PROCEDURAL GUIDELINES FOR HYDROGEOLOGIC INVESTIGATIONS

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INTRODUCTION

Since 1917, the concept of "prior appropriation" has been the central tenet of Washington water law. This means that, "as between appropriations, the first in time shall be the first in right" (RCW 90.03.010). The ground-water code, passed in 1945, extended this principle to include ground-water withdrawals (RCW 90.44.020). Subsequent statutes clearly require the protection of prior surface-water rights from junior ground-water withdrawals (RCW 90.44.030 and RCW 90.54.020). These statutes could result in denial or restrictions on many ground-water applications due to potential impairment of surface-water rights. With surface water fully appropriated in many streams, this creates a dynamic tension between protection of our water resource and accommodation of ground-water development for new growth.

"Hydraulic continuity" refers to the hydraulic connection and dynamic interactions between ground water and surface water. An aquifer is in hydraulic continuity with lakes, streams, rivers or other surface water bodies whenever it is discharging to, or being recharged by, surface water. Where hydraulic continuity occurs, surface water and ground water cannot be considered as separate sources. A withdrawal from one will have some effect on the other.

Determination of hydraulic-continuity effects, such as the impact of ground-water withdrawals on stream flow, is technically complex. The magnitude of effect is a function of many variables including, among others, time, distance between the well and surface-water body, permeability of the soils, and the hydraulic characteristics of aquifers and confining layers. Data for detailed analyses are often inadequate but the money and time to collect new data are rarely available. Therefore, hydrogeologists must often do evaluations based on available data only. This means hydrogeologists must make assumptions about the water-transmitting properties of the aquifers and aquitards in the local hydrogeologic system. Obviously, the more we know about a hydrogeologic system in an area of concern, the better our assumptions will be. A clear understanding of the hydrologic dynamics in a basin, will result in better calculations and estimates of impacts related to hydraulic continuity. This, in turn, will result in logical, scientifically defensible technical conclusions.

Hydrogeologists (HG's) play key roles in the hydraulic-continuity issue because of the need to describe and quantify the extent of hydraulic interconnection between ground water and surface water at specific sites.

The following are procedural guidelines for conducting hydrogeologic analyses in support of water-rights administration in the Water Resources Program. We have specifically written procedural *guidelines* instead of standard procedures because the varied geology in Washington precludes use of standard procedures. These guidelines were originally developed for hydrogeologic analyses related to hydraulic continuity but they are equally applicable to any hydrogeologic analysis, such as for well interference or sea-water intrusion.

PHILOSOPHY

1. The hydrogeologist's role is to provide timely, objective, defensible, and unbiased analyses using "the best available information, professional judgement, and qualitative and quantitative analysis" (quoted material from: Draft Hydraulic Continuity Policy, Sept. 1992).

2. Thorough documentation of all technical work, organizing and filing information for future reference (including data entry into computer data bases and GIS applications), and taking the time to learn and apply new technical methods are all part of an HG's regular duties.

3. "Given the highly variable geologic conditions in Washington State, basin-specific hydraulic continuity evaluations should be conducted. Furthermore, these evaluations need to examine the problem from a basin-wide perspective (not simply application-by-application), so that cumulative effects of diversions and withdrawals can be taken into account." (Draft Hydraulic Continuity Policy, Sept. 1992).

4. Daily work on case-by-case analyses or analyses of a group of geographically-adjacent applications will be used to gradually build basin-wide[1] technical understanding.

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[1] As used herein, "basin" refers loosely to either a ground-water basin or drainage basin - something that can be related to the flow and/or the storage of water and is separated from adjacent basins by geologic or hydrologic boundaries. Fetter (1988) defines drainage basin as, "The land area from which surface runoff drains into a stream system". He defines ground-water basin as, "A rather vague designation pertaining to a ground-water reservoir that is more or less separate from neighboring ground-water reservoirs. A ground-water basin could be separated from adjacent basins by geologic boundaries or hydrologic boundaries". "Basin" does *not* refer to huge features such as WRIA's or river basins - these large features must be broken down into workable units, sub-basins or even sub-sub-basins that can be reasonably evaluated with respect to local water rights.

5. Applications within the same watershed or area will be dealt with as a group, to the extent possible.

6. The determination of the "significance of the effect" of ground-water withdrawals on streamflow or the "significance of impairment" on senior rights cannot be determined by technical methods. Technical methods provide objective, quantitative and/or qualitative estimates of an effect. Since a specific standard of significance has not been defined *by policy*, HG's have no basis for determining, and cannot be expected to determine, "significance".

GROUND RULES

1. All applicable sources of information that can be obtained within a reasonable time should be used.

2. All sources of information should be documented clearly for future reference, preferably in computer files backed up by hard copy.

3. The technical evaluation process followed should be documented clearly for future reference, preferably in computer files backed up by hard copy.

   Technical conclusions and supporting information should be described in a report. The report may be a memorandum, a Water Resources Program Open-File Report, or a formal Ecology publication depending upon the scope of the analysis and the intended audience. Memo reports that contain data, technical discussions, or conclusions should be included in the Water Resources Program Open-File Report series, if appropriate.

4. As Program computer capabilities expand, HG's will be able to utilize that technology. It is expected that the Program will develop data management capabilities, such as a ground-water database, which will employ Management Information Systems and Geographic Information Systems (MIS and GIS, respectively). This will allow for storage, organization, manipulation, and analysis of data. Such systems will supply output of reports and maps and will facilitate retrieval and use of information for subsequent researchers.

5. Initial technical analyses should normally be completed prior to initiation of field data collection.

6. HG's should strive to complete initial technical analyses before additional information is collected through issuance of preliminary permits.

7. When preliminary permits are issued, HG's should be very specific about what data is to be collected, why it is needed, and what is to be accomplished by data collection.

8. The following minimum hydrogeologic conclusions are common to all initial hydraulic continuity analyses and should be provided regardless of how much information is available. Initial analyses should be based on the best available information, professional judgement, and qualitative and quantitative analysis. The level of confidence in the conclusions and the supporting data should be clearly indicated and, where necessary, ranges of possible answers should be given.

   a. Minimum hydrogeologic conclusions:

      i. Which aquifer will be pumped?

      ii. To which stream(s) or other aquifer(s) may the pumped aquifer be hydraulically connected?

      iii. Which stream(s) may be affected by pumping?

      iv. Will the pumping affect any stream indirectly through another aquifer?

      v. When pumping for a permit will occur year around, the effects of the pumping will eventually reach a steady-state condition. That is, the hydraulic and hydrologic effects of pumping will have become fully developed and no further hydraulic or hydrologic changes will result from the specified pumping.

      The time needed to reach a steady-state may vary from less than a day to many thousands of years, depending upon the hydrogeologic setting.

      In the strict and exact sense, once the steady-state occurs, 100% of the pumped ground water will be captured from streamflow, somewhere in the drainage basin and not necessarily from the closest stream reach.

      vi. For seasonal pumping, using best professional judgement, but not necessarily any mathematical method, estimate how much streamflow will be reduced, relative to a percentage of the pumping rate, during or for some time after the pumping. It may be helpful to place this estimate within a range of streamflow reduction such as, <25%, 25% to 50%, 50% to 75%, or 75% to 100% of the pumping rate.

b. Optional hydrogeologic conclusions:

   i. Refine the prediction of stream-flow depletion if a simple analytical model can be applied to the hydrogeologic setting.

   ii. For seasonal pumping, predict the seasonal timing of the depletion if a simple analytical method can be applied to the hydrogeologic setting.

   iii. For groups of applications, and where the extra effort is warranted, refine the predictions of the quantities and timings of depletion using a 2- or 3-dimensional numeric computer model.

   iv. Use any appropriate analytical method from simple 3-point problems to complex methods such as Darcy-flux/flow-tube analyses, that help to clarify the hydrogeologic characteristics of the basin.

CASE-BY-CASE VS. BASIN-WIDE ASSESSMENTS

Technical analyses of hydraulic continuity may be directed toward either: 1) assessments of individual (case-by-case) water-right applications, or 2) basin-wide assessments which apply to groups of applications and future applications by providing a comprehensive understanding of basin water resources.

The difference between the technical analyses in these two cases is more of magnitude than substance. The information needed to reach technical conclusions in each case is essentially the same. With the case-by-case approach, however, information gathered for individual cases may overlap data gathered for previous or later cases. Data may be stored in an individual case file and may be difficult to find or lost to subsequent researchers. As a result, the case-by-case approach tends to waste time because of duplicated efforts. The basin-wide approach may initially appear time consuming, but the process tends to promote consistent and technically defensible conclusions because of the regional perspective used. Deliberately planned, basin-wide assessments should result in greater time savings and better organization of supporting data.

IMPORTANCE OF BUILDING A CONCEPTUAL UNDERSTANDING OF HYDROGEOLOGIC RELATIONSHIPS

All analyses of hydraulic interactions between ground-water and surface-water (hydraulic continuity) require a conceptual understanding of the basin hydrogeology. This is true whether the assessment is for an individual application (case-by-case) or for a group of applications (basin-wide). A conceptual understanding of basin hydrogeology is the foundation for all subsequent technical analyses and conclusions about hydrogeologic relationships within the basin. Subsequently, the clearer the conceptual understanding, the easier, more accurate, and defensible the technical analysis will be.

Methods to build a conceptual understanding may vary widely depending upon the hydrogeologic character of the area and the methods preferred by individual hydrogeologists. In all cases, though, the conceptual understanding should be based on sound scientific principles, best available information, and sound professional judgement.

ELEMENTS OF TECHNICAL ANALYSES

The following is a listing of elements that are important to technical analyses for water-rights processing and building a clear, conceptual understanding of hydrogeologic relationships. The elements are arranged in the approximate order in which they would be done in a typical technical analysis. These elements apply to both case-by-case analyses and basin-wide analyses.

It is important to realize that the following is not intended to be a comprehensive listing, but suggestions only. ***Each ground-water or surface-water basin is distinctly unique.*** *This uniqueness necessitates flexibility in the analytical approaches used. Just because an analytical approach is listed here does not mean it is necessarily appropriate for all basin analyses. Conversely, if an analytical approach that would be useful in a particular situation is not listed, it should be used in spite of not being on this list.* ***An analytical approach that works well in one case may be inappropriate in another.*** Innovative approaches, so long as they are appropriate to the hydrogeologic situation, are strongly encouraged.

I. Coordinate Ecology's technical work with regional/basin planning efforts. There are many entities outside of Ecology involved in sundry water resource planning efforts. Ecology is usually involved, to some extent, in these projects and it would be prudent and advantageous to coordinate our work with these efforts.

II. Compile available data[2]

A. Sources of published reports are:

1. U.S. Geological Survey

2. Geologic Maps

3. Washington Department of Ecology

4. Washington Department of Natural Resources, Division of Geology and Earth Resources

5. Graduate Theses and Doctorate Dissertations

6. Soil Conservation Service

7. Ecology Grants Program reports such as those generated by the Ground-Water Management Area (GWMA) Program

B. Sources of unpublished reports are:

1. Ecology in-house studies

2. Ecology letter/memo reports

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[2] Compilation of available data and study of published reports is an initial and mandatory aspect of any technical study. In spite of it's importance, this aspect of study may be neglected during case-by-case analyses because of a perceived lack of time. Using a basin-wide approach, data for a particular basin is used to build a conceptual understanding of basin hydrogeology and to evaluate multiple water-right applications within the basin. This approach makes it easier to recognize data relationships in the basin. In the case-by-case approach, however, the same data sources are often reviewed repeatedly yet relationships between sites may remain obscure. This situation is compounded when more than one hydrogeologist is working on different applications within the same basin. This problem illustrates the importance of follow-through at the end of case-by-case work. If information learned during case-by-case evaluations is routinely entered into a ground-water database and the information is used to periodically up-date a Geographic Information Systems (GIS) database and maps, then a great deal of duplicated effort could be avoided.

3. Well construction reports

4. Consultant's reports

C. There are also many miscellaneous unpublished sources:

1. Verbal communication with known authorities in the area of interest

2. Water rights in a basin of interest or in the vicinity of a water-rights application (WRATS, WRIS, or Regional files)

3. CD-ROM files at Ecology Headquarters (contains stream flow data and climate data).

4. NWIS (contains USGS well-construction, water-level and water-quality data).

5. STORET (contains EPA water-quality data)

6. WA Dept of Health has water quality data for public water systems

7. County and city governments often have sundry hydrology data that they are willing to share.

8. Irrigation district or reservoir records

III. Plot pertinent data on maps and enter into database (when it becomes available) so it can be manipulated and used for the analysis.

IV. Based on available information, construct maps and diagrams of the geology and hydrogeology

A. Maps

1. Geologic map

2. Structure-contour maps

3. Well-distribution maps and cross-sections showing lateral and vertical

distribution of wells.

4. Areal extent of confining layers

5. Areal extent of aquifers

B. Cross-sections and/or fence diagrams

C. Columnar sections of well logs

V. Based on available information, construct maps, diagrams, and graphs of the hydrology

A. Water-level-contour maps.

B. Ground-water-flow-direction maps.

C. Evaluate aquifer (pump) tests to determine hydraulic properties of aquifers and aquitards.

1. Plot the aquifer-test data

a. Time-drawdown graphs

b. Time-recovery graphs

c. Distance-drawdown graphs

d. Residual drawdown graphs

2. Calculate the hydraulic properties[3] of aquifers such as:

a. Transmissivity (T)

b. Storativity (S)

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[3] The level of confidence in calculated aquifer properties should always be indicated along with the methods and assumptions that were used.

c. Horizontal and vertical hydraulic conductivity (K) of aquifers and confining layers. These values can be estimated by using basic assumptions about the relative aquifer and aquitard characteristics or by using published tables of typical values such as in Freeze & Cherry (1979, p. 29) and Davis (1969).

d. Estimate transmissivity (T) from well-log specific capacity data if aquifer test data are limited.

D. Construct distribution maps of aquifer properties (T, K, and others).

E. Define ground-water-flow boundaries

F. Plot water-level hydrographs for wells

G. Plot stream flow hydrographs

H. Water-quality information and maps

Note: Many of the graphics listed in parts IV and V, above, can be generated by Geographic Information Systems (GIS) or computer mapping software. If GIS or computer mapping software is used to create appropriate technical illustrations as an investigation progresses, the task of updating the data base, listed in part XII below, pretty much takes care of itself. The time needed for follow through at the end of projects should be shortened considerably.

VI. Field investigations[4]

A. Field check geology and hydrology to resolve conflicting information or to gain basic knowledge needed for the evaluation at hand.

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[4] Due to tight time constraints on the permitting process, field investigations must be limited mostly to field checks of published geology, data collection to gain a "snap-shot" look at water levels or stream flow, or field inspections of an applicant's hydrogeologic situation. Long-term data collection or extensive hydrogeologic field work would have to be pre-approved as part of a specific project designed to answer technical questions of basin-wide or state-wide concern.

B. Collect local data critical to the investigation. Data collection should be limited to work that can be justified by immediate data needs of the project.

VII. Revise the geologic and hydrologic interpretations of sections IV and V above, as necessary, based on information learned in the field investigations.

VIII. Analyze the basic water budget[5] (water balance) or the head response to stresses.

A. Traditional methods of water-budget analyses generally incorporate basic elements such as:

1. Precipitation

2. Evapotranspiration (ET)

3. Runoff

4. Soil moisture holding capacity

5. Ground-water recharge

6. Ground-water discharge

7. Water use - considering consumptive/non-consumptive use

B. Practical Methods: In lieu of a formal water-budget analysis, alternative practical approaches such as an "aquifer head-response analysis" may be appropriate. In such an analysis we may attempt to do the following:

1. Determine the aquifer's long-term head response to ground-water and surface-water withdrawals, and urban or agricultural development. Long-term seasonal hydrographs can be plotted to determine if aquifers

[5] Water-budget analyses can be a valuable tool for gaining a conceptual understanding of basin hydrology. However, some of the elements of water budgets, such as ET, recharge, discharge, and water use are difficult to ascertain and are often derived through the use of assumptions. The veracity of the water budget analysis can be questioned if the assumptions used and inherent limitations are not factored into the analysis.

are being dewatered or if they are able to recover seasonally.

2. Estimate how urban development in recharge areas affects recharge.

   a. Returns from on-site septic systems

   b. Creation of impermeable surfaces such as housing and commercial developments, parking lots, and industrial development.

   c. Large scale site de-watering

   d. Existence of storm water retention or drainage facilities - attempts to recharge aquifers with captured storm water

3. Estimate how area aquifers would react to installation of sewers in the area.

IX. Analyze ground-water flow and ground-water/surface-water interactions.

A. Do analyses, as necessary, to reach the hydrogeologic conclusions as listed in No. 8a of the ground rules, above.

B. Do optional hydrogeologic analyses, if appropriate, as listed in No. 8b of the ground rules, above.

X. Analyze the need for additional data and recommend long-term data collection or further studies.

A. Long-term-monitoring networks

1. Surface-water flows

2. Lake levels

3. Ground-water static water levels

4. Ground-water quality

B. Water-use-monitoring networks

XI. Coordinate data-collection efforts

A. Data collection by Ecology

B. Cooperative data collection by water-right owners and water-right applicants

C. Cooperative data collection by tribes, local governments, or volunteer groups.

D. Data collection required by permits or certificates

XII. Follow through with projects and coordinated data collection (section XI) to get all information into the data base for future reference and updates of GIS maps.

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