A QUALITY-ASSURANCE PLAN FOR DISTRICT GROUND-WATER ACTIVITIES OF THE U.S. GEOLOGICAL SURVEY

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ABSTRACT

As the Nation's principal earth-science information agency, the U.S. Geological Survey (USGS) is depended upon to collect data of the highest quality. This document provides the framework for collecting, analyzing and reporting ground-water data that are quality assured and quality controlled.

INTRODUCTION

The Water Resources Division (WRD) of the U.S. Geological Survey (USGS) performs a wide variety of ground-water data-collection programs and investigations to assess the status of the Nation's ground-water resources. Results of these activities are used to aid the Nation in developing, managing, and maintaining its ground-water resources.

As the Nation's principal earth-science information agency, the USGS is depended upon to collect accurate data and produce factual and impartial interpretive reports. Methods for data collection and analysis that were developed by the USGS have become standard techniques used by numerous Federal, State, and local agencies and by private enterprises. Data collected by scientific organizations such as the USGS are being used increasingly by the public to define and examine a variety of natural-resource and environmental problems. Many of these problems are addressed through an open, public process. As a result, scientific organizations are being challenged to demonstrate the credibility of their data on the basis of objective evidence rather than on the organization's history and reputation.

To address these demands and expectations, the WRD has implemented a program designed to ensure that all scientific work done by or for the WRD is conducted in accordance with a quality-assurance (QA) program. The Office of Ground Water (OGW), in coordination with the Branch of Technical Development and Quality Systems, has the responsibility to develop, coordinate, and implement the quality-assurance program for District ground-water activities. As part of that program, the OGW has directed the preparation of a Ground-Water Quality-Assurance Plan (GWQAP) which covers all ground-water activities by District offices of the USGS. USGS Open-File Reports (OFR) 92-136 (Schroder and Shampine, 1992) and 92-162 (Shampine and others, 1992) outline the guidelines for preparing District quality-assurance plans and

integrating the quality assurance into project work plans. Guidelines presented here are intended to supplement these two reports and provide more specific details related to ground-water activities.

A quality-assurance plan (QAP) can be defined as a formal document that describes the management policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of a responsible organizational unit or group for ensuring quality in its products. The implementation of a GWQAP will enhance ground-water data collected by the USGS by providing for the following:

- Consistency (across projects, subdistricts, WRD, and so forth);
- Accountability (to client, scientific community, and regulatory agencies);
- Comparability (yields results of known quality);
- Traceability (written record of how, who, and when work was performed, training, equipment, etc.);
- Repeatability (documentation of technique that leads to the similar results time after time with the same accuracy).

This report is a quality-assurance plan for ground-water activities conducted by the USGS and is meant to complement quality-assurance plans for surface-water and water-quality activities and similar plans for District and general project activities throughout the USGS.

The purpose of this GWQAP is to establish a minimum set of guidelines and practices to be used by Districts to assure quality in ground-water activities. Included within these practices are the assignment of responsibilities for implementing quality-assurance activities in the District and establishment of review procedures needed to ensure the technical quality and reliability of the ground-water products.

This report presents quality-assurance policies pertaining to the collection, processing, analysis, storage, review, and publication of ground-water data. In addition, policies related to organizational responsibilities, training, and project planning are presented. These policies and practices pertain to all ground-water activities conducted by or for the District offices of the USGS. Ground-water activities include all tasks pertaining to data-collection programs, interpretive and research projects, and data management.

ORGANIZATION AND RESPONSIBILITIES

Though quality assurance is a personal responsibility of all employees of the USGS, ultimate quality-assurance responsibility within each District lies with the District Chief. Clear statements of specific responsibilities promote an understanding of each person's role in the overall process of assuring quality and can help to prevent errors and deficiencies that may otherwise occur. Implementation and follow-up responsibilities lie with data-collection staff, project chiefs, section chiefs, discipline specialists, District Chiefs, regional specialists, and others. Even if quality-assurance responsibilities are ancillary duties for some employees, these functions are to be documented.

The following is a list of specific responsibilities of District personnel for implementing the GWQAP for ground-water activities.

The District Chief is responsible for:

- Managing and directing the District program, including all ground-water activities.
- Ensuring that ground-water activities in the District meet the needs of cooperating agencies, including state and local agencies; the general public; and the Federal Government.
- Ensuring that all aspects of this GWQAP are understood and followed by District personnel.
- Providing final resolution of any conflicts or disputes related to ground-water activities within the District.
- Keeping District staff briefed on procedural and technical communications from Region and Headquarters.
- Ensuring that technical reviews of all ground-water activities are conducted.
- Ensuring that all publications and other technical communications released by the District are accurate and are in accord with USGS policy.
- Ensuring that ground-water training is incorporated into each employee's training plan, where appropriate.

The section chief is responsible for:

- Managing and directing ground-water activities assigned to the section and ensuring that the stated objectives are met in a timely manner.
- Reviewing the work plans for ground-water programs and projects.
- Providing the project chief with technical and administrative support as needed.

- Creating, with ground-water personnel in the section, a training plan for each employee, where appropriate.
- Reviewing ground-water reports under his or her direction.
- Monitoring progress of ground-water project chiefs in implementing the GWQAP for their respective projects.

The ground-water project chief is responsible for:

- Directing and conducting the technical work of the project, including all phases of data collection, data review, data storage, data analysis, and report preparation according to appropriate procedures.
- Communicating project plans, progress, and problems to supervisors by providing written progress reports at periodic reviews.
- Preparing written work plans, documenting project activities, and ensuring that data are placed in the USGS National Water Information System (NWIS) data base, as appropriate, prior to project termination.
- Maintaining a project file containing memoranda, personal communications, technical-procedure documents used, original data, and other documentation.
- Ensuring that project activities are carried out in a timely manner.
- Creating, with the supervisor, a personal training plan.
- Archiving of project files, at the completion of the project.

Some of the duties of the District ground-water specialist may be delegated to other personnel. For the remainder of this report, "District ground-water specialist" will refer to these individuals. The District shall appoint a ground-water specialist whose duties shall include but not be limited to:

- Maintaining current ground-water technical expertise for the District.
- Maintaining the ground-water technical-procedure documents file.
- Consulting with the District staff on ground-water technical matters.
- Advising on training needs for employees engaged in ground-water activities.
- Participating in technical reviews of ground-water activities.
- Reviewing ground-water related project proposals.
- Reviewing ground-water related project reports.

TRAINING

Employee training is an investment that has short-term and long-term benefits to District ground-water activities. The immediate benefits permit confidence that the work is being performed correctly and accurately. The long-term benefits provide for technically competent employees that are of great value to the organization. Because all work in the scientific arena is receiving increased scrutiny, the qualifications of ground-water personnel relative to the technical demands of the work to be performed must be well-documented. Training already received as well as current and planned training need to be incorporated into a documented training plan for each employee. Periodic reviews of these plans by District management will help determine additional training needs.

The following quality-assurance activities shall be performed by the District:

1. A written, reviewed, and approved training plan shall be prepared for each employee (including observers and volunteers, as appropriate) performing technical tasks relating to ground water.
    a. Each training plan shall include an individual's short-term training needs, such as the knowledge and skills needed to perform currently assigned tasks as well as long-term training needs, such as skills needed to perform future tasks and for career development.
    b. Training plans should be reviewed and updated at least annually.
2. Individuals shall receive appropriate training before assigned tasks are performed. Appropriate training includes new employee training, USGS National Training Center courses, mentoring, on-the-job training (OJT), vendor-provided training, and academic courses.
3. Each training activity shall be documented according to existing policy. The District shall establish a training file to facilitate cross referencing by critical task and individual training. Qualifications of contractors performing tasks shall be documented. Qualifications of cooperators (Federal, State, and local agencies) performing tasks shall be to the satisfaction of the District Chief.

PLANNING

Districts routinely conduct technical ground-water projects and data-collection programs. The success of these activities is dependent on a careful, deliberate, and systematic planning process. Quality-assurance requirements should be integrated into the project proposal, if one is required for the ground-water activity. Whether a ground-water program or project requires a separate quality-assurance plan should be evaluated on the basis of the complexity of the work, the needs of the District or cooperator, or other criteria as described by Shampine and others (1992).

A workplan shall be developed for every ground-water program or project. The workplan can be a part of the proposal or a stand-alone document. The complexity of the program or project will determine the detail of the workplan. The project proposal may satisfy the requirement of a workplan where ground-water activities are routine or highly standardized. The workplan shall include, as appropriate, data-collection and storage plans, equipment and instrumentation needs, data-analysis techniques, report plans, cost estimates, time schedules, availability of personnel, training needs, and other elements, as necessary. Without appropriate project planning (Green, 1991) and the documentation of individual project tasks, quality objectives and project deadlines may not be reasonably known. Initial project/ program planning can be guided by a detailed workplan, continued planning can be guided by periodic reviews.

Workplans

To quality assure workplans, the following steps shall be performed by the District:

1. Workplans for programs with ground-water activities should clearly state that the GWQAP will be implemented.
2. To the extent practicable, workplans should state data-quality objectives and describe the strategies to collect data to meet the intended use. When developing data-quality objectives, broader network needs should be considered as well as immediate objectives.

> ***Data-Quality Objectives*** are those qualitative and quantitative statements developed by data users to specify the quality of data needed from a particular data-collection activity. For example, in

order to describe land subsidence in an area, ground-water levels need to be measured using a particular method, at a particular frequency, and to a particular accuracy.

3. The workplan shall specify the means for cataloging and archiving all ground-water activities and files according to WRD policy (Hubbard, 1992).

Development of workplans might also include the following:

1. A bibliographic search of available reports, articles, data, and other pertinent information.
2. Retrieval of relevant data from existing data bases in order to determine the availability of and the need for additional data. Errors or inconsistencies in the data base should be identified and corrected at this time.
3. Review of other USGS file (paper) data, such as field canvass sheets, water-level records, geophysical logs, lithologic logs, water-quality laboratory analytical sheets, or other original data.

Project Reviews

Project reviews are conducted periodically by District management, technical advisors, or discipline specialists to ensure that project objectives are being met and to evaluate implementation of the GWQAP. Project reviews are used to maintain consistency in data collection, data analysis, and reporting. The following quality-assurance functions related to project reviews shall be performed by the District:

1. The District shall establish and implement a ground-water program and project review schedule that considers the technical development and progress of the endeavor. The District shall schedule regular, periodic reviews such as quarterly reviews, or at the 10-, 40-, and 70-percent (10/40/70) milestones of the project. Regularly planned reviews shall ensure that the ground-water program or project is implemented and performed in a manner that results in a quality product done efficiently. The 10/40/70 review process has been used by numerous Districts successfully. In general, the 10-percent review ensures that the project begins properly, that no major technical item is overlooked in

the planning, and that the objectives can be accomplished with the proposed approach. The 10-percent review is scheduled after initial reconnaissance, bibliographic and data-base searches, and before any systematic data collection. A topical outline and initial report writing are begun at this early stage. An annotated report outline, including draft illustrations, and a base map typically should be completed at this stage. At the 40-percent review, data collection is well underway, preliminary conclusions made, and any problems in achieving project objectives should be identified. The 40-percent review shall confirm that all the tasks are on track to meet the planned objectives. The purpose of the 70-percent review is to ensure that all the data required to meet the objectives have been obtained, that the data-analysis process is on schedule and is yielding expected or reasonable results, and that the report is on schedule.

2. The District shall develop a procedure for documenting project reviews. At a minimum the following information should be included in project review documentation:
   - Date of review.
   - Type of review (quarterly, 10/40/70, discipline).
   - Names of reviewers and/or attendees.
   - Response to recommended action items from the last review.
   - Status, plans, and problems with data collection, data analysis, and report writing.
   - Major findings.
   - Cooperator/customer contacts.
   - Training needs.
   - Recommended follow-up or action items.
   - Date for next review.
3. The District shall develop a procedure for archiving project review comments, addressing the presence or absence of project deficiencies and all actions to fix deficiencies or document why a fix cannot be made.

DATA COLLECTION

Documentation of Technical Procedures

Written records of exactly how data are collected are critical to establishing the consistency, comparability, repeatability, and traceability of scientific data. The methods

used to collect a specific data set shall be documented and the documentation shall be maintained with the data. For routine field activities, technical-procedure documents are a means of ensuring that detailed documentation is generated prior to data collection and shall be identified or prepared during the formal planning phase of the project, as applicable.

> A ***technical-procedure document*** is a detailed description of a sequence of actions to be used to collect data to ensure repeatability of the work and comparability of results.

If it is necessary to deviate from the technical-procedure documents when collecting data, then these deviations must be clearly described in the project records. When data-collection methods are new or experimental, a record of the conduct, progress, and results of these methods shall be maintained in a procedures notebook.

The following quality-assurance activities shall be performed by the District.

1. Technical-procedure documents shall be prepared for routine field data collection that is performed in support of ground-water activities. The water-quality aspects of ground-water activities that are addressed in the quality-assurance plan for water quality need not be duplicated. Technical-procedure documents shall be in place prior to data collection and shall contain the following:
    a. A cover sheet that indicates the technical-procedure document number, title, author or compiler, reviewer, approval, effective dates for the procedure, and identification number for any technical-procedure documents superseded by the current technical-procedure document.
    b. Purpose of the technical procedure; for example, "this procedure explains how to measure water levels within 0.01 feet by using a chalked steel tape."
    c. Identification of materials and instruments used to collect data.
    d. Quantitative statement of the accuracy of data collected using the procedure (for example, "to the nearest 0.1 foot") and limitations on the use of these data.
    e. Statements about the advantages, disadvantages, and assumptions of the procedure.

f. Step-by-step instructions to collect data that would enable an independent, qualified person to repeat the work and produce comparable results.
g. A description of how data collected by using the procedure are recorded and preserved.
h. A description of samples to be collected or used, if applicable.
i. A listing of technical references used to compile the technical-procedure document.
j. Attachments (field forms, operator's manual, diagrams, and other pertinent supporting information).

2. The technical procedure used to collect data shall be indicated on the field form.
3. The District shall establish and maintain a file of technical-procedure documents.
   a. Technical-procedure documents shall be identified with a unique number and cataloged and indexed.
   b. The file shall be maintained by the District ground-water specialist or designee.
   c. The file shall contain all current and superseded versions of technical-procedure documents.
4. Deviations from approved technical procedures shall be documented by the project chief and reviewed by the District ground-water specialist to determine if a formal revision of the technical-procedure document is warranted.
5. New or revised technical-procedure documents shall be reviewed by an independent reviewer and approved by the District ground-water specialist.
   a. Reviews shall address the following:
      1. Applicability and appropriateness of the selected methods for the intended purpose.
      2. Correctness of facts, figures, tables, and equations.
      3. Completeness and clarity of step-by-step instructions and technical content.
      4. Evaluation of the stated accuracy of the procedure.
   b. Approval of technical-procedure documents used within the District will be the responsibility of the District ground-water specialist. Upon approval, the technical-procedure document shall be placed in the District file and a copy of it forwarded to the Regional ground-water specialist.

Documentation of non-routine activities

1. When data-collection methods are new, non-routine, or research oriented and involve a high degree of professional judgement or trial-and-error, an active record of the conduct, progress, and results of the data collection shall be maintained in a procedures notebook. These records shall be prepared and maintained in accordance with the following:
   a. Prior to use of a procedures notebook, the project chief shall consult with the District ground-water specialist concerning the appropriateness of a non-routine method for planned data collection.
   b. Each procedures notebook entry shall include the names of the individuals performing the work, the date on which the work was performed, and the name of the individual making the entries.
   c. At the conclusion of the method development, procedures notebooks shall be placed in the project file.
2. The results of the technique developed in the procedures notebook shall be reviewed by the District ground-water specialist to ensure that work is proceeding in a technically appropriate and relevant manner.
3. If the technique which has been documented in the procedures notebook becomes a routine procedure for the District, then a technical-procedure document shall be developed.

Instrumentation

All instruments, devices, and equipment (including steel tapes) used to collect ground-water data are categorized as instruments. Because of the complexity of some instruments, their effect on the quality of the data may be unknown or unquantifiable. To ensure the consistency, comparability, and repeatability of collected data, instruments must be identified, calibrated, maintained, and operated in an appropriate manner.

> ***Calibration*** is the comparison of the output from an instrument to a standard or to the output from another instrument or procedure of known accuracy in order to detect, correlate, report, or eliminate by adjustment variations in the accuracy of the instrument being evaluated.

The following quality-assurance activities shall be performed by the District.

1. Instruments used to collect data shall be identified with a unique identifier on the field form.
2. Calibration procedures and schedules shall be established for each instrument based on the stability characteristics of the instrument, required accuracy, intended use, manufacturer's recommendation, and other conditions that may affect the quality of the data. The calibration procedure and schedule shall be documented in the technical-procedure document that requires use of the instrument, or in a stand-alone technical-procedure document if not satisfactorily documented in the user's manual for the instrument. Instruments shall be identified by type, manufacturer, and model. Calibration shall be performed whenever the accuracy of the instrument is suspect, regardless of the calibration schedule. Instruments consistently found to be out-of-calibration shall be repaired or replaced.
3. A log shall be maintained for each instrument requiring calibration. The log shall contain all information pertinent to calibration, whether performed by District staff or by an outside organization or vendor. Calibration documentation recorded in the log shall include:
   a. Name of organization and individual performing the calibration.
   b. Identification of the instrument by type, manufacturer, model, serial number, or other unique and permanent identifier.
   c. Identification of calibration standard, including the range and accuracy.
   d. Identification of the document that describes the calibration process.
   e. Date of current calibration and date or milestone for next scheduled calibration.
   f. Records of instrument readings before and after any calibration.
4. Data collected with instruments found to be out-of-calibration shall be evaluated to determine the effect on the intended use of the data. Affected data shall be discarded or their limitations documented in the data base and in any application of the data.
5. All instruments used to collect data shall be operated in accordance with the manufacturer's manual, unless otherwise documented. Modifications to the

manufacturer's operating procedure shall be appended to the manufacturer's manual, which shall be kept with the equipment at all times. Duplicate manuals for all instruments shall also be kept on file. Operating procedures may be included in technical-procedure documents.

6. Instrument maintenance shall be performed in accordance with the manufacturer's recommendations. A log shall be used to record maintenance performed.

Identification and Control of Samples

During the course of many ground-water investigations, samples of various types of earth materials are collected to supplement field observations or to allow laboratory tests, analyses, and measurements that are not possible to perform in the field. Types of samples include rock core, drill cuttings, soil, and outcrop. Because these samples can be critical scientific evidence to support interpretations, samples must be easily identifiable, handled and stored in a controlled manner, and be traceable. The relation between samples and the data set they represent must be maintained.

The following quality-assurance activities shall be performed by the District.

1. Develop a unique identifier which shall be placed on each individual sample or sample container using materials and methods that are clearly visible, legible, and durable.
   a. The unique identifier, as well as other information that is critical for the intended use of a sample (such as orientation), shall be recorded on field forms and laboratory log books.
   b. If a sample is subdivided for analysis, the sample identifier shall be transferred to each part of the sample, or its container.
2. Establish a sample-control system to record information pertinent to each set of samples. This may be achieved by maintaining a log book, a set of forms, or other appropriate documentation. The sample-control system shall contain the following information for each sample:
   a. Unique identifier
   b. Type of sample and general description
   c. Source location specifications (x, y, z)

d. Date and time of collection
e. Reference to technical-procedure document or procedures notebook describing sample collection, handling, preservation, transportation, and storage.
f. Storage location

3. Sample-control system documentation shall be placed in the project file.

DATA PROCESSING, REVIEW, AND STORAGE

A data-management plan describes the procedures used for data processing, review, and storage, and may also include archiving. After ground-water data are collected, they often are processed using one or more procedures, such as the application of time or datum corrections, and then are stored in computerized or physical files. Descriptive information on data-collection sites, such as well construction data and location, also should be stored. In general, data are most accessible and useful to the project chief and other District employees, as well as to those outside the District office, if they are stored in a computerized data base. Storage in a single data base also enables interpretations to be more easily verified and repeated. All water data collected as part of the routine data collection of the WRD, which are all ground-water data collected by basic data programs and District projects (OGW Technical Memorandum 93.03) (see appendix), must be stored in computer files of the USGS National Water Information System (NWIS). In addition, "all data collected by others -- such as cooperators, universities, or consultants --that are used to support published USGS documents and not published or archived elsewhere, shall be placed in NWIS" (Hubbard, 1992). Exceptions to these requirements are spatial data coverages and other data for which appropriate data-base capabilities do not exist in NWIS.

A quality data base is maintained by:

- checking data-base files against original data files to ensure accuracy,
- performing internal cross-checks of the data in the data base to identify anomalous data, and

- maintaining the original data in paper or electronic archives to ensure integrity.

> ***Original data*** are those data -- from automated data-collection sites, laboratories, outside sources, and non-automated field observations -- unmodified as collected or received, once put into conventional units (engineering units, generally with a decimal) (Hubbard, 1992).

The following quality-assurance activities shall be performed by the District.

1. All original data in paper form shall be placed in project or data-collection program files. Original data in electronic form shall be stored in NWIS. All original data shall be preserved unmodified as collected or received.
2. All data collected as part of the routine data collection of the WRD, and all existing data collected by WRD and others that are used to support published USGS documents and not published or archived elsewhere, shall be placed in NWIS unless excluded under current WRD policy (Hubbard, 1992). Excluded data are spatial data coverages and other data that cannot be stored in NWIS
3. The District shall prepare and implement a District Data-Management Plan, which documents established policies, conventions, and responsibilities for data processing, data review, handling project and data-collection program files, and computerized data bases. OFR 94-61 (Martin and Cohen, 1994), offers an example of such a document. The District Data-Management Plans shall:
   - Describe the processing of each type of data through such steps as entry on a field form, data review, data entry, and filing of the original data. Data processing that is described in a technical-procedure document may be referenced.
   - Include descriptions of filing systems for site data and maps, local well-numbering systems, requirements for field-checking sites, and District-specific data-base management policies and practices.
   - Indicate how the District ensures that data are reviewed promptly after data collection. Data reviews shall verify that as data are collected, they are entered in the data base and that the data in the data

base have been checked against the original data, including the processing of electronic data to original data, application of shifts and datums, correction of transducer drift, and so forth. Data reviews shall be documented during project reviews.

- Document any data bases external to NWIS. Documentation should include a description of data elements (data dictionary), information about the data base table or file structure, copies of customized program code, and information about any algorithms used by the data base to calculate results for storage or output. If the data base is described in a separate report, the documentation may be referenced by the District Data-Management Plan and a copy of the documentation kept with the plan.
- Include a plan for performing periodic internal checks of ground-water data in NWIS and any other ground-water data bases to identify and correct anomalous data.

4. Data shall be reviewed promptly after any data-processing procedure is completed to ensure that the procedure was correctly applied and that the results are consistent both internally to the data set and with other data for the same site. This review shall be performed prior to publication or other dissemination to the general public and prior to the technical review of publications that contain the data or that use the data in interpretations. The District shall establish a review schedule for data in addition to or in conjunction with other reviews. Reviews should be scheduled and implemented for data-collection programs as well as interpretive projects.

DATA ANALYSIS

Analysis of ground-water data includes activities ranging from simple statistical applications to the development and application of complex, numerical models. Quality assurance of data analysis begins with a well thought out and detailed workplan that describes methods and approaches of data analyses. Analysis procedures shall be reviewed as part of the proposal and workplan development, and during project reviews as appropriate. The methods by which data, or the results of data analyses, are "interpreted," such as the insight involved in the interpolation of water-level data to produce a potentiometric-surface map or

the interpretation of the results of model simulations, cannot be completely documented. However such interpretations must be appropriately qualified, including descriptions of model limitations and data uncertainty.

Reviews of data-analysis procedures ensure that selected analysis techniques are appropriate for meeting project objectives. Data-analysis techniques are identified, at least preliminarily, during development of the project workplan. During project reviews, at about 10 percent of project completion, after a better understanding of the project is developed, data-analysis procedures should be reviewed for suitability in meeting the project's objectives. At about 40 percent of project completion, data-analysis techniques should be reviewed to ensure that preliminary analyses produce valid results. If modifications to procedures are warranted, these modifications are documented in review comments. At a point when data analysis is complete, at approximately 70 percent of project completion, all data that were collected for a project, and the results of intermediate and final data analyses, are assembled and reviewed. Original data, data analyses, and data that were collected but not used in analysis, along with reasons for the exclusion, are documented as a part of the project review and placed in the project file.

The following quality assurance activities shall be performed by the District.

1. Data-analysis procedures shall be referenced and new data-analysis procedures, including those implemented by software, shall be documented in a report released prior to, or as part of, the report giving the results of that technique. Documentation might include:
   - a description of the theoretical basis and computational procedure in sufficient detail to perform the analysis,
   - all data requirements or options for the data-analysis procedure, and
   - comparisons of the technique with known or accepted solutions.

Office of Ground Water Technical Memorandums 79.04, 91.04, and 96.04 (see appendix) have outlined documentation requirements for data-analysis procedures implemented by software.

2. The results of data analysis shall not be presented at a finer spatial or temporal resolution than supported by the input data. The results shall not be displayed with an accuracy that exceeds the capability of the analysis or the accuracy of the data-collection methods.

Interpretations of data analysis, shall be appropriately qualified, including descriptions of limitations and data uncertainty.

3. Districts shall establish a written policy for reviewing data-analysis procedures and documenting the review. The results of any data analysis shall be reviewed, prior to release, to ensure that the analysis is valid. The reviewer shall be provided with any necessary background information to adequately perform the review. The District shall establish a procedure for resolving the reviewers' concerns that ensures that the review comments are carefully considered and revisions made, if appropriate, and that direct interaction occurs between the project chief and the reviewer. The District also shall establish and implement an archiving process for the review documents.

PUBLICATIONS

Disseminating information to Congress and the general public has been required of the USGS, since its creation in the Organic Act of 1875. The report review process ensures the quality of the written report, which is the culmination and final result of the training, planning, data collection, and data analysis. To satisfy national responsibilities and to produce accurate and timely reports, the District shall perform the following quality-assurance activities.

1. All ground-water data collected in USGS data-collection programs and interpretive and research projects shall be published in a timely manner. Data in NWIS that have been reviewed and approved are available to the general public, and can be considered published.
2. The District Chief in consultation with the Office of Ground Water shall approve, in writing, any exceptions to the requirement to publish all data, including data collected under an agreement of confidentiality.
3. Data furnished by sources other than WRD may be used for analysis and published if the source of the information approves and if (1) the data have been appropriately quality assured, or (2) the data have not been thoroughly quality-assured but are described in terms of appropriate qualifications and limitations. In either case, the source of the data must be acknowledged. Care should be taken to assure that data are published with the correct number of significant figures.

4. Reports shall be reviewed and approved according to current District and WRD policy.

ARCHIVING

Archiving is the final step in the processes of data collection, analysis, and interpretation. Although the report represents the summary of the current work, the data and its interpretation should be available for further analysis.

> ***Archiving*** is the systematic process of storing data and information to protect it from change or loss, by providing the necessary security.
>
> ***Electronic archiving*** is the systematic process of removing data from active, on-line computer storage and preserving it with the capability to recover the data.

To quality assure the archiving process, the following steps shall be performed by the District:

1. All data shall be archived as specified by current WRD policy.
2. All model related computer files and appropriate simulation results shall be archived as outlined in OGW Technical Memorandum 93.01 (see appendix).
3. All aquifer-test data and results shall be archived as outlined in OGW Technical Memorandum 94.02 (see appendix).
4. An Archiving Plan for the District which documents the disposition of all project information upon completion of District projects shall be established. The Archiving Plan shall document the archiving process and the responsibilities of personnel assigned to archiving tasks. The disposition of technical-procedure documents and procedures notebooks developed for an individual project should be described in the Archiving Plan.

Internal California District policy (Instruction 1641.1A, July 9, 1991, Ron Fogelman, California District, written communication) and Indiana District data management and archival policies (Martin and Cohen, 1994) are examples of archiving plans. Parts of the project files may be incorporated into the Districtwide file system, as appropriate.

AUDIT

Audits are designed to ensure that all tasks described in the GWQAP are being performed. Audits will be performed during the Technical District Reviews.

> ***Audits*** are documented quality-assurance activities performed to determine compliance with the GWQAP and associated documents and the effectiveness of their implementation. Audits include observing field data-collection activities and reviewing office documentation. Audits are usually peer reviews.

The following quality-assurance activities shall be performed by the Office of Ground Water.

1. Develop an Audit Plan to monitor compliance with the requirements of the GWQAP. Audits apply to all ground-water field and office activities. The Audit Plan identifies the activities to be audited, scope of the audit, requirements governing the audit, organizations to be notified (if any), applicable documents, and tentative audit schedule. The audit shall, as a minimum, address the following questions:
   - Do training plans, workplans, technical-procedure documents, calibration records, and maintenance logs exist, are they complete, and are the plans and technical-procedure documents being implemented?
   - Do data-management and archiving plans exist, are they complete and up-to-date, and are they being implemented?
   - Are project reviews being performed and documented according to the GWQAP?
2. Conduct the audit during the technical review of the District program.
3. Document all comments and recommendations in the technical review report.
4. Send all comments and recommendations to the Regional Hydrologist and the District.

The Region is responsible to see that all recommendations are addressed. The Office of Ground Water will receive copies of all correspondence between the District and the Regional Hydrologist relating to audits and audit plans.

SUMMARY

This report provides a plan to direct the quality assurance of ground-water activities in District offices of the USGS, and presents policies pertaining to training; planning; data collection, processing, review, analysis, and storage; publications; archiving; and audits as they relate to these activities. The implementation of a GWQAP will enhance the consistency, accountability, comparability, traceability, and repeatability of ground-water activities of the USGS.

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Green, J.H., 1991, WRD Project and Report Management Guide: U.S. Geological Survey Open-File Report 91-224, 152 p.

Hubbard, E.F., *compiler*, 1992, Policy recommendations for management and retention of hydrologic data of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 92-56, 32 p.

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Schroder, L.J., and Shampine, W.J., 1992, Guidelines for preparing a quality assurance plan for district offices of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 92-136, 14 p.

Shampine, W.J., Pope, L.M., and Koterba, M.T., 1992, Integrating quality assurance in project work plans of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 92-162, 12 p.

APPENDIX

Copies of the following policy memorandums are appended.

Office of Ground Water Technical Memorandums 79.04, 91.04, 93.01, 93.03, 94.02, 96.04

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

Code: 4351-5016

February 26, 1979

GROUND WATER BRANCH TECHNICAL MEMORANDUM NO. 79.04

SUBJECT: QUALITY CONTROL -- Documentation of computer programs used for aquifer modeling

Significant modifications to existing models or newly devised computer programs used to simulate aquifer processes should be documented before the programs or interpretations based on them are released. This memorandum amplifies earlier instructions regarding the need to document modifications of existing computer programs, and provides guidelines for documentation of new computer programs.

Ground Water Branch Technical Memorandum No. 75.11 (a copy is attached) provided guidelines for reporting and documenting aquifer modeling analyses. Item #7 of that memo indicated, among other things, that if the computer program used is "substantially different" from a published version, the "significant modifications" of the original program should be described in an open file or published report. A "significant modification" to a computer program means any change in the computational scheme that can give computed results that may differ from those that would be obtained using the published version of the program. Changes in format of data input and/or output are not considered significant. However, changes in the approximating equations and/or the algorithm used to solve those equations are considered significant. If the description of those modifications is extensive or is believed to disrupt the continuity of the report, those modifications can be described in an appendix to the report.

A newly developed program, representing a computational approach that is different from published approaches, should be documented in a report released prior to, or as a part of, the report giving results of a hydrologic analysis using that program. The documentation should precede, or be coincident with, release of copies of the computer program for use outside of the Geological Survey. The "documentation" of newly developed programs and major program modifications should include at a minimum a description of the computational procedure in sufficient detail to provide enough information to independently develop an equivalent computer program. However, if a newly developed program is intended for widespread use in the U.S. Geological Survey, it would be preferable for the documentation to include a generalized flow chart, program listing, definitions of program variable, instructions for the preparation of the data input, and a sample of the output.

One Hundred Years of Earth Science in the Public Service

These requirements are intended to assure that adequate information on computer programs used to make hydrologic analyses is released in a timely fashion.

Gerald Meyer
Chief, Ground Water Branch

Attachment

WRD Distribution: A, B, S, FO, PO

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092

In Reply Refer To:
Mail Stop 411

August 14, 1991

OFFICE OF GROUND WATER TECHNICAL MEMORANDUM NO. 91.04

SUBJECT: Policy for the documentation of non-U.S. Geological Survey computer programs used for analysis in ground-water projects

The purpose of this memorandum is to define policy for the documentation of computer programs that will be used or cited in ground-water project reports that receive Director's approval. The long-standing policy of the U.S. Geological Survey (USGS) is that a program written by USGS employees to perform other than routine tasks must be documented (either in a separately approved report or in a report that makes use of the program) before it can be cited or used in a USGS report (see Office of Ground Water Technical Memorandum No. 79.04). However, no clear policy has been defined for required documentation of programs written by outside sources. The proliferation of programs from non-USGS sources makes it important that guidelines be established for use of these programs in USGS investigations.

The two classifications for computer programs written outside of USGS are: (1) public domain and (2) proprietary. Public-domain programs are not copyrighted. Common sources of public-domain programs are universities and other government agencies. Proprietary programs are developed by businesses or organizations in order to sell them to customers and are copyrighted.

Public-domain programs are held to the same requirements as in-house programs. The policy for use of a public-domain computer programs is:

1. The program must be documented in a published report.

2. The documentation must describe both the theoretical basis for the calculations performed by the program and the implementation of the theory. This documentation should show that the program functions as described, and if not shown, independent checks must

be undertaken by the user. The results of any testing should be placed in the project files and made available to reviewers of project reports.

3. The source code for the program must be included in the documentation or be available from a formal distribution center.

Proprietary computer programs cause policy difficulties due to the secrecy that vendors require in order to protect their products. Complete documentation as described above is generally not provided for proprietary programs; in particular, the source code is usually not available.

The broad purpose of the requirements for documentation of in-house programs is to ensure a high probability that the programs function correctly, ensure that the theoretical basis is explained and defensible, allow others to learn from our work, and allow others to reproduce and evaluate our work. In order to attain the same purpose without requiring disclosure of source code, the following policy has been adopted for the use of proprietary computer programs in USGS reports.

1. The proprietary program must be available for purchase by anyone.

2. The vendor must provide documentation with the program that describes how to use the program and the theoretical basis for calculations. If the standard documentation provided by the vendor does not contain an adequate description of the theoretical basis, then the user must contact the vendor to obtain the theoretical basis and must reference or describe this theory in the reports that use the program.

3. The user of a proprietary program must make tests by comparing results from the program to known solutions to show that the program functions as claimed by the vendor and as used in their project work. Users should retest new versions of a program to make sure errors have not been introduced. The results of the testing should be placed in the project files and made available to reviewers of project reports.

This policy is intended to insure the reliability and reproducibility of our work.

Any question regarding this policy and the applicability to specific software should be clarified in the early stages of a project by contacting the Office of Ground Water.

Thomas E. Reilly
Acting Chief, Office
of Ground Water

WRD Distribution: A, B, S, FO, PO

United States Department of the Interior

GEOLOGICAL SURVEY

RESTON, VA 22092

In Reply Refer To:
Mail Stop 411

October 28, 1992

OFFICE OF GROUND WATER TECHNICAL MEMORANDUM NO. 93.01

Subject: PROGRAMS AND PLANS--Establishment of a National Policy to Archive Ground-Water Flow and Transport Models

POLICY

Ground-water flow and transport models are an integral part of our interpretive ground-water investigations, and the results of these models form the basis for many of the conclusions published in U.S. Geological Survey reports. The numerical data and related information that comprise these models need to remain available to: (1) support and validate the results in published reports, (2) assure that working versions of all models are available for future scientific use, and (3) assure that the data are available to the public when requested. The appropriate model data and related information are to be stored in a permanent, well-documented manner to ensure their continued availability.

Effective as of the date of this memorandum, a national ground-water model archive is established. All ground-water flow and transport models that are a significant part of ground-water investigations with completion dates of October 1993 or later are to be included in the archive. Where feasible, districts also should archive models from completed investigations and from current projects to be completed prior to October 1993. The Regional Ground Water Specialists are to act on behalf of the Office of Ground Water to assure that all required information is present in the archive. Status of the archives also will be examined as a routine part of district ground-water discipline reviews. Design and implementation requirements for the archive are presented in Attachments 1 and 2 to this memorandum.

The archive is for internal Water Resources Division (WRD) access and use and is to serve as the source of ground-water model data supplied to the public upon request. The public release of

specific information contained in the archive is subject to compliance with any existing WRD policies that may apply to the public release of such information.

The ground-water model archive does not relieve individual investigators of the need to fully describe and document model analyses in their reports.

Joseph S. Rosenshein
Acting Chief, Office
of Ground Water

2 Attachments

WRD Distribution: A, B, S, FO, PO

ATTACHMENT 1

DESIGN AND IMPLEMENTATION OF DISTRICT GROUND WATER MODEL ARCHIVES

STRUCTURE AND CONTENTS:

The archive will consist of a main directory called GWMARCIV. A report subdirectory, located directly below GWMARCIV, will be established for each published report containing a ground-water flow or transport model analysis. Each report subdirectory should be given a name that clearly reflects the U.S. Geological Survey report number. The archive must include the model source codes, input files, macros and operating files such as JCL, CPL, and UNIX shell codes, and model output files for each simulation described in the report. These simulations will include (when applicable) the final calibrated steady-state and transient results and any predictive results described in the publication. Model results of minor importance, such as interim calibration runs, should not be archived. Model output will be archived for future verification that the input data files properly reproduce the published results when the input files are rerun. The storage of additional ancillary data is optional, but is strongly encouraged. Examples of ancillary data that might be stored are pertinent pre- and post-processor codes, related data, or other files directly related to the model simulations.

A subdirectory named CONTENTS, located immediately below each report directory, will include one or more files that contain: (1) the full reference for the subject report; (2) descriptions of the subdirectory structure and of the files contained in each subdirectory, (3) descriptions of data file formats, when appropriate; (4) the sequence of model runs; and (5) instructions for running simulations. Attachment 2 shows one example of what an archive directory structure might look like for a typical project.

When the input data of one model depends directly on output from another model, both models are to be included in the archive. If the models are documented in separate reports, a cross-reference between the reports must be included in the CONTENTS directory of the archive entry for each report.

Model input files must be stored in ASCII format to assure that they can be processed in the future on virtually any computer

without the need for specialized or proprietary software. In cases where model input files are derived from either proprietary or machine-dependent software, ASCII versions of the model input files must be included in the archive.

IMPLEMENTATION:

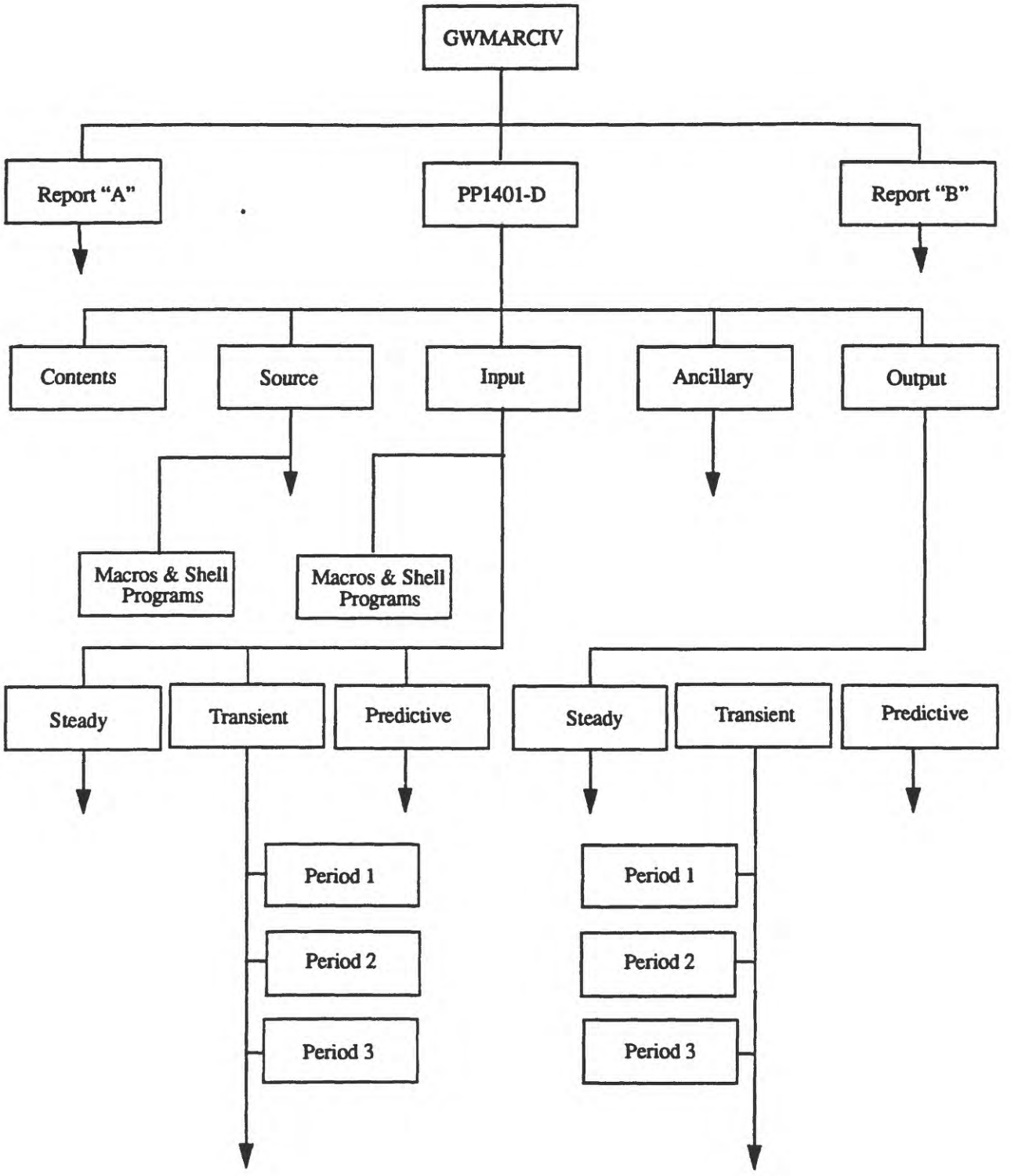
Each district will set up an archive on a locally based computer. The district staff is responsible for designing a subdirectory structure that permits efficient and logical storage of the required information for each specific model. Files will be accumulated and stored in the on-line archive until the final interpretive report is approved, after which time the files are to be moved to permanent storage.

For all studies with completion dates of October 1993 or later, the appropriate model files must reside on-line in the district archive when the report is submitted to the Region for approval. Verification of compliance with this policy is the responsibility of the Regional Ground Water Specialists. Reports returned to the district for revision that require new or additional model simulations will require an archive update.

Upon final approval of the interpretive report, the archive is to be copied to permanent storage on an optical disk using WORM (write once, read many) technology. A copy of the WORM disk will remain in the originating district to service requests for data, and a duplicate copy will be furnished to the Region for off-site backup. A WORM disk may contain model data for one or more published reports provided the disk is indexed appropriately. The archive may be transferred to tape as a short-term storage option if the district does not have immediate access to WORM disk production equipment. The period of interim storage on tape should not exceed 1 year. The archive process is considered complete only when a WORM disk has been produced. On-line storage of the archived data may be discontinued at the discretion of the district following transfer of the archive to WORM disk or to interim tape storage.

Attachment 2

Sample Directory Structure for Ground-Water Model Archive



↓ denotes continuing subdirectory structure that is not shown

United States Department of the Interior

GEOLOGICAL SURVEY

RESTON, VA 22092

In Reply Refer To:
Mail Stop 411

January 25, 1993

OFFICE OF GROUND WATER TECHNICAL MEMORANDUM NO. 93.03

Subject: Interim Policy Memorandum about Storing Data in the National Water Information System

The purpose of this memorandum is to restate and clarify existing policy regarding the use of the National Water Information System (NWIS) to store ground-water data collected by the U.S. Geological Survey, Water Resources Division (WRD).

Problems and Concerns

Discipline reviews are finding that not all ground-water data collected by WRD are being stored in NWIS. It appears that some elements of policy detailed in WRD Memorandum Nos. 76.44, 77.136, 83.89, and 86.28 have been misunderstood and have not been vigorously enforced at the Regional and Headquarters levels.

Clarification and Restatement of Policy

WRD Memorandum 92.59 has recently been released and states that the recommendations made by the Data Policy Committee (Open-File Report 92-56) have been accepted as official policy. That policy includes the following:

> "The current policy in WRD is that all water data collected as part of the routine data collection of the WRD (both basic and project data) must be stored in the computer files of the National Water Information System. One purpose of this policy is to enable all WRD work to be verifiable and repeatable to the greatest extent possible at any time in the future."

The Office of Ground Water (OGW) interprets "routine data collection of the WRD" to include all ground-water data collected by WRD basic data programs and District projects. Any request for exemption from this policy must be approved by OGW. The only exceptions to this requirement are proprietary data, and data that cannot be stored in NWIS because they do not functionally fit. When the new version II of NWIS software is completed, it is expected that many of the ground-water data that WRD collects will functionally fit in NWIS, including many types of geophysical, hydrogeological, and hydraulic test data.

Implementation of Policy

The OGW and the Regional Ground-Water Specialists will review compliance with this policy during District technical and selected project reviews and by actual interrogation of NWIS. Several recent District reviews by OGW have included an additional person on the review team for the purpose of examining data-related issues. The OGW has added a staff person to specifically address the issues of data and data bases. The OGW also has created the Ground-Water Data Committee to develop recommendations about issues of policy and management of ground-water data. Future memorandums will address other aspects of ground-water data policy.

William M. Alley
Acting Chief, Office
of Ground Water

WRD Distribution: A, B, S, FO, PO

United States Department of the Interior

GEOLOGICAL SURVEY

RESTON, VA 22092

In Reply Refer To:
Mail Stop 411

June 2, 1994

OFFICE OF GROUND WATER TECHNICAL MEMORANDUM 94.02

Subject: Guidance for the preparation, approval, and archiving of aquifer-test results

Analyses of aquifer tests to define the hydraulic characteristics of a specific aquifer or aquifer system are an integral part of our interpretive ground-water investigations. The results of these analyses are critical components of flow-system or solute-transport analyses and important to conclusions published in U.S. Geological Survey (USGS) reports. Consequently, reported aquifer characteristics such as hydraulic conductivity, transmissivity, storativity and other hydraulic characteristics derived from aquifer-test analyses must be clearly documented and technically defensible. The purpose of this memorandum is to describe guidelines and procedures necessary to obtain approval for the results of aquifer tests analyzed by employees of the Water Resources Division (WRD) and to provide guidelines for archival of the test results.

BACKGROUND

According to WRD Publications Guide (Article 11.01.2) "....calculated hydraulic characteristics such as transmissivity, hydraulic conductivity, and storage coefficient, are interpretive and must be approved by the Director, unless cited from a Director-approved report." In a memorandum dated March 11, 1992, the Assistant Chief Hydrologist, Scientific Information Management, delegated authority to approve aquifer-test results to the Regional Hydrologists. Approval is required for all calculations of aquifer-hydraulic characteristics to be released to the general public, to cooperators, or published in or otherwise used to support the results of investigations reported in USGS-approved reports.

Estimates of aquifer-hydraulic characteristics commonly are obtained from "textbook" or published values for various lithologies. These are not considered calculations of aquifer characteristics and do not require approval under the terms of this memorandum. In addition, estimates of transmissivity determined on the basis of specific-capacity measurements do not require approval.

DOCUMENTATION, APPROVAL, AND ARCHIVAL OF AQUIFER-TEST RESULTS

While the USGS encourages the publication of aquifer-test results, it is not feasible to publish the data and graphical results for every test conducted. In all cases, either as part of a formal report or as a separate packet, aquifer-test results should be submitted to the Regional Ground-Water Specialist for review and subsequent approval by the Regional Hydrologist. The Regional Ground-Water Specialist reviews the report manuscript or aquifer-test packet to assess (1) that the report or packet contains the necessary data and related information to properly analyze the subject test(s), and (2) that the analyses and results are technically defensible.

Elements that typically should be submitted for review are listed below. These elements assume an aquifer test comprising a pumping well and one or more observation wells and should be modified as appropriate for other types of tests such as a single-well slug test. The eight elements are as follows.

1. A brief description of the test (this can be neatly hand written) which includes the purpose, date, test procedures, and methods of analysis of the results. Any unique or unusual features or problems related to the test or to the collection and analysis of test data should be described. A brief description of the assumptions used in analyzing the test results also should be included, as needed to clarify the test.

2. A sketch of the test site showing the distances from the pumped well to all observation wells and the location of any boundaries, streams, springs, ditches, pumping or flowing wells, or other features that possibly could influence test results. Where the test includes multiple wells, the sketch of the test site should be drawn to scale.

3. Description of test and observation well construction, including screened and open interval(s), casing and screen diameters, and location of filter pack and grouted intervals.

4. A description of the site hydrogeologic characteristics, including sections that show the major water-bearing and confining zones or units. The intervals of the pumping and observation wells that are screened or open should be depicted on the logs or sections.

5. Time-discharge records of the pumped well (all measurements, not just average discharge).

6. Water-level records and hydrographs showing pre-test trends and water levels during the pumping and recovery phases.

7. Description of methods and computations showing adjustments to drawdown for pre-test trends, adjustments of recovery for projected drawdown, or adjustments to account for extraneous effects not related to pumping or recovery, such as barometric and tidal effects or other interferences.

8. All plots of observed or adjusted drawdown or recovery data used to determine hydraulic characteristics, showing match points, when used, and computations.

It is recognized that in some cases it is not possible to provide a complete description of these eight elements. Investigators are encouraged to discuss their plans with the Regional Ground-Water Specialist to determine the requirements for a particular test packet or report before they forward it for review and approval.

A transmittal memorandum, indicating that the test results have been reviewed by the District or Area ground-water specialist or his or her designee, should be included with the test packet or report. This review should include at least some checking of the field data and a verification that the test results are appropriate, given the site hydrogeology, well construction, and test conditions and that the test results have been reviewed independently before being submitted for regional review and approval.

Following approval by the Regional Hydrologist, the packet or report will be returned to the originating District or Office where the hydraulic characteristics and related site and well data should be entered into the Ground-Water Site Inventory System or National Water Information System (NWIS) and the packet and associated information appropriately archived in a District "aquifer-test file." These archived aquifer-test files should include the draft-report routing sheet or packet-review transmittal memorandum. Districts also are encouraged to archive test analyses and results completed prior to this memorandum. The aquifer-test files will be reviewed as a routine part of District ground-water discipline reviews.

If computer software is used in the aquifer-test analysis, the policy outlined in Office of Ground Water Technical Memorandum 91.04, dated August 14, 1991, must be followed. This policy requires that the theoretical basis of the software be documented and that it be demonstrated that a test-data set can be correctly analyzed using the software. Submittal of a computer-software analysis does not eliminate the need for the information described in item element 8, above.

This memorandum discusses information needs in the context of single- or multiple-well aquifer tests. Aquifer characteristics also may be calculated by other methods, such as, determination of aquifer diffusivity from attenuation of a tidal pulse or

flood wave through an aquifer, or using hydrograph-recession characteristics. The same review procedures should be followed for these types of analyses, and information in the report manuscript or packet must be adequate to enable reviewers to visualize the physical system, evaluate all data, verify all calculations, and assess that the methods and results are defensible.

Sincerely,

William M. Alley

William M. Alley
Chief, Office of
Ground Water

Distribution: A, B, S, FO, PO

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Reston, Virginia 22092

In Reply Refer To:
Mail Stop 411

April 24, 1996

OFFICE OF GROUND WATER TECHNICAL MEMORANDUM NO. 96.04

Subject: PUBLICATIONS--Policy on documenting the use of ground-water simulation in project reports

It has been more than two decades since Ground Water Branch Technical Memorandum No. 75.11 was released on the subject of documenting the use of ground-water simulation in project reports. Because of the time lapse, changes in modeling techniques, and the frequency of problems found when reports are reviewed, a revisit to policy on this subject is appropriate.

There is no rigid checklist or recipe for reporting on the use of simulation in a ground-water study. The appropriate level of documentation will vary depending on the project objectives and the complexity of the simulations. The general structure of a well-constructed report describing simulation is much the same as that for any investigative study. It should present (1) the objectives of the study, (2) a description of the work that was done, (3) logical arguments to convince the reader that the methods and analyses used in the study are valid, and (4) results and conclusions.

Specific topics that should be addressed in reports that describe studies in which simulation is used include the following.

1. Describe the purpose of the study and the role that simulation plays in addressing that purpose.

The objective of the simulation must be clearly stated. The model should be represented as a tool to help solve specific problems or answer specific questions rather than as an end product.

2. Describe the hydrologic system under investigation.

The extent, nature of boundaries, transmitting properties, storage properties, sources of water, discharge mechanisms and other relevant components of the ground-water system should be described as known or conceptualized. Usually this can be accomplished in part by referencing previous works, but major relevant system characteristics should be summarized in the report that describes the simulation.

3. Describe the mathematical methods used and their appropriateness to the problem being solved.

In most cases, a reference to a readily available publication will be sufficient to document mathematical details; however, it will usually be desirable to briefly summarize the methods that are used. For a well-documented computer program, this will often require only a paragraph or two. If a documented computer program is modified such that computed values are affected, the modifications should be documented and evidence that the modifications are correct should be supplied.

4. Describe the hydrogeologic character of the boundary conditions used in the simulation of the system.

In many cases, the model boundaries are placed where the aquifer terminates against relatively impermeable rocks or is intersected by a perennial stream whose head variation in time and space is known. In other cases, the aquifer may be so extensive relative to the area of interest that the modeled area may need to extend beyond the project area to accurately simulate the natural boundaries of the aquifer system. If the modeled area is arbitrarily truncated at some distance from the area of interest, it should be shown that the selection of the arbitrary boundary condition does not materially affect the ability of the model to simulate the system for the purposes of the study. Internal boundaries such as streams, lakes, and pinchouts of important hydrogeologic zones should be identified and their representation in the model should be described in the report. A clear, convincing argument of the appropriateness of the boundary conditions used in the model to represent the actual system should be made for the entire bounding surface of the modeled volume or cross section, as well as for any internal boundaries.

5. If the method of simulation involves discretizing the system (finite-difference and finite-element methods for example), describe and justify the discretized network used.

The spacing and distribution of the blocks, elements, or subregions should reflect, in part, the spatial variability of the hydraulic parameters and the location of boundaries (for example streams, lakes, bed pinchouts), human-made features (for example wells and dams), and stresses. In most cases, a map showing the discretized network superimposed on the study area is required. Vertical discretization should be described and/or shown on illustrations. The manner in which time is discretized for transient models also should be described. If a steady-state model is used to simulate an average or approximate steady-state condition, discuss the errors that could be introduced in the study results as a consequence of using a steady-state model.

6. Describe the aquifer system properties that are modeled.

Explain whatever inferences are made from field data and previous studies as to the spatial variation of hydraulic properties of aquifers and confining beds and how discretized values are computed throughout the simulated area. During model calibration (see item 9), modeled values are often changed; the final aquifer system properties that are modeled should be described in the report. This can be through maps or descriptions in the text. Lists of model arrays do not generally provide much understanding of the model and accordingly should not be included in the report unless it is expected that readers will want to repeat the simulations. If lists of arrays are included, they should usually be provided on electronic media. Note that Office of Ground Water Technical Memorandum No. 93.01 describes the separate requirement for archiving the complete model data sets used in ground-water projects.

7. Describe all the stresses modeled such as pumpage, evapotranspiration from ground water, recharge from infiltration, river stage changes, leakage from other aquifers, and source concentrations in transport models.

The relations between observed and modeled stresses should be described. For example, it usually is desirable to provide a representative sample of actual pumping histories and the corresponding modeled pumping histories, although such information would not necessarily be provided for every pumped well. The manner in which stresses are averaged within the discretized time and space scheme should also be described. If a steady-state model is used to simulate an average or approximate steady-state condition, describe how the average stresses representing this system are calculated.

8. For transient models, describe the initial conditions that are used in the simulations.

Ideally, a transient simulation will start from a steady-state condition, and the steady-state initial conditions will be generated by a steady-state simulation using the same model. In this case, the steady-state simulation must use the same hydraulic and stress parameters that are used in the transient simulation, except that the transient stresses are removed. In situations where it is not possible to start a transient model from a simulated steady-state condition, it is necessary to describe how the initial conditions were derived. It is also important to estimate the error in the derived values and the possible impact on the model results.

9. If a model is calibrated, present the calibration criteria, procedure, and results.

Describe the source of the observed data to which model results are compared. Explain the appropriateness of using these data

for model comparisons and the rationale for any adjustments made to actual observations when making the comparisons.. For example, when steady-state models are used to simulate an approximate steady-state condition, it is important to explain to what extent the observations that have been made at specific points in time correspond to the approximate steady-state condition being simulated. Give a representative sample of the actual comparisons used for calibration, and show the locations of the observation points on maps. When the number of observations is extensive, locations of representative points can be shown. It is important to report and use as many types of data as possible for calibration. For example, in a flow model, both head and flow observations are desirable for use in calibration.

10. Discuss the limitations of the model's representation of the actual system and the impact those limitations have on the results and conclusions presented in the report.

Evaluating the sensitivity of the computed model responses to changes in parameter values that reflect plausible parameter uncertainty helps to assess the model reliability. If the model is to be used to make specific projections, it is useful to estimate the impacts of the uncertainty of parameter values on the projections. In calibrated models, a concern is non-uniqueness, which is the extent to which other combinations of parameter values or configurations may result in an equally good fit to the observed data. Discuss the extent to which nonuniqueness may affect the use of the model in the study.

In summary, a report describing a study in which simulation is used should address the above topics; however, there is considerable flexibility in the form of such a report. The report should describe the purpose of the simulation and convince the reader that the use of simulation is credible. The report should further describe the system being simulated, the methods of simulation, and the data that are used.

William M. Alley

William M. Alley
Chief, Office of Ground Water

Distribution: A, B, S, FO, PO

This memorandum supersedes Ground Water Branch Technical Memorandum No. 75.11