HYDROGEOLOGY REPORT GUIDELINES

First Edition
June 2005

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ACKNOWLEDGEMENTS

These guidelines were prepared by the Oregon Registered Geologists who volunteered their time as the Hydrogeology Task Force. The Task Force was authorized by the Oregon State Board of Geologist Examiners (Board) in early 2003, and was charged with development of these guidelines. A broader group of Oregon Registered Geologists reviewed the first draft and provided comments in winter 2005. These guidelines were adopted by unanimous Board vote on June 10, 2005. For development of the initial draft, the Hydrogeology Task Force included:

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AUTHORITY OF THE OREGON STATE BOARD OF GEOLOGIST EXAMINERS

In the State of Oregon, the Oregon State Board of Geologist Examiners (Board) is charged with regulating the practice of geology. Geology is defined in Oregon Revised Statute (ORS) 672.505(6) as "that science which treats of the earth in general; investigation of the earth's crust and the rocks and other materials which compose it; and the applied science of utilizing knowledge of the earth and its constituent rocks, minerals, liquids, gases, and other materials for the benefit of mankind". Hydrogeology is the branch of geology that deals with subsurface waters (groundwater) and the related aspects of surface water.

The mission of the Board of Geologist Examiners is to help assure the safety, health, and welfare of Oregonians with regard to the public practice of geology through:

- Licensing of those engaged in the public practice of geology;
- Response to complaints from the public and members of the profession;
- Public education directed at appropriate regulatory communities;
- Cooperation with closely related Boards and Commissions;
- Attention to ethics; and
- Systematic outreach to counties, cities, and registrants.

The Board has a responsibility to maintain compliance with Oregon laws and rules related to the practice of geology by Registered Geologists and non-registrants, in accordance with Oregon Administrative Rules (OAR) 809.055.000(2). The quality of hydrogeology work and reports prepared for similar sites or projects has varied widely. A hydrogeology report is the manifestation of the work performed. A reference guideline has not been available against which the Board could specifically assess hydrogeology work products. Thus, the Board presents this Hydrogeology Report Guidelines as a tool for preparing and evaluating hydrogeology work and reports prepared as part of the public practice of geology in Oregon.

GUIDELINES PURPOSE

The purpose of these guidelines is to encourage best practices in the field of hydrogeology in Oregon. Such best practices optimize and support protection of Oregonians and their interests, as mandated by Oregon Revised Statute (ORS) 672.505(7), which states that the public practice of geology, and thus hydrogeology, includes "consultation, investigation, surveys, evaluation, planning, mapping, and inspection of geological work, in which the performance is related to public welfare or safeguarding of life, health, property and the environment…"

The objectives of these guidelines are two-fold: to assist generators of hydrogeology reports in producing a work product that meets a generally accepted minimum industry standard, and provides a guideline for the Board to use in reviewing hydrogeology reports during the usual business of the Board.

Background

It is the Board's charge to regulate the practice of geology and hydrogeology in Oregon. In recent years, the Board has been obligated to respond to complaints of substandard hydrogeology reports prepared by registrants and non-registrants. This tool was developed to provide a minimum guideline by which the Board compares hydrogeology reports through complaint evaluations, regardless of whether such reports have met a minimum guideline established by county or local government, or other agencies in Oregon.

Guidelines Scope

These guidelines propose recommended contents and suggested formats for geologic reports involving groundwater issues in Oregon, and attempts to incorporate the major topics normally encountered in such studies. This document does not include a theoretical or technical background to each area of hydrogeology. Possession of the technical proficiencies required to prepare the reports is the responsibility of the registrant author, and the technical practice of hydrogeology in Oregon is regulated by the Board as part of the public practice of geology (ORS) 672.505(7). The suggested contents presume that a hydrogeology report is prepared as a stand-alone document. Therefore, the purpose of these guidelines is to protect the public from substandard geology work in the form of poorly documented reports. The objectives of these guidelines are to:

- Provide a basis for the Board to use in reviewing complaints involving hydrogeology reports or work that involves the public practice of geology that include hydrogeology;
- Establish minimum thresholds for hydrogeologic work to protect the consumer public from poor practices, that may include inaccurate results, unfounded recommendations, and poor design of facilities or programs, which may adversely affect a wide variety of people; and
- Most importantly, protect the citizens of Oregon from the potential results of poor hydrogeologic work that may include depletion, contamination, or misuse of Oregon's groundwater resources.

HOW THE BOARD WILL USE THESE GUIDELINES

During evaluation of reports or complaints, the Board will consider the guidelines as providing the basic information required for producing a hydrogeologic report. The guidelines will be available to Oregon's Registered Geologists as a reference for producing hydrogeologic reports. The guidelines will be available for the general public to use as a reference when considering hydrogeologic reports submitted as part of contracted work by a Registered Geologist.

OREGON WATER LAWS AND RULES

In Oregon, groundwater belongs to the State. It is managed as a perpetual resource, and most of its uses require issuance of a State-authorized water right. Some limited uses, such as domestic, or stock watering, are exempt from filing for a water right but are not exempt from regulation (ORS 537.545). State regulation of groundwater is managed through the authority of three agencies:

- The Oregon Water Resources Department (OWRD) regulates and manages the quantity of groundwater resources of the State. OWRD also regulates well construction by licensing well constructors and adopting well construction standards (www.wrd.state.or.us).
- The Oregon Department of Environmental Quality (DEQ) regulates the groundwater quality of the state (www.deq.state.or.us).

- The Department of Human Services - Health Division (OHD) regulates the quality of groundwater used for human consumption (www.ohd.hr.state.or.us).

There is some overlap between the statutory responsibilities of these agencies. When preparing hydrogeology reports, it is the author's responsibility to comply with applicable reporting regulations or criteria mandated by the authority of these three State agencies.

Regulatory agency requirements take precedence over other purposes, where the protection of human health, property, and the environment are at stake. It is not intended that these guidelines replace any regulatory guidelines, but rather, it should be used to support or augment the standards, quality minimums, and/or contents required by those other guidelines.

These guidelines are to be used to supplement regulatory guidelines applicable to a site or project. Further, these guidelines are not to be construed as an enforceable standard.

Oregon Water Resources Department

Oregon Administrative Rules specify how Oregon laws are implemented. Rules pertaining to groundwater management (OAR 690) include:

- Division 8 - Statutory Ground Water Terms;
- Division 9 - Ground Water Interference with Surface Water;
- Division 200 to 240 - Well Construction and Maintenance;
- Division 350 Artificial Recharge of Groundwater and Aquifer Storage and Recovery;
- Division 410 Statewide Water Resources Management; and
- Division 500 - Basin Programs.

The hydrogeology report writer should be familiar with applicable Oregon water law. Oregon water law (ORS 537) is based on the prior appropriation doctrine, or "the first in time is the first in right". The following portions of law describe groundwater management in Oregon:

- Beneficial use without waste, within the capacity of available sources, should be the basis, measure, and extent of the right to appropriate groundwater.
- Adequate and safe supplies of groundwater for human consumption should be assured, while conserving maximum supplies of groundwater for agricultural, commercial, industrial, thermal, recreational, and other beneficial uses.
- Reasonably stable groundwater levels should be determined and maintained.
- Depletion of groundwater supplies below economic levels, impairment of natural quality of groundwater by pollution and wasteful practices in connection with groundwater should be prevented or controlled within practicable limits.

Refer also to Section 6.4, Groundwater Management Areas. More information concerning water law and rules can be found on the OWRD website.

Oregon Department of Environmental Quality

The Oregon Department of Environmental Quality (DEQ) is a regulatory agency whose job is to protect the quality of Oregon's Environment. DEQ is responsible for protecting and enhancing Oregon's water and air quality, for cleaning up spills and releases of hazardous materials, and for managing the proper disposal of hazardous and solid wastes.

The U.S. Environmental Protection Agency (EPA) designated the DEQ as the lead agency for development and implementation of Oregon's Wellhead Protection Program (WHPP). In addition to local programs, the EPA delegates authority to DEQ to operate federal environmental programs within the state. A geologist preparing a hydrogeology report for an environmental study or assessment should be familiar with, and adhere to, the requirements of the DEQ relative to the applicability of protection of the environment for a hydrogeological project.

Oregon Department of Human Services – Health Division

Wellhead protection programs will vary from community to community, owing to different land uses and aquifer conditions. WHPPs should have the following key elements:

- Public education and outreach;
- Delineation and management of the Wellhead Protection Area (WHPA);
- Inventory of Potential Contaminants;
- Contingency planning; and
- Assessment of impacts of new wells.

Guidance documents dealing with delineation, contaminant inventory, and management strategies are in various phases of completion. State agencies can provide technical assistance with conducting hydrogeological assessments in Oregon. Contact OHD or local community WHPP facilitators to determine the applicability of OHD's WHPP criteria when preparing hydrogeology reports.

In Oregon, drinking water protection is promoted through a partnership of the DEQ and the OHD. The other principal agency involved with the State WHPP is the OHD. The DHS Drinking Water Program also regulates public drinking water supplies including supplies from wells under OAR Chapter 333. These rules include standards for facility design and construction and prescribe monitoring and reporting requirements.

INTRODUCTION

This document consists of two parts:

Part I

Outline of Guidelines for Preparing Hydrogeologic Reports in Oregon

Part II

Complete Guidelines for Preparing Hydrogeology reports in Oregon

It is suggested that the Part I would suffice as a primary reference document for most hydrogeology reports. The more detailed guideline presented in Part II, would also be useful, as it provides a more in-depth consideration of a broader spectrum of hydrogeologic topics.

PART I

OUTLINE OF GUIDELINES FOR PREPARING HYDROGEOLOGY REPORTS IN OREGON

INTRODUCTION AND BACKGROUND

The main purpose of these guidelines are to facilitate protection of Oregon citizens and their interests from inadequate geology work in the form of poorly documented work. The objectives of the guidelines are to:

- Provide a basis for the Board to use in reviewing complaints involving hydrogeology reports or work that involves the public practice of geology that include hydrogeology;
- Establish minimum thresholds for hydrogeologic work to protect the consumer public from poor practices, that may include inaccurate results, unfounded recommendations, and poor design of facilities or programs, which may adversely affect a wide variety of people; and
- Most importantly, protect the citizens of Oregon from the potential results of poor hydrogeologic work that may include depletion, contamination, or misuse of Oregon's groundwater resources.

This document does not include a theoretical or technical background to each discipline within the field of hydrogeology. Possession of the technical proficiencies required to prepare the reports is the responsibility of the registrant author, and the technical practice of hydrogeology in Oregon is regulated by the Board as part of the public practice of geology per Oregon Revised Statute (ORS) 672.505(7).

Professional judgment, based on technical skills and competence in geologic and other sciences, is required in preparing a hydrogeology report. The nature and scope of hydrogeology studies range from the very simple to the highly complex; thus, it is neither possible nor necessarily advisable to apply a guideline to the preparation of all hydrogeology reports. As such, these guidelines are intended to describe topics that should be considered in preparing hydrogeologic reports and may be used in tandem with other guidelines, as applicable. Professional discretion is recommended in trying to apply the topics presented herein to a particular project and the resulting report.

Some reporting guidelines already exist, as developed by other Oregon agencies (i.e., Oregon Department of Environmental Quality [DEQ]) for contaminant-focused groundwater investigations and reports that are performed as part of remedial investigations/feasibility studies (RI/FS) at contamination sites. On projects encompassing a broader spectrum of work in geology, engineering geology, water resources, environmental hydrogeology, or other areas of hydrogeology, federal, State, and local guidelines should also be considered.

These guidelines will be revised as warranted.

GENERAL REPORT COMPONENTS

As noted above, the content of a hydrogeologic report will vary according to the specific project. Standalone hydrogeologic reports should be well organized and include most or all of the following elements, as appropriate:

- Title Page
- Signature Page
- Table of Contents
- Lists of Tables, Figures, and Appendices
- Introduction
- Purpose
- Description of Hydrogeologic Systems
- Methods of Data Collection
- Groundwater Use and Development
- Analysis Procedures and Methods
- Hydrogeologic Assessment
- Numerical Model Documentation (if modeling is performed)
- Water Quality
- Conclusions
- Recommendations, if necessary
- Report Limitations
- References and Data Sources
- Tables, Figures, and Appendices

Larger and more complex reports may be divided into multiple volumes, and may also include an Executive Summary, which summarizes key conclusions, findings, and recommendations. While the above contents are important, the exact format of the report is left to the discretion of the author.

The RG stamp can be placed either on the title page, a signature page, or another location, which indicates that the stamp and its accompanying RG signature represent the entire contents of the report. If multiple volumes are required for a single report, only the main or initial volume needs to be stamped and signed by an RG. Similarly, technical memos containing content qualifying them as ‘reports’ should be considered as such and properly signed stamped.

GENERAL REPORT CONTENTS

The following items should be addressed in hydrogeology reports:

Purpose and Scope. State the purpose and scope of the report and hydrogeology investigation, including a proposed use of a site, if applicable. Also, identify the level of the study, i.e., feasibility, preliminary, or final. Summarize the report in an executive summary.

Client. Identify the client or party that commissioned the report.

Geologist Name. Name of the geologist in responsible charge for the preparation of the report. A disclosure statement of the geologist's financial interest, if any, in the project or client's organization, should also be clarified.

Data Collection Documentation. Data collection dates and procedures should be documented.

Site Description. The location and size of the study area, and its general setting with respect to major or regional geographic and geologic features, should be described. Describe the general nature, distribution, and surface exposure of earth material within the study area.

Geologic Setting. The geologic setting includes a physiographic setting of the study area on a regional and local scale. The geologist should describe the nature of subsurface and surface material, structural features and relationships, and the 3-dimensional distribution of earth materials, aquifers, and confining units exposed and inferred within the area.

Rock and soil types should be identified, and textural or genetic descriptions of unconsolidated deposits are presented. Use the relative and absolute age, and where possible, confirm the presence of named formations and other formal or informally named stratigraphic units. Using the Natural Resources Conservation Service (NRCS) soil designation may be useful to describe unconsolidated material.

Indicate the surface and subsurface expressions, aerial distributions, and thicknesses of geologic units. Discuss the distribution, dimensional characteristics, variations in thickness, degree of soil development, surface expression, and the originating process of geologic materials. Present pertinent physical characteristics including: color, grain size, texture (degree of rounding), mineralogy/lithology, porosity and permeability, stratification, cementation, thickness, strength and variability. State any special physical or chemical features present (instability, expansive clays, water chemistry and quality, hot springs, fumaroles).

Structural features should be described such as: the structural occurrence, distribution, dimensions, orientation and variability, both within and projecting into the study area, and the degree that structure plays a role in groundwater behavior; relative ages of structures where known or pertinent; the spacing, size, orientation, and infilling of fractures, if present and special features of faults, a prediction of whether they would affect groundwater, and how much of an affect is predicted or observed.

Hydrogeologic Setting. A hydrogeologic conceptual model may be appropriate. Describe the effects of groundwater, springs, streams, and irrigation canals, and how these may be affected by fluctuations in precipitation and temperature, and the occurrence, distribution and variations in drainage, ponds, wetlands, springs, seeps. Include the relation of groundwater to topographic and geologic features, and surface water-groundwater interaction. Other significant geologic and hydrogeologic characteristics or concerns, such as a fluctuating water table and the effects of proposed water use modifications on future groundwater conditions.

Document aquifers and confining units; depths to groundwater and long-term fluctuations in water levels, flow directions, gradients, hydrogeologic boundaries, hydraulic properties, recharge and discharge, current and proposed usage. Historic records of water use and water rights should be presented, where applicable.

Surface Features. Describe the topography, drainage and hydrogeologic factors within or affecting the study area. Identify regional and local aquifers, and confining units. Include water quality, flow rates/directions, test results (i.e., aquifer properties.), water level information, water quality, hydrogeochemistry, and potential sources of recharge and discharge. The hydrogeologic report should contain descriptions and accurate maps of pertinent geologic units, structural features, aquifers, confining units, and topographic features recognized or inferred within the study area.

Seismic Conditions. While not routinely considered, seismic conditions, such as the potential for induced seismicity from injection activities, could be applicable.

Data Sources. The nature and source of data used (published, unpublished, verbal) should be cited. Basic sources include boring logs, as-built well construction diagrams, geophysical logs, etc.

Figures. The report should include one or more appropriately oriented and scaled cross-sections to show subsurface relationships and reinforce written descriptions. Fence or block diagrams may also be appropriate.

Data Tables. Tabulated data presenting the data upon which the interpretations are based (including but not limited to well/boring logs, water level measurements, laboratory testing results) should be provided. Manipulated data should be identified, and the type and level of manipulation should be described.

Risk of Groundwater Impact. A disclosure should be described of known or suspected risks to groundwater affecting the study area.

Field Data Collection. Field data collection techniques should be described. If relevant, field data collection forms or photocopies of field log books should be presented. Describe field data collection and exploration procedures (i.e., surface geologic reconnaissance, drilling, trenching, geophysical surveys, logging). Indicate where interpretations are added to direct field observations and provide the basis for such interpretations. A clear distinction should be made between observed and inferred features and relationships.

Laboratory Testing Methods and Reports. Analytical methods used to test the samples collected should be referenced. Final laboratory reports and chain-of-custody documentation should be provided in an appendix.

Data Analysis and Interpretation. A discussion of the analysis and interpretation of the data, methods of interpretation, the basis for conclusions, and a discussion of alternative interpretations and uncertainty should be presented. Using the references cited and the data collected and analyzed, discuss key hydrogeologic findings.

Hypotheses. State any hypotheses made relative to the study area.

Conclusions. In formulating conclusions, it is important to describe the scientific reasoning behind the conclusions. Discuss any conclusion uncertainties and alternative interpretations. Provide a statement of the limitations or disclaimers of the study. Detail the conclusions or findings of the work and testing documented in the report.

Recommendations. While required by some clients or agencies, and not by others, if appropriate, include recommendations for follow-up work in the study area. Recommendations, if included in the scope of work for the project, should be defensible and supported by the conclusions. Recommendations based on sound, well-supported conclusions allow stakeholders to make better decisions for follow-up investigation, if necessary. The bottom line for formulating and presenting recommendations in a hydrogeology report is for the protection of the public.

Stamp and Signature of Geologist. The geologist in responsible charge of the report shall sign and stamp the hydrogeologic report.

PART II

COMPLETE GUIDELINES FOR PREPARING HYDROGEOLOGY REPORTS IN OREGON

Part II: Table of Contents

Page No.

Part II: Table of Contents

Page No.

1.0 GENERAL REPORT GUIDELINES

Regardless of intent, reports containing geologic and hydrogeologic interpretation must be stamped by an Oregon-registered geologist (OAR 809-050-0000). The Board considers the following to apply to hydrogeology reports:

- Clearly identify data sources and include references.
- Clearly identify assumptions, interpretations, and professional judgments use in the study and report.
- Support conclusions and recommendations with information and data provided in the report, and further, ensure that they follow defensible scientific practices.

Address major regulatory constraints that apply, including those potentially related to the Endangered Species Act, Clean Water Act, and others that may apply.

1.1 Report Contents

As noted above, the content of a hydrogeologic report will vary according to the specific project. Despite this variation, hydrogeologic reports should be organized and include most or all of the following, as appropriate:

- Title Page
- Signature Page
- Table of Contents
- Lists of Tables, Figures, and Appendices
- Introduction
- Purpose
- Description of Hydrogeological Systems
- Methods of Data Collection
- Groundwater Use and Development
- Analysis Procedures and Methods
- Hydrogeologic Assessment
- Numerical Model Documentation (if modeling is performed)
- Water Quality
- Conclusions
- Recommendations, if necessary
- Report Limitations
- References and Data Sources
- Tables, Figures, and Appendices

Larger and more complex reports may be divided into multiple volumes, and may also include an Executive Summary, which summarizes key conclusions, findings, and recommendations.

While the above contents are important, the exact format of the report is left to the discretion of the author. As such, the RG stamp can be placed either on the title page, a signature page, or another location, which indicates that the stamp and its accompanying RG signature represent the entire contents of the report. If multiple volumes are required for a single report, only the main or initial volume needs to be stamped and signed by an RG. Similarly, technical memos containing content qualifying them as 'reports' should be considered as such and properly signed stamped.

The basic contents of a hydrogeology report are presented and discussed in the following sections.

1.2 Report Introduction

The Introduction Section of a hydrogeology report gives the context for the main body of the report. This section should present sufficient background information such that the reader understands the nature and scope of the project, the purpose and approach of the groundwater assessment, the assessment timeframe, and appropriate information on project authorization and report approval and acceptance. The Introduction may also discuss previous investigations, introduce a site location map, describe how the report is organized, acknowledge the efforts of individuals who contributed to the project and report, and indicate the end user of the report.

The Introduction Section is an appropriate place to cite acknowledgments of assistance and cooperation of others in completing the project.

Several subheadings may be appropriate, depending on the length or complexity of the report. The Introduction Section also may include a brief summary of the conclusions and recommendations.

1.3 Report Purpose

The purposes of most hydrogeology reports are to identify and evaluate hydrogeologic conditions (including the relationship to surface water, where appropriate) and to provide a framework for evaluating impacts to or from proposed projects. These projects may relate to land use changes, regulatory permitting, water quality compliance, and other issues. A hydrogeology report should be prepared with a level of care for use by planners, geologists, engineers, regulators, landowners, stakeholders, and public-support services at such a standard that the public welfare is protected and that the safeguarding of life, health, property, and the environment are assured under Oregon Revised Statute (ORS) 672.505(7).

2.0 DESCRIPTION OF HYDROGEOLOGIC SYSTEMS

This section presents the geologic and hydrologic understanding and framework for analyses and conclusions presented elsewhere in the report.

2.1 Physiographic Setting

A well-defined description of the physiographic setting provides the location of a site followed by descriptions of physical characteristics, especially the surface features, of an area. These physical characteristics include topography, climatic conditions, map identifiers such as latitude and longitude, township and range, section, landmarks, boundaries, geomorphologic attributes, water body features and resources, drainage patterns and conditions, erosion, the extent of these features, and other physical qualities of the site and surrounding area. This section also could present anthropomorphic data, such as site and vicinity land uses, community development, and effects of human activity. Inclusion of a topographic map is recommended.

2.2 Geologic Setting

Present information and background on the geologic setting in sufficient detail to support and/or complement the development of the hydrogeologic setting and the report conclusions and recommendations.

2.2.1 Regional Geology

Several sources and methods are used to describe regional geology. Using these methods (i.e., field mapping, citing geology maps), identify regional geologic units, and describe their lithology, mineralogy, porosity and permeability, if known, thickness, age, extent, source, depositional environment, structure, stratigraphy, geomorphic setting, physiographic region, province, hazards (landslides, active seismic areas, volcanic areas). Provide geologic maps, if available.

Cite published resources. If data are used from non-published sources, state the source of the information and the manner of data collection (i.e., interview, letter, work in progress).

2.2.2 Local Geology

Based on one's knowledge of regional geology, a more detailed and focused description can be presented for the geology of a project site. Additional geologic information relevant to a site's vicinity also should be described, where such geologic conditions may affect the project. Such descriptions on a local level may include known faults, wells, geologic hazards, permeability, and porosity, and may best be represented by a local geologic map in an appendix, if feasible.

A lithology description of the unsaturated and saturated zones is key to understanding the hydrogeologic framework. The level of detail necessary is based upon the report reader and the report's end use, considering that an appropriate level of detail is required to substantiate and defend the data and conclusions contained in the report.

2.3 Hydrogeologic Setting

Introduce and describe the principal water-bearing units (aquifers) and non-water-bearing units (confining units) that are present at the project site. Describe whether groundwater is present under unconfined or confined conditions, general depths to water (and head) as understood within the depth to which the project investigation developed and assessed subsurface information.

2.3.1 Regional Hydrogeology

Regional hydrogeology is described initially by identifying the aquifers present and the geologic conditions under which they occur. Common data sources give the aquifer name (i.e., Troutdale Gravel Aquifer) and its characteristics (i.e., lithology, mineralogy, sorting, grading, well yields, recharge areas and rates, discharge areas and rates, confining conditions, seasonal and long-term fluctuations, occurrence, among others). Chemical properties used to describe aquifer quality include hardness, chloride, sulfate, and nitrate, phosphate, boron, fluoride, iron, manganese, and other constituents. Water uses, such as irrigation, domestic, industrial, engineering, aesthetic quality, or municipal are included in hydrogeology reports. On a smaller regional scale, groundwater flow directions and interactions with surface water may be known.

Describe (and, if appropriate, illustrate using maps) the known thickness and extent of important hydrostratigraphic units. Organize and illustrate one or more generalized stratigraphic sections (from top to bottom or youngest to oldest) that show the vertical relationship between the principal water-bearing and non-water-bearing units found on the project site or study area. This information is particularly relevant for regional studies.

2.3.2 Local Hydrogeology

Applying regional groundwater conditions to a project site typically results in more detail. Data sources may be previous work conducted at the same or a nearby site, published or unpublished. The local hydrogeology of a site is usually quantified through field testing, sampling and assessment. Using the field data, additional information may be generated such as well types and locations, well construction and elevation surveys, water levels, aquifer testing results, yields, water quality, groundwater flow direction, gradients, and so on.

If previous work has not been conducted at a site, or the previously generated data are not available for public use, a geologist must make educated assumptions based on what *is* known about a site's hydrogeology. All assumptions made in a hydrogeology report should be clearly stated as assumptions.

Driller's logs provide useful information to identify principal water bearing units and other characteristics of groundwater in the project area. However, drillers are not required to provide a detailed, accurate description of subsurface materials encountered in a boring. Use lithologic descriptions indicated on driller's logs with caution. When used, provide copies of driller's logs in an appendix and note the limitation in using driller's lithology descriptions.

2.3.3 Physical and Hydraulic Properties

Characterize known or estimated physical properties of each hydrogeologic unit such as: rock or sediment type, mineralogy, grain size, texture, geologic structures such as fractures, and primary and/or secondary porosity. Use tables to manage the data. Further include for each unit the known or estimated hydraulic properties such as hydraulic conductivity, (horizontal and/or vertical), transmissivity, and storativity (or specific yield in the unconfined aquifer case).

2.3.4 Spatial Variability

Describe the degree of spatial variability in groundwater occurrence and hydrostratigraphy, and if there are data, variability in physical and hydraulic properties, both vertically and horizontally. Consider whether units are laterally or vertically continuous in extent and properties, and if not what the implications of this heterogeneity are in terms of groundwater behavior.

2.4 Groundwater Flow System Description

Describe how groundwater moves through the subsurface. Describe the overall, large-scale (regional) groundwater flow regime of all known (or relevant) aquifer systems, indicating the likely flow direction(s), flow rate(s) and seasonal changes. To the extent the data allow, describe the nature of shallow, local (or site-specific) groundwater flow, including direction, rate of flow and seasonal changes.

2.4.1 Hydrogeologic and Physical Boundaries

Identify known and/or hypothesized hydrologic and physical boundaries to the groundwater system being investigated. If possible, show these features on a map and illustrate them in cross section.

2.4.2 Groundwater Recharge and Discharge

Describe how water enters and exits the groundwater system, including the sources and locations of groundwater recharge, and the relative contribution of each source. Also indicate groundwater discharge mechanisms (including pumping), describing where and how groundwater is exiting the system.

2.5 Groundwater and Surface Water Interactions

For all types of aquifers, particularly shallow or unconfined aquifers, assess and describe the relation between groundwater and surface water in the studied area. Identify the nearest surface water resources to the project site or study area. Determine if groundwater normally discharges to surface water, or if surface water sources normally recharge groundwater and if so under what conditions. For confined aquifers, ascertain the degree of hydraulic and physical isolation from surface water afforded by the presence of continuous confining units. Determine if pumping would induce recharge from surface water to groundwater. Reference should be made to any applicable basin rules governing allowable or classified uses of surface water and any implications these rules would have on groundwater.

2.6 Conceptual Groundwater Model

Provide a discussion of the conceptual groundwater model, including a narrative and illustrations (such as cross-sections and block diagram) covering the major topics outlined below.

2.6.1 Generalized Hydrogeologic Cross Sections

Provide one or more generalized hydrogeologic cross sections (or block diagrams) that depict the vertical and lateral relationships between the major hydrostratigraphic units in simplified form to support the text. These sections should be drawn to scale and be located on a map.

The drawings may also indicate other features of the groundwater system such as aquifer or aquitard properties, recharge and discharge locations, and flow directions.

2.6.2 Groundwater Response to Stresses

The narrative should describe how the aquifer(s) respond to externally imposed stresses such as precipitation and pumping, and characterize this in terms of expected responses using traditionally applied analytical models (i.e., Theis response to constant rate pumping in an unconfined aquifer).

2.6.3 Hydrologic Balance

Hydrologic balances are particularly important in investigations involving modeling and evaluations of surface water and groundwater. This often involves addressing safe yield concepts. The conceptual model should present each component of the hydrologic balance and the basis on which the balance is calculated.

3.0 METHODS OF DATA COLLECTION

The groundwater investigation report should clearly describe data sources, methods of data collection, and assess the quality and reliability of the data. While a general assessment of existing data may be discussed, the methods section of a hydrogeology report normally does not include data interpretation. Interpretive statements developed from the data should appear later in the report.

3.1 Project Data Sources

The database existing at the outset of the investigation sets the stage for subsequent investigations. The subsections below briefly review what may be included in the project database. Cite all sources of information used in the text and in a references section. Include an assessment of the data as a basis for identifying data and knowledge gaps. Discuss the availability of reports and whether they were reviewed.

Cite interviewed sources. Describe the applicable field methods used, their advantages, and their limitations.

3.1.1 Maps and Cross-Sections

If published maps or maps prepared by others are duplicated or cited, note the reference, and provide copies of relevant maps and cross-sections used. The maps produced should have minimum components (i.e., drawn to scale, have a legend and north arrow). If cross sections are presented, their locations in plan view should be shown on a topographic or geologic map. Refer also to Section II of the Board's guidelines for engineering geologic reports (Oregon State Board of Geologist Examiners, 1996).

3.1.2 Study Area Boring and Well Logs

The report should clearly identify or segregate water well, monitoring well, and geotechnical boring reports collected as part of a routine well inventory and distinguish those reports used by the investigator for interpretation of geologic and hydrogeologic conditions. It is recommended that photocopies of pertinent water well, monitoring well, and geotechnical boring reports be provided in the report appendices.

3.1.3 Remote-Sensing Imagery

Cite the sources of remote-sensing images used, and provide photocopies or a web link or description of where the images are maintained.

3.1.4 Water-Level Data

Describe the sources of water level data and the datum used in determining groundwater elevations from the groundwater data. Describe the method(s) used to collect water-level data, i.e., manual or transducer. Note any uncertainties with respect to water level data collected by others. It is beneficial to note the range of historical data and whether it is considered representative and sufficiently complete for the purposes of the study.

3.1.5 Geophysical and Other Data

Cite geophysical data that may be derived from an existing project database. The report should distinguish whether "raw" or "processed" geophysical data were used, and state the limitations in using data for a project that may not have been envisioned when the data were originally collected. If applicable, provide the source for precipitation and other atmospheric data.

3.2 Field Mapping and Data Collection

In groundwater reports, the need for and design of field investigations should be presented and include a discussion of applicable field methods used, their advantages, and their limitations. Reference the technique(s) used to locate physical features and indicate the relative accuracy of the locating method (i.e., quarter-quarter section). See Section II of the Board's guidelines for engineering geologic reports (Oregon State Board of Geologist Examiners, 1998).

3.2.1 Subsurface Exploration Methods

Provide the rationale for the chosen exploration method(s) in consideration of the site setting and site access, and the nature of the groundwater system being investigated. Describe the surface method(s) used, equipment, personnel involved, sampling procedures, and how the exploration was performed and supervised. Note difficulties in completing explorations, if any.

3.2.2 Drilling and Well Installation

Identify the drilling firm and indicate the level of oversight provided by the geologist or other professional (i.e., engineer). Describe the drilling operations, well design, well installation, development and testing in the report or its appendices. A description and identification of soils and rock materials should use industry-accepted standards, such as American Society for Testing and Materials (ASTM) D2487 or D2488. Locate all wells on a map of appropriate scale. Identify on the well logs zones of groundwater production, or likely production, and other pertinent hydrogeologic data. Include observations made during drilling and the procedures for designing the well(s) for the intended purpose. Tabulate Oregon well report data if there are numerous wells. Consider including a completion diagram with casing depths, for each well, or append the water well report.

3.2.3 Surface Water and Stream Gauging

Describe the stream flow and stream level data collection and/or interpretation. Note the source data and method(s) used to obtain stream gage and stream flow data for the project.

3.2.4 Water and Soil Sampling

Physical and chemical, soil and water sampling and analysis methods should be documented, including methods of sample collection, analysis, reporting, quality assurance, and quality control.

3.2.5 Geophysical Surveys

Provide an adequate description of surface and borehole geophysical surveys, including the equipment used, data collection and processing methods, and a data quality assessment. Document whether the data were crosschecked and "ground truthed" with other subsurface data such as borehole stratigraphy.

3.3 Well Monitoring and Testing

3.3.1 Water-Level Measurements

Describe the equipment used, its accuracy, and the number of measurements taken including date and time. Reference a standard elevation and location from which the measurements were taken (i.e., a specific point on top of the well casing). If data are voluminous, provide an appendix with a database or spreadsheet of the raw and processed measurements.

3.3.2 Aquifer Testing Methods and Parameters Monitored

Discuss the design and objective of the well testing performed, details on data collection, and whether test conditions reasonably matched the assumptions of the analysis performed. Document how flow rates and/or volumes were measured and how the flow rate was controlled during the testing. Describe the equipment and instruments used, calibration, and redundant data collection (i.e., manual water levels combined with pressure transducers).

3.3.3 Water Sampling and Analysis

Document what water quality testing is performed in the field and in the laboratory. Document which parameters were measured in the field and why, and the equipment and methods used, including calibration standards. Similarly, document which parameters were analyzed in the laboratory and which methods were used. Describe sample collection methods, personnel, and equipment and reference standard methods or a project-specific sampling plan if one was prepared.

3.4 Data Quality Management

This subsection explains methods for documenting how project data were processed and managed.

3.4.1 Field Documentation and Records

Include appropriate copies of field data collection forms and notes in a report appendix, or note the availability of such information in the project file.

3.4.2 Data Reduction and Verification

Describe procedures used to convert raw data to processed data, including unit conversions, data corrections, statistical analyses, and other calculations. Also discuss data validation and verification procedures, as appropriate.

3.4.3 Analysis Methods and Data Quality

Assess the data quality and sufficiency for the analysis methods performed. Describe uncertainties or gaps in the data that impact the reliability of the analyses performed.

3.4.4 Data Tables, Graphs, and Figures

Data are presented in report tables, graphs, and/or figures. References to data clearly lead the reader to the appropriate section of the report or project database.

4.0 GROUNDWATER USE, DEVELOPMENT, AND MANAGEMENT

Building on the previous sections, evaluate the potential project impacts to groundwater resources, uses, management limitations, and the potential for the proposed project to interfere with surface-water resources, and existing and future conjunctive uses. Describe both beneficial and adverse impacts and evaluate mitigation options. Whenever possible, use illustrations and photographs to help convey important information.

4.1 General Nature and Extent of Project Impacts

Provide a general description of the potential on- and off-site impacts from the project relative to groundwater and surface water resources, and conjunctive uses in the area. Explain if the proposed water-use project is within the capacity of the resource. Determine to what extent the proposed water-use project will interfere with existing ground-water users. Define to what extent the proposed water-use project will interfere with surface water. Verify whether the proposed water-use project will potentially degrade water quality, including thermal properties. The description of these potential impacts should consider the following key areas.

4.1.1 Recharge and Discharge Changes

Detail potential changes that the proposed project could cause to groundwater recharge and discharge rates. Evaluate potential short- and long-term impacts to the aquifer and describe potential mitigation options.

4.1.2 Groundwater and Surface Water Connection and Interference

Describe the extent of hydraulic connection between groundwater and surface water, well-to-well interference, and detail how the proposed project could affect this interaction on a short- and long-term basis, both in terms of water quantity and water quality. Be familiar with the criteria used by OWRD to determine whether a well will be regulated to control interference and discuss the results of the applicability of these criteria in the hydrogeology report.

4.1.3 Project Permitting Requirements

Describe what, if any, permits will be required for the proposed water use. The description should include both water-use and water-quality permitting requirements and indicate what, if any, third party agreements are likely to be needed.

4.2 Current and Reasonably Likely Future Beneficial Water Uses

Discuss the existing and future water uses likely to occur in the project area and how these uses could be affected over the lifespan of the proposed project such as drinking water; agricultural (irrigation, livestock watering); industrial; engineering (i.e., heat exchange, dewatering); aquatic life (i.e., minimum stream flows); recreation; and aesthetic quality. Identify and describe wells and water uses in the study area, and quantify the water usage to the extent possible. Discuss the applicability of the following criteria used by OWRD to evaluation new groundwater applications:

- Is the aquifer over appropriated during any period of the proposed use?
- Will groundwater be available in the amounts requested without injury to prior water rights?
- Will groundwater be available within the capacity of the resource?
- Will the groundwater resource be hydraulically connected to surface waters and if so, will surface water be available for appropriation?

Also identify and describe whether ESA-listed species that are dependent on local groundwater and surface-water resources or sensitive habitats are present in the project area. Use maps and other graphic documentation to show the locations of wells, ESA-listed species, and sensitive habitats.

Identify the beneficial water uses that are likely to occur in the project area over the life of the proposed project. Local land-use planning agencies should be consulted for information on future zoning and population growth in the project area. Watermasters and local water purveyors (if present) should also be consulted for water demand projections. Consider the following.

- Duration of Project
- Land Use Plans
- Water Demand Projections

4.3 Water Quantity and Quality

Describe potential water quantity impacts that could occur from the project relative to the identified water resources and current and likely future beneficial uses. Consider the following.

- Threatened and Endangered Species
- Wild and Scenic Rivers
- Water Rights/In-stream Flows
- Basin Rules
- OWRD Division 9 Rules

Describe potential water quality impacts that could occur from the project relative to the identified water resources and current and future beneficial uses. Consider the following.

- Regional Conditions
- Contamination Sources
- Project Interferences

4.4 Groundwater Management Areas

During report preparation, be aware of the different kinds of administrative areas established to manage groundwater in Oregon. They include:

- Groundwater Limited Areas (GWLAs);
- Classified or Withdrawn Areas;
- Critical Groundwater Areas. and
- Groundwater Management Areas.

Limited, classified, or withdrawn areas basically limit new uses in an area. Limited, classified, or withdrawn areas are created through a rule righting process. The critical groundwater area designation allows the Water Resources Department to restrict existing uses.

Groundwater Management Areas are declared by Oregon DEQ, based on area-wide groundwater contamination issues.

Report whether special well construction standards are applicable to the study area. For example, Lakeview, Oregon, is the only area for which special standards have been established.

4.5 Groundwater Recharge, and Aquifer Storage and Recovery

Groundwater artificial recharge (ORS 537.135), and aquifer storage and recovery (ORS 537.531 - 537-534) are permitted by the OWRD with cooperation from DEQ and Department of Human Services - Health Division. Depending on whether groundwater recharge or ASR is being considered, the statutes and rules vary as to specific requirements. Groundwater recharge can include recharge through the spreading of water on the surface, whereas ASR by definition refers to water being injected and recovered through a well, and that it be treated to drinking water standards. There are typically variations in water quality standards between the two methods.

The rules (OAR 690-350) specify procedures to be followed in the development of Artificial

Recharge (AR) and Aquifer Storage and Recovery (ASR) systems, and including reporting requirements. To fulfill these requirements, hydrogeology reports are typically prepared to support AR/ASR projects, including a Feasibility Study and associated reports supporting the development of a work plan to implement a Pilot Testing phase, and additional reports documenting the recharge program results.

4.6 Geothermal Systems, Springs, and Wells

This section covers the major differences that should be addressed for thermal aquifer studies in addition to the relevant hydrogeologic information (i.e., geology, regional and local aquifers) described in the main body of the guidelines. If applicable to your project, describe and illustrate the thermal characteristics (e.g., temperatures significantly greater than regional or local surface water, or groundwater) and chemical plume characteristics (i.e., high concentrations of silica, boron, fluoride, sulfate or hydrogen sulfide gas relative to cooler regional and local waters) of the thermal aquifer. Describe potential connections with other aquifer systems. When planning to conduct or conducting work involving geothermal aquifers, it should be remembered that DOGAMI is the regulatory authority for this type of work.

As with normal aquifers, these systems should be investigated and described using the methods listed in these guidelines. Some differences and exceptions as noted below.

4.6.1 Sampling Methods and Chemical Analysis

Several guidance documents are available to assist in assessing and describing thermal waters. Typically the protocol used is very similar to that described in the DSIR New Zealand publication titled, “Collection and Analysis of Geothermal and Volcanic Water and Gas Samples” by Giggenbach and Goguel (1989), and the United Nations Unitar publication titled, “Applications of Geochemistry in Geothermal Reservoir Development” edited by Franco D’Amore, Rome 1991. A good reference is the USGS online field manual titled, “U.S. Geological Survey Techniques of Water Resources Investigations”, Book 9”.

Include descriptions of chemical analyses utilized in the analysis phase of thermal systems. Typical analysis includes: pH, silicon dioxide (SiO_2), boron (B), lithium (Li), sodium (Na), potassium (K), magnesium (Mg), rubidium (Rb), chloride (Cl), bromine (Br), sulfate (SO_4), total bicarbonate (HCO_3), ammonia (NH_3), deuterium, and oxygen-18 isotopes, (with iron [Fe] and aluminum [Al] reserved for acidic samples). Quality assurance protocols should be explained, such as duplicate sampling conducted to monitor consistency in the laboratory’s analytical quality assurance program.

4.6.2 Geothermal Modeling

The models used in handling geothermal reservoirs typically are limited to less than three, with the Tuff II model originally developed at Lawrence Livermore Laboratories (Livermore, California) being the most popular and useful. Whichever model is used, describe the model and its parameters used, similar to those described below in Section 9.0.

4.7 Suggested Data Sources

Although not exhaustive, the following are readily data sources applicable to groundwater use and development issues:

- OWRD:
- Groundwater Resource Information Distribution (GRID)
- Water Rights Information System (WRIS) databases
- District Watermasters Offices
- Oregon Department of Human Services Drinking Water Program
- County and City Land-Use Planning Departments
- Oregon Fish & Wildlife (ODF&W) Oregon Rivers Information System (ORIS) database
- Oregon Division of State Lands (DSL) Wetlands Program
- National Wetland Inventory Maps

- U.S. Environmental Protection Agency Geographic Information System (GIS) database
- U.S. Geological Survey, such as Open-File Reports on groundwater use.

5.0 GROUNDWATER QUALITY

An assessment of groundwater quality often is part of a hydrogeologic investigation and may be of primary concern in some studies. Typically, the objective is to determine the native groundwater quality and then determine if there have been, or are likely to be any, changes to groundwater quality that may impact the project or the resource.

Water quality data may be presented in graphs (i.e., time-series plots) or other illustrations of groundwater quality. Presentation and assessment of time-series plots of measured water quality parameters and statistical analyses of data are important components to many groundwater quality investigations.

In projects involving an aquifer in hydraulic connection with surface water, there should also be an assessment of the surface and groundwater quality relationships.

Depending on the scope of the project and data, the section of the report covering water quality should describe whether groundwater quality appears to vary spatially and identify potential causes of any observed variations (i.e., naturally occurring seasonal or pumping-induced changes).

It often is useful to assess groundwater quality from several perspectives. Federal, State, or local groundwater quality standards, including enforceable standards, if addressed in a report, should be referenced and cited.

5.1 Review of Existing Groundwater Quality Data

Describe sources of existing information on general groundwater quality in the area and aquifer of interest. Include a description of naturally occurring physical, inorganic, and organic constituents. If there is a potential for water quality impacts from contamination, land use, or other causes, describe the constituents of concern.

5.2 Water Quality Assessment

A water quality assessment should describe the water quality analysis and discuss the significance of reported results. In addition, the overall quality and representativeness should be described for the tested samples, and indicate whether additional sampling is needed to allow a more full assessment. Typically, a report appendix should include the full laboratory report for all analyses and a data table summarizing results listed by well identification or sampling date.

Standards for water quality vary depending on the situation, and impact or use of the water (i.e., health-based standards for drinking water, ecologically based standards, and other uses, such as agriculture and industry).

Generally describe data objectives and data quality objectives, and when applicable, reference the sampling and analysis plan used to assess groundwater quality for the project site.

Describe or summarize field methods for sample collection, field water quality parameter measurement, sample preservation, and sample custody. Include information on chain-of-custody procedures (provide forms); instrument calibration (for field equipment); and laboratory quality assurance and quality control, detection limits, and laboratory certifications. Some of this information may be included in the report section describing methods of data collection.

5.3 Water Quality Modeling

Document the model used, input parameters, and simplifying assumptions. Provide appropriate literature reference for the modeling, and show governing equations and how the model calculates concentrations. The reporting of water quality modeling should follow the recommendations in Section 9.0 below.

5.3.1 Analytical Solute Transport Modeling

Document the model used, input parameters, and simplifying assumptions. Provide appropriate literature reference for the modeling, and show governing equations and how the model calculates concentrations.

5.3.2 Numerical Solute Transport or Contaminant Fate Modeling

Document the model used, input parameters, and simplifying assumptions (see Section 9.0). Provide the appropriate literature reference for the model used, showing governing equations, and explain how the model calculates concentrations.

5.4 Groundwater Contamination

Groundwater contaminant assessments typically are coordinated with the DEQ. Geologists conducting these types of assessments are referred to the appropriate regional DEQ office staff for further guidance. Additional information is provided at the DEQ website.

6.0 ANALYSIS PROCEDURES AND METHODS

Hydrogeology reports should document and present data analysis pertaining to groundwater flow and aquifer hydraulics. The discussion typically begins with groundwater (contour) maps, proceeds through the various methods used to characterize physical and hydraulic aquifer properties, and finishes with a discussion of groundwater flow analysis.

6.1 Groundwater Data Analysis and Methods

The foundation of accurate groundwater maps is the collection of accurate water-level information from wells that are properly installed, maintained, and optimally located. Reports of field and laboratory activities document the implemented programs for the reader, and need to be as complete and accurate as possible.

6.1.1 Aquifer Head Measurements and Maps

Water levels or piezometric data maps are essential components of hydrogeologic reports. These maps should present the geologist's interpretation of the groundwater elevation data collected during an investigation, and depict the horizontal and vertical directions of groundwater flow.

Note the method used to establish the location and elevation of well casing reference mark(s) used to compute water level elevations, and the associated accuracy or uncertainty associated with using these elevations.

Note the time period the data were collected in and whether or not external influences such as precipitation, changes in atmospheric pressure or pumping were taken into account in the analysis. Use and document the appropriate number of data points (i.e., wells) in constructing water table maps, potentiometric maps, and flow nets.

Separate maps are normally prepared for different data sets; these data sets may be organized according to time/date of data collection or by aquifer/water-bearing zone.

6.1.1.1 Comparison of Software and Manual Mapping Methods

When software is used to illustrate groundwater elevation contours and estimated flow directions, the boundary conditions or control points are not easily observable by the reader. The report should identify those conditions and indicate how the software or its parameters was modified to address those elements. In addition, the results should be compared with manually derived contours and flow directions (see Section 9.0).

6.1.1.2 Comparison of Local and Regional Groundwater Conditions

Cite local or site-specific groundwater maps used to evaluate groundwater flow of the project and limited surrounding area. Cite other sources of groundwater maps such as those published by the USGS, OWRD (i.e., for the Klamath, Portland, Deschutes, and Willamette Basins), other agencies or organizations, universities, or consulting firms.

6.1.2 Groundwater Flow Analysis

Document the various analytical methods used to analyze groundwater flow, including hydraulic gradient calculation, determining geologic properties such as particle size and porosity, performing flow analysis using Darcy's Law, analyzing data from aquifer (pumping) tests, and conducting tracer tests.

6.1.2.1 Hydraulic Gradient Calculation

Groundwater flow should be described as a 3-dimensional system, although flow in the horizontal sense or vertical sense are often treated separately in hydrogeologic studies. Describe the horizontal potentiometric surface and vertical gradients for each aquifer or hydrostratigraphic unit of concern. A report containing gradient calculations should document:

- The well water levels used in determining the gradient(s) and the time of year the data were collected;
- The distance along the flow path used in the calculation;
- The horizontal gradient (vertical feet per horizontal foot);
- The vertical gradient in vertical feet per vertical feet (i.e. the distance between the zones measured), and
- The groundwater flow direction or vertical gradient direction (up or down).

6.1.2.2 Sieve Analysis

State whether the sample particle sizes are field estimates or laboratory derived. If laboratory derived, cite the method used to determine particle size (i.e., ASTM D1921-01 Standard test method for particle size of plastic material; and ASTM D422-63 (2002) Standard test method for the particle size analysis of soils). A report including sieve-size analysis should include:

- Field observations made during sample collection;
- Documentation of the type of field or laboratory method used;
- The sample collection date;
- The time the sample is in storage and transport to the laboratory;
- Quantitative laboratory results (if applicable);
- ASTM report requirements; and
- The sieve-size analysis results.

6.1.2.3 Porosity

Reports with porosity data should include the field notes and mapped sample collection locations, the laboratory results, and the method(s) used to calculate porosity.

6.1.2.4 Hydraulic Properties - Slug or Bail Testing Analysis

Report relevant information on the well design, construction, and testing conditions when conducting a slug test analysis. State the test data limitations, including the range of aquifer hydraulic properties that can reasonably be tested and how conditions adjacent to the well may not be representative of the bulk aquifer properties. Online software is available for use in conducting these analyses. A report for a project using slug or bail testing should document:

- Test dates;
- Wells tested, and the number of times tests were repeated on each well;
- Pre-testing water levels;
- An explanation for the selection of the test used;
- The volume of water added to or removed from each well;
- Well construction details (i.e., well depth, inside diameter of well screen and well casing, filter pack material, and information on well development);
- Length and location of the well screen;
- The response of the aquifer to the test, and the time of each reading measured as hours, minutes, and seconds from start of test;
- The name of the data file on the data logger, if an electronic data logger and pressure transducer are used;

- Discussions of pre- and post-test water-level trends;
- Barometric effects (and, if necessary, barometric corrections);
- The analysis method for estimating hydraulic conductivity and associated governing equations;
- The rationale for the selected methods;
- The result of the analysis; and
- Disposition of the withdrawn test water.

6.1.2.5 Hydraulic Properties - Aquifer and Pumping Test Analysis

The two most common well tests are the variable discharge, or step-rate, test that is primarily used to evaluate well hydraulics and the constant-rate pumping test that is primarily used to evaluate aquifer hydraulics. Refer also to 5.3 well monitoring and testing. The pumping test analysis should document the following:

- The date and duration of the pumping test;
- The type of aquifer tested (i.e., sand and gravel, fractured bedrock);
- The pumping-test design (i.e., pumping rates, included wells, expected test duration);
- Information on the test pump and associated equipment (i.e., manufacturer's pump curve, rated horsepower, depth setting, how flow controlled, measured, and discharged)
- The well logs for the pumping and observation wells; the radial distance between wells, if these distances are used in the analysis (i.e., to estimate storativity or to perform distance-drawdown analysis);
- The saturated thickness of the aquifer;
- The method of analysis used to calculate aquifer properties (i.e., Theis method or Jacob method) and the governing assumptions of each method used, and the technique use (i.e., software, manual curve fitting or automated curve fitting);
- Plots of the data with clearly labeled well identifiers and date/time of test. Include at a minimum an arithmetic hydrograph of time versus water level (i.e., drawdown and recovery), semi-logarithmic time versus drawdown and logarithmic time versus drawdown, plus additional plots depending on the analytical methods used;
- The rationale for the selected methods;
- Documentation or references on any software tools used to perform the pumping test analysis;
- The direction of groundwater flow prior to the test;
- The times of measurements, and the drawdown noted in each of the observations wells and in the pumping well;
- The recovery data and associated analyses;
- Copies of the data plots, equations, units, and calculations; and
- The calculation of well and aquifer hydraulic parameters based on the data from the pumping tests (transmissivity [T], specific storage [S],).
- What portion of the data (i.e., early time, late time, recovery) are being used to estimate aquifer parameters and why.

For step tests, show the time-drawdown data for each step, and provide documentation of the analysis performed on the data to evaluate well losses. Software tools are available that make it possible to estimate T with step test data. If used, document the methods of analysis and the software tool used.

6.1.2.6 Tracer Tests

A tracer may be naturally occurring in the environment, or artificially introduced into the subsurface. DEQ allows tracer tests that comply with OAR 340-044-0011(5)(e). Tracer test reports should include:

- Information on the tracer used;
- The wells involved in the testing program;
- The geology and hydrogeology of the monitored aquifer;
- The measurement method(s) used; and
- The test results.

Successful tracer testing requires good planning. Include the plan for the tracer test in the report.

6.2 Groundwater Flow Characterization

The hydrogeology report may include further characterization of groundwater flow that applies the values using a basic Darcy analysis or other analyses. Reports including analysis of groundwater flow on the basis of Darcy's Law should clearly depict the source of data used in the analysis, including assumptions about certain variables such as porosity, and always illustrate the analysis by including the Darcy equation(s). Reports containing Darcy flow and velocity calculations should include:

- The method(s) used to calculate velocity;
- Explanation of Darcy's Law and illustration of the equation(s) used;
- Justification of the parameters chosen for the equations (i.e., porosity and hydraulic conductivity values); and
- The results of the calculation.

6.3 Other Types of Flow Analyses

There are numerous other applications of Darcy's Law and other groundwater flow principles in the solving of common hydrogeologic problems. These may include one or more of the following:

- Excavation dewatering assessment
- Wellhead protection area delineations
- Well interference analysis
- Stream depletion analysis
- Infiltration (storm water) assessment

The documentation principles for these types of analyses are similar to those already described. The hydrogeologist should clearly present the data, explain the assumptions, and illustrate the analysis using equations, maps, cross sections, other figures, and graphs as appropriate.

6.4 Contaminant Data Analysis and Methods

Reports for studies that incorporate environmental water samples should document full field and laboratory Quality Assurance/Quality Control (QA/QC) program elements, providing sufficient duplicate samples, trip blanks, and equipment blanks, depending on the sampling methods used and the project specific work plan.

The DEQ Laboratory is certified by the National Environmental Laboratory Accreditation Program (NELAP) to serve as a national environmental laboratory accreditation authority. The Oregon Environmental Laboratory Accreditation Program (ORELAP) accredits laboratories for testing used to analyze environmental samples.

If the laboratory used for a study is not ORELAP certified, then basic quality control data sheets need to be included in the report with the laboratory data. All data must conform to EPA approved methods contained in various sources of EPA Standard Test Methods. Explain the use of other methods that deviate from the approved methods based on the needs of the relevant agency that will review the report.

EPA Requirements for Quality Assurance Project Plans (2001) should be referenced to determine the QA program needs and expectations.

USGS maintains an on line Field Manual at that was generated to support consistency in the scientific methods and procedures used by USGS, and in the methods used to document those methods and procedures. This manual can offer relevant information to establish a sound and credible sampling program.

DEQ also has several guidance documents available online for implementing a field sampling program and analyzing samples.

Reports with the results from a sampling program should include:

- A project description;
- A list of project members and their responsibilities;
- A description of the sampling program;

- Field data collection procedures;
- Field documentation and procedures;
- Field equipment calibration and analyses;
- The number and type of QC samples to be collected and submitted for analysis (i.e., trip and equipment blanks, rinsate blanks, or duplicate samples);
- The results of testing, the methods used, and minimum detection limits that laboratories achieved when analyzing the samples;
- The analytical QC results or information that the laboratory used during the program is certified by ORELAP for the analyses conducted; and
- Additional sampling, analytical, or QA/QC requirements that deviate from approved methods.

7.0 NUMERICAL MODEL DOCUMENTATION

Groundwater flow models typically consist of two parts: the data set and the computer code. All pertinent components of the conceptual model, numerical model construction, and model code should be documented in a report section on numerical modeling.

The reporting should allow reviewers and decision makers to formulate their own opinions as to the credibility of the model. Present the modeling findings, procedures, and assumptions inherent in the study area in detail enough that an independent modeler could duplicate the model results.

Information presented in these guidelines is paraphrased or derived directly from two primary sources: 1) ASTM Standard D5447-93; and 2) Anderson and Woessner, 1991.

The application of a groundwater model ideally would follow several basic steps to achieve an acceptable representation of the physical hydrogeologic system and to document the results of the model study. The primary study steps that should be included in modeling documentation are:

- The primary study steps that should be included in modeling documentation are:
- Define the study area, study objectives, and model objectives;
- Develop a conceptual model with estimated uncertainties;
- Describe the model design and modeling results, including information on calibration and sensitivity testing, as well as any verification studies;
- Describe model limitations;
- Summarize significant findings and conclusions;
- Document references;
- Develop appendices that include supporting data.

These steps are designed to ascertain and document an understanding of a system, the transition from conceptual model to mathematical model, and the degree of uncertainty in the model predictions. The use of these guidelines to develop and document a groundwater flow model does not guarantee that the model is valid.

7.1 Define the Study Area, Study Objectives, and Model Objectives

The study area, study objectives, and model objectives should be clearly defined before starting a modeling project to provide the reader with a basis for evaluating the validity of the modeling application and the results. The objectives and scale of a study dictate the approach, modeling code, design, and data needs. A model constructed to accomplish particular objectives at a particular study area may not be suitable for accomplishing a different set of objectives at the same area.

7.2 Conceptual Model - Understanding of the Hydrogeologic Setting

7.2.1 Geologic Framework

Describe the distribution and configuration of aquifers and confining units. Of primary importance to document are the thickness, continuity, grain size and fracture distribution, and geologic structures of those units that are relevant to the purpose of the study.

7.2.2 Hydrologic Framework

Describe the hydrologic framework in the conceptual model includes the physical extents of the aquifer system, hydraulic features that impact or control the groundwater flow system, analysis of groundwater flow directions, media type, and porosity and permeability. The conceptual model should address the degree to which the aquifer system behaves as a porous media (fracture or matrix porosity and permeability, or both).

7.2.3 Hydraulic Properties

Document field and laboratory measurements of the hydraulic properties used in the conceptual model and to set bounds or acceptable ranges for guiding model calibration.

7.2.4 Sources and Sinks

Sources and sinks of water to the aquifer system impact the pattern of groundwater flow. The most common examples of sources and sinks include recharge, evapotranspiration, pumping wells, flowing wells, injection wells, drains, and flow to or from surface water bodies. Identify and describe sources and sinks within the aquifer system in the conceptual model. The description includes the rates and temporal variability of the sources and sinks.

7.2.5 Hydrologic balance

Quantifying sources and sinks should include a discussion of methods of estimating or calculating the various parts of the hydrologic balance.

7.2.6 Data Deficiencies and Potential Error Sources

Provide an analysis of data deficiencies and potential sources of error with the conceptual model. The conceptual model usually contains areas of uncertainty, because of the lack of field data. Identify these areas and their significance to the conceptual model evaluated with respect to project objectives.

7.3 Model Design and Results

Indicate the purpose of the modeling exercise. State the code used, the relation between the parameter values used in the model and those used to formulate the conceptual model, calibration targets and procedures, modeling results, and a demonstration of model sensitivities. Describe the appropriate use of the simulation results.

7.3.1 Computer Code Description

The computer code that was used should be described and why that particular code was selected. Only a reference citation is needed to describe the code if a well-documented, public-domain code is used without modification.

7.3.2 Model Construction

Describe how the conceptual model was translated to the grid of the numerical model. The description should include how space and time were descretized, how model boundaries were defined, and how parameter values were assigned to each node or element of the model grid.

7.3.3 Spatial and Temporal Dimensionality

The selection of a two-, three-, or quasi three-dimensional approach should be justified based on the conceptual model of the flow system. Specify the temporal dimensionality used in the model.

7.3.4 Spatial Discretization

In numerical models such as Modflow (McDonald and Harbaugh,1988), spatial discretization is a critical step in the model construction process. The number of grid blocks or elements and the number of nodes in the grid should be specified. The relation between hydrogeologic units and model layers, as well as locations of model boundaries should be illustrated.

7.3.5 Temporal Discretization

The temporal discretization (i.e., number and size of time steps) used in the model should be specified in the model report. Describe the stress periods.

7.3.6 Boundary Conditions

Specify the boundary conditions used in the model should be specified in the model report.

7.3.7 Initial Conditions

Initial conditions provide a starting point for transient model calculations. In numerical groundwater flow models, the initial conditions consist of hydraulic heads (and surface water levels) specified at the beginning of the simulation. Specify the origin of the initial conditions.

7.3.8 Hydraulic Properties

Clearly state the source of the hydraulic property values used in the model.

7.3.9 Stresses

Discuss the method and rationale used to assign stresses. The types of stresses and assumptions made in locating the stresses should be described in the text.

7.3.10 Calibration

Describe how model calibration was achieved. Illustrations and statistics should be included in the report to show the similarities and differences between the observed and simulated values. Multiple types of data should be used in model calibration. Models calibrated to only head data or flow data are often of limited use.

7.3.11 Sensitivity analysis

Document the sensitivity of the modelling results to variations made to parameter values, grid size, boundary conditions, and calibration criteria. Discuss and justify the scope of the sensitivity analysis and provide a set of illustrations showing the results of the analyses.

7.3.12 Predictive Simulations

Document all the data inputs and assumptions used in predictive simulations. Describe thoroughly the changes made to the model to generate the predictive change.

7.3.13 Model Limitations

State modeling limitations and assumptions, and discuss the reliability of the calibration and the sensitivity of the model to various parameters in the context of the assumptions used in constructing the model. Also discuss the degree of uncertainty of the model predictions and the appropriate use of the modeling results. An option is to suggest future work to modify or improve the model.

7.3.14 Summary and Conclusions

Present a brief summary of the modeling results that include important information learned from the modeling effort. List conclusions derived from the modeling effort.

7.3.15 References

Provide a complete list of references that help support all aspects of the modeling study.

7.3.16 Appendices

Appendices should contain additional or supplemental information such as documentation of modified computer code or listings of the code. Compilations of geologic logs, well inventories, water level measurements, determinations of hydraulic parameters, and details of hydrologic balance calculations also should be included to support the discussions in the text. If data input files are not included in the appendices, the accessibility and location of these files must be mentioned in the text.

8.0 CONCLUSIONS

Conclusions and Recommendations must be based and supported by information and data provided in the report. Further, they must follow defensible scientific practices. The conclusions section is not the place to present an issue or data for the first time in a report. Issues presented in a conclusions section must be based on data presented and discussed previously in a report.

9.0 RECOMMENDATIONS

While recommendations may assist the client in evaluating a potential next phase of work for a project, some clients may prefer that recommendations be prepared and submitted separately, and if this is the case the report should clearly state this

Explain in the report whether recommendations are provided and if so how and where the reader might obtain that information.

10.0 REFERENCES AND DATA SOURCES

A basic foundation of hydrogeology reports is the inclusion of technical references as with any report of a scientific nature. If a reference is not given, then the author is suggesting credit for the data or idea. While reference styles may vary widely, depending upon agency or firm styles, a common and useful reference guide for the presentation and listing of references is found in Suggestions to Authors of the Reports of the USGS (1991; page 234).

11.0 FIGURES, MAPS, PLATES, AND DIAGRAMS

Figures, maps, plates, diagrams, charts, and other data illustration tools are important to the interpretation of hydrogeology reports. Maps should be prepared on a suitable topographic base or aerial photograph, at an appropriate scale with satisfactory horizontal and vertical control. Figures should provide enough information to be useful but not so all-inclusive that they do not get the message across to the reader.

Typical hydrogeology report maps should show:

- An outline of the study area with major geographic features,
- The location of the study basin or regional study boundaries,
- Study areas of the U.S. Geological Survey Water-Supply Papers, State of Oregon Groundwater Reports, and other published maps in the study area or region,
- The surficial extent or expression of hydrogeologic units,
- The distribution of various data , such as distribution of average annual effective recharge for various systems, total groundwater pumping volumes in the study area.

Diagrams should indicate:

- Geologic cross-sections,
- Hydrogeologic sections,
- Topographic sections,
- Fence diagrams,
- The extent and thickness of aquifer units,
- Water levels for aquifer units,
- Daily water level fluctuations in wells,
- The regional relation between generalized geologic units and hydrogeologic units,
- Statistical distributions of hydraulic conductivity, specific capacity, or other aquifer properties of hydrogeologic units,
- Chemical data distribution,
- Grids and layers for cross-sectional groundwater flow models,
- Model grids and layers with pathlines.

Charts should illustrate:

- Mean annual and mean monthly precipitation,
- Mean monthly discharge for the study area major streams or tributaries,
- Water-level hydrographs,

- Contaminant fate and transport maps,
- Groundwater modeling results.

The above examples may not apply to all hydrogeology report but are commonly included. Overall, report maps should include:

- Scale (or indicate the map is not to scale),
- North arrow,
- Units of measurement or count,
- Representative site features,
- References to the date of groundwater data collection, and associated supporting data (i.e., field forms, spreadsheets).

12.0 TABLES

Tables are important tools to be used for the interpretation of collected data and provide the user/reviewer the ability to quickly scan a data set. Tables should not be a substitute for properly showing spatial data trends represented by figures. Data tables should be formatted to clearly show trends. If selected data are used in the table, there should be a note in the table stating this.

Typical hydrogeology report tables include:

- Discharge characteristics for selected rivers;
- Data collection summary,
- Analytical results,
- Well inventories,
- Precipitation and recharge rates,
- Groundwater pumping rates and volumes,
- Statistical summaries of water-quality characteristics,
- Data estimations, calculations, and results,
- Model grid system information,
- Stream and spring inventories and locations, properties, and discharge rates for cross-sectional flow models,
- Hydraulic characteristics used in models,
- Flow budgets for cross-sectional models.

Driller's log data generally should utilize the data provided by the OWRD well log search database output.

13.0 APPENDICES

As with any report, appendices present data supportive of the main text of the report. While it is not necessary to be exhaustive in inclusion, appendices may contain such information as:

- Boring and well logs;
- Laboratory reports;
- Raw data (i.e., field sheets);
- Groundwater modeling data and results and calibration inputs;
- Water analysis methods used; and
- Other material that supports the text, tables, or figures, for example model files on CD.

There is considerable flexibility as to how the main body of the report is organized as well as the content of technical appendices. The methods, results and analyses of field investigations often are placed in technical appendices, along with data presentations, and copies of technical documents that are necessary to make the report as complete as possible.

14.0 DISCLAIMER

Professional judgment is required in preparing a hydrogeology report. As such, these guidelines are intended to describe many of the topics that should be considered when preparing hydrogeology reports and may be used in tandem with other guidelines, as applicable. On projects encompassing a broad spectrum of work in geology, engineering geology, water resources, environmental hydrogeology, or other areas of hydrogeology, federal, State, and local guidelines should also be considered. These guidelines will be revised as warranted.

The nature and scope of hydrogeology studies range from the very simple to highly complex and understands that it is neither possible nor necessary to institute a single standard to the preparation of hydrogeology reports. Within the broad range of project types, it is useful to consider a general subdivision of projects into two general types:

- A "preliminary" study typically limited to the review and interpretation of existing data, sufficient to result in a qualitative understanding of the groundwater system.
- A study that builds on existing data by collecting new information, (frequently involving some form of subsurface exploration, testing, and data analyses) and results in a more quantitative understanding of the groundwater system.

This format is not applicable to all hydrogeology reports (particularly those for multi-phase or multidiscipline projects) provided that appropriate references are cited.

In addition, reporting guidelines already exist (as developed by State agencies (i.e., Oregon Department of Environmental Quality [DEQ]) for contaminant-focused groundwater investigations and reports that are performed as part of remedial investigation/feasibility studies (RI/FS) studies at contamination sites.

It is suggested that hydrogeology reports prepared by Oregon registrants follow these general guidelines. Further, it is suggested that reports explain reasons for deviating from the guidelines. While not comprehensive in its approach, these guidelines attempts to cover basic topics encountered during preparation of typical hydrogeology reports. Not all items would be applicable to each project site. Therefore, professional discretion is recommended in trying to apply all of the topics presented here to every project and resulting subsequent reports. These guidelines will be revised as warranted.

15.0 REFERENCES USED

ASTM, American Society for Testing and Materials, www.astm.org.

Anderson, M. and W. Woessner, 1991. Applied Groundwater Modeling: Simulation of Flow & Advective Transport; Academic Press, 381 p.

Giggenbach, W.F. and Goguel, R.L. 1989. Collection and Analysis of Geothermal and Volcanic Water and Gas Samples; DSIR New Zealand, Report No. CD 2387, 53 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite difference ground-water flow model: U.S. Geological Survey, Techniques of Water Resources Investigations, book 6, chap. A1, 586 p.

Oregon State Board of Geologist Examiners, 1996. Guidelines for Preparing Engineering Geologic Reports in Oregon.

U.S. Geological Survey, 1991. Suggestions to Authors of the Reports of the United States Geological Survey, Seventh Ed., U.S. Government Printing Office.