies may exist within the unsaturated zone; also, Vadose zone and Zone of aeration.

Zone I - the protective radius required around a public water supply well or wellfield (310 CMR 22.00).

Zone II - that area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated (180 days of pumping at safe yield, with no recharge from precipitation). It is bounded by the ground water divides that result from pumping the well, and by the contact of the aquifer with less permeable materials such as till or bedrock. In some cases streams or lakes may act as recharge boundaries. In all cases, Zone II shall extend upgradient to its point of intersection with prevailing hydrogeological boundaries (a groundwater flow divide, a contact with till or bedrock, or a recharge boundary) (310 CMR 22.00).

Zone III - that land area beyond the area of Zone II from which surface water and ground water drain into Zone II. The surface water drainage divides as determined by topography will be used to delineate Zone II. In some locations, where surface and ground water are not coincident, Zone III shall consist of both the surface drainage and the ground water drainage areas (310 CMR 22.00).

Zone of contribution - the three-dimensional volumetric portion of an aquifer from which ground water flow is diverted to a pumping well; also, Capture zone and Zone of diversion.

Zone of diversion - see Zone of contribution.