NEW JERSEY GEOLOGICAL &

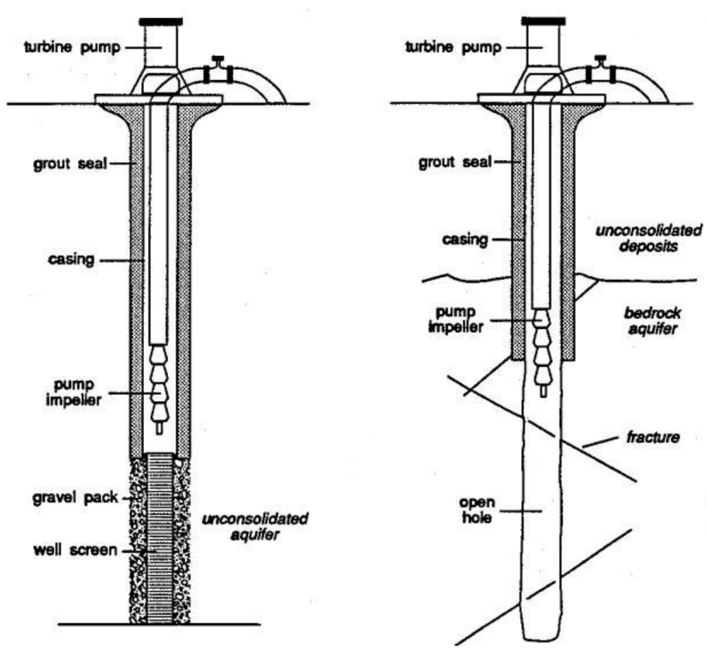
WATER SURVEY

Technical Memorandum 12-2

Hydrogeologic Testing and Reporting Procedures

in Support of

New Jersey Water Allocation Permit Applications



New Jersey Department of Environmental Protection

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

NJDEP's core mission is and will continue to be the protection of the air, waters, land and natural and historic resources of the State to ensure continued public benefit. The Department's mission is advanced through effective and balanced implementation and enforcement of environmental laws to protect these resources and the health and safety of our residents.

At the same time, it is crucial to understand how actions of this agency can impact the State's economic growth, to recognize the interconnection of the health of New Jersey's environment and its economy, and to appreciate that environmental stewardship and positive economic growth are not mutually exclusive goals: we will continue to protect the environment while playing a key role in positively impacting the economic growth of the state.

NEW JERSEY GEOLOGICAL and WATER SURVEY

The mission of the New Jersey Geological and Water Survey is to map, research, interpret and provide scientific information regarding the state's geology and groundwater resources. This information supports the regulatory and planning functions of DEP and other governmental agencies and provides the business community and public with information necessary to address environmental concerns and make economic decisions.

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On the cover: Schematic diagrams of wells drawing water from unconsolidated and bedrock aquifers. Modified from Heath, 1983, p. 52.

NEW JERSEY GEOLOGICAL AND WATER SURVEY
Technical Memorandum 12-2

Hydrogeologic Testing and Reporting Procedures in Support of New Jersey Water Allocation Permit Applications

by

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2012

Conversion Factors

Multiply inch-pound units	by	to obtain metric (SI) units
VOLUME		
cubic inches (in^3)	16.39	cubic centimeters (cm^3)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
gallons (gal)	3.785	liters (L)
gallons (gal)	$3.785X10^{-3}$	cubic meters (m^3)

Multiply inch-pound units	by	to obtain metric (SI) units
FLOW RATE		
million gallons/day (mgd)	0.04381	cubic meters/second (m^3/s)
cubic feet per second (cfs)	2,447.	Cubic meters/day (m^3/d)
million gallons/year (mgy)	3,785.	Cubic meters/year(m^3/y)
gallons/minute (gpm)	.06309	liters/second (L/s)

Note: In this report 1 billion = 1,000 million; 1 trillion = 1,000 billion

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"No one shall draw water without an authorization from Caesar, that is, no one shall draw water from the public supply without a license, and no one shall draw more than has been granted."
- Sextus Julius Frontinus, The Aqueducts of Rome (ca 100 CE). Frontinus lived between approximately 35 and 103 CE. He was appointed water commissioner for Rome by Nerva Augustus about 97 CE. He was governor of Britain from 75-97 CE. (Evans, 1997)

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Hydrogeologic Testing and Reporting Procedures in Support of New Jersey Water Allocation Permit Applications

I. Abstract

The New Jersey Department of Environmental Protection (NJDEP) regulates all major groundwater diversions of fresh water and of non-fresh water that may impact fresh water. Major diversions are defined as those capable of withdrawing 100,000 gallons per day or more, from one or more wells. This regulation is done by requiring a water allocation permit for all major diversions. Before NJDEP issues this permit, an applicant must show that the diversion will not adversely impact other groundwater users, or the natural environment and waterways of the State, now and in the future. An aquifer test is usually required to generate sufficient information to allow evaluation of the groundwater diversion's potential impacts.

Aquifer tests are expensive to plan, conduct and review. They also add months onto the permit-application process. NJDEP's experience is that careful and thorough planning, execution, and reporting greatly increases the probability that a test will provide the data necessary for evaluation of the proposed diversion. Poor planning, shoddy test methodology, and inadequate hydrogeological reports increase the chance that the permit application process will be delayed. This report presents clear guidance on NJDEP's required technical procedures for proposing and executing aquifer tests as well as preparing a hydrogeologic report. These procedures allow applicants to more efficiently design and conduct aquifer tests that meet NJDEP's testing and reporting criteria.

Overall steps in the aquifer-test process include a pre-application meeting to discuss general issues, an aquifer-test proposal which details the test and monitoring, and a hydrogeologic report on aquifer properties and potential impacts.

At the pre-application meeting the applicant and NJDEP staff informally discuss estimated water demands, available water sources, any programmatic limits on potential water supplies, nearby groundwater users who may be impacted, and areas of environmental concern. NJDEP requires the use of selected web-based screening tools at this step to identify probable water availability and to identify permitting-process impediments.

Before conducting the aquifer test the applicant must submit an aquifer-test proposal to the NJDEP. The proposal details water source, test duration, pumping rates, all monitoring points, and all monitoring frequencies. The proposal must address all of the areas of concern discussed at the pre-application meeting. NJDEP must approve the aquifer-test proposal before the applicant conducts the aquifer test. This report includes a checklist of all items required in the aquifer-test proposal.

The hydrogeologic report presents the results of the aquifer test, an evaluation of the water-bearing properties of the aquifer, and an estimate of potential impacts on other groundwater users and the environment. The hydrogeologic report must include all data

collected during the test in appropriate formats. This report includes a checklist of all items required in the hydrogeologic report.

This report does not provide the standards by which any estimated impacts are judged to be acceptable or unacceptable. These standards are provided in the Water Allocation regulations N.J.A.C. 7:19. This report is also not a guide to completing the entire application package which must accompany a request for a water allocation permit.

II. Introduction

II.A. Purpose

This report presents procedures for planning, conducting and reporting a hydrogeologic study acceptable to the New Jersey Department of Environmental Protection (NJDEP). This is done in support of an application to the NJDEP for a new water allocation permit or a major modification to an existing one. Hydrogeologic reports in support of these applications are required by regulation (N.J.A.C. 7:19) and must present an analysis of the geology, hydrogeology, and expected impacts of the proposed diversion on the resource and other users of that resource.

Well diversions may have regional effects on groundwater levels and flow patterns as well as negative impacts on other users, contaminated sites, wetlands and surface water (Alley and others, 1999; Galloway and others, 2003; Taylor and Alley, 2001; Winters and others, 1998). Ensuring that such a well is properly located so as to provide the volume of water necessary to meet demands without causing unacceptable impacts justifies requiring an accurate and thorough hydrogeologic evaluation. Additionally, drilling monitoring wells, testing the aquifer, and installing pumps and waterlines is expensive. Performing an aquifer test correctly the first time is more economical than having to redo it. For these reasons, NJDEP recommends properly planning and conducting the aquifer test the first time.

This process usually involves two reports. First is an aquifer-test proposal which details where and how the test will be performed. After the proposal is approved by the NJDEP the applicant conducts the aquifer test. Next, the applicant submits a hydrogeologic report which details test results, presents aquifer properties, and estimates the impact of the proposed groundwater diversion.

This report includes details on what is expected in an aquifer-test proposal. It also includes guidance on designing an adequate hydrogeologic investigation as well as what should be included in the hydrogeologic report.

This report does not provide the standards by which any estimated impacts are judged to be acceptable or unacceptable. These standards are provided in the water allocation regulations N.J.A.C. 7:19. This report is also is not a guide to completing the full application package which must accompany a request for a water allocation permit.

It is the NJDEP's experience that an aquifer test which does not yield sufficiently-comprehensive data cannot support an acceptable evaluation of potential impacts. Additionally, a hydrogeologic report which does not provide sufficient information on the geologic and hydrogeologic setting of the site, contains inappropriate investigational and data-analysis techniques, inadequately reports original data, or contains unsupported statements, may delay the application review and could cause a denial of the permit application. Following the procedures presented in this report will reduce this possibility.

The goal of this report is to provide applicants with clear guidance on what NJDEP expects to see in the aquifer-test proposal and the hydrogeologic report. The evaluation criteria NJDEP uses to evaluate these two reports cover four general areas:

Test proposal:	1) Aquifer-test design
Hydrogeologic report:	2) Aquifer-test details with observed data 3) Analysis of aquifer properties 4) Estimated impacts on other users and the environment

These four areas are not independent. For example, a particular environmental concern will guide test design and help determine test parameters and monitoring locations. Then the collected data must support an analysis of aquifer properties and a quantification of the impact of the proposed diversion on that environmental concern.

The most efficient path to successfully planning and conducting an aquifer test starts with a pre-application meeting to explore the need for water, discuss potential water sources and limits on those sources, and identifies NJDEP's areas of concern. Based on these considerations, the applicant develops and submits an aquifer-test proposal. The proposal details test design and explains how test data will support an appropriate analysis of aquifer properties that will allow a quantification of impacts. If the NJDEP determines the proposal to be insufficient, the applicant must revise it and resubmit or provide appropriate supplemental material.

Once the proposal is accepted the applicant conducts the aquifer test following the approved design. Then the applicant prepares a hydrogeologic report that describes test protocols and results, presents the analysis of aquifer properties, and uses the properties to estimate impacts. The hydrogeologic report is submitted to the NJDEP for review along with a complete water supply allocation permit application package.

This report does not cover all details of aquifer-testing procedures and groundwater hydraulics. Many groundwater texts do this; some are listed in the references. This report presents procedures that, when appropriate to the hydrogeology and properly executed, are considered acceptable by the Bureau of Water Allocation and Well Permitting (BWAWP). It also briefly describes appropriate methods of data analysis. Responsibility for the thoroughness of the aquifer test, accuracy of the data, and appropriateness of the analysis techniques lies with the applicant and the applicant's representative.

This report is primarily intended for groundwater permit applications. However sections of it, particularly those on administrative steps, may apply to requests for surface-water diversions. N.J.A.C. 7:19 provides more details.

Figure 1 is a flow chart summarizing the aquifer-test portion of obtaining a water allocation permit. This figure, and this report, do not cover the entire application process, only those steps involving planning, conducting, and reporting acceptable aquifer tests.

This report reflects BWAWP's current (2012) practices. These are subject to change. Applicants should contact the BWAWP to learn of any such changes.

II.B. Authority

Pursuant to the Water Supply Management Act (N.J.S.A. 58:1A -1 et seq.) the New Jersey Department of Environmental Protection (NJDEP), through Bureau of Water Allocation and Well Permitting (BWAWP), manages use of the State's water resources through a comprehensive permitting program under the Water Supply Allocation and Resource Management Rules N.J.A.C. 7:19. This permitting program regulates water diversions of more than 100,000 gallons per day (gpd), and diversions of more than 50,000 gpd within Highlands Preservation Area (N.J.A.C. 7:38).

The Water Supply Management Act (N.J.S.A 58:1A-1 et seq.) and its implementing regulations (N.J.A.C. 7:19) are the primary sources of authority. The Safe Drinking Water Act (N.J.S.A. 58:11-59 et seq.) and its implementing regulations (N.J.A.C. 7:10-11 et seq.,) provides additional authority, as does the Highlands Water Protection and Planning Act (N.J.S.A. 13:20-1 et seq) and its implementing regulations (N.J.A.C. 7:38-1).

Copies of the rules and necessary forms are on the NJDEP's website at www.nj.gov/dep/watersupply. BWAWP can be contacted at 609-984-6831 and can provide guidance on specific questions. Table 1 shows other potentially relevant regulations.

Table 1. Programs and regulations applicable to aquifer testing and water-supply wells.

Program	Statute	Regulations
<u>Water Allocation</u>	N.J.S.A 58:1A-1 et seq,	
Water Supply Allocation and Resource Management.		N.J.A.C. 7:19
Agricultural water use certifications		N.J.A.C. 7: 20A-1,2
Sealing of abandoned wells	N.J.S.A. 58:4A-4.1 et seq.	N.J.A.C. 7:9D-3
<u>Safe Drinking Water</u>	N.J.S.A. 58:12A-1 et seq.	
Physical connection permits		N.J.A.C. 7:10-1et seq
Standards for the construction of public non-community and non-public water systems		N.J.A.C. 7:10-12.1 et seq.
Standards for the construction of public community water systems	N.J.S.A. 58:11-59 et seq.	N.J.A.C. 7:10-11.1 et seq.
<u>Water Quality Standards</u>		
Surface Water	N.J.S.A. 58:10A-1 et seq. &	N.J.A.C. 7:9B
Groundwater	58:11A-1 et seq.	N.J.A.C. 7:9C
<u>Discharges</u>		
New Jersey Pollution Discharge Elimination System (NJPDES)	N.J.S.A. 58:10A- 1 et seq.	N.J.A.C. 7:14A-1.1 et seq.
<u>Land Use Regulation Element</u>		
Freshwater Wetlands	N.J.S.A. 13:9B	N.J.A.C. 7:7A-1 et seq.
<u>Pinelands Commission</u>	N.J.S.A. 13:18A et seq.	
Pinelands Management Act		N.J.A.C. 7:50-4,5,6
<u>Highlands Council</u>		
Highlands Rules	N.J.S.A. 13:20-1 et seq.	N.J.A.C. 7:38 et seq.

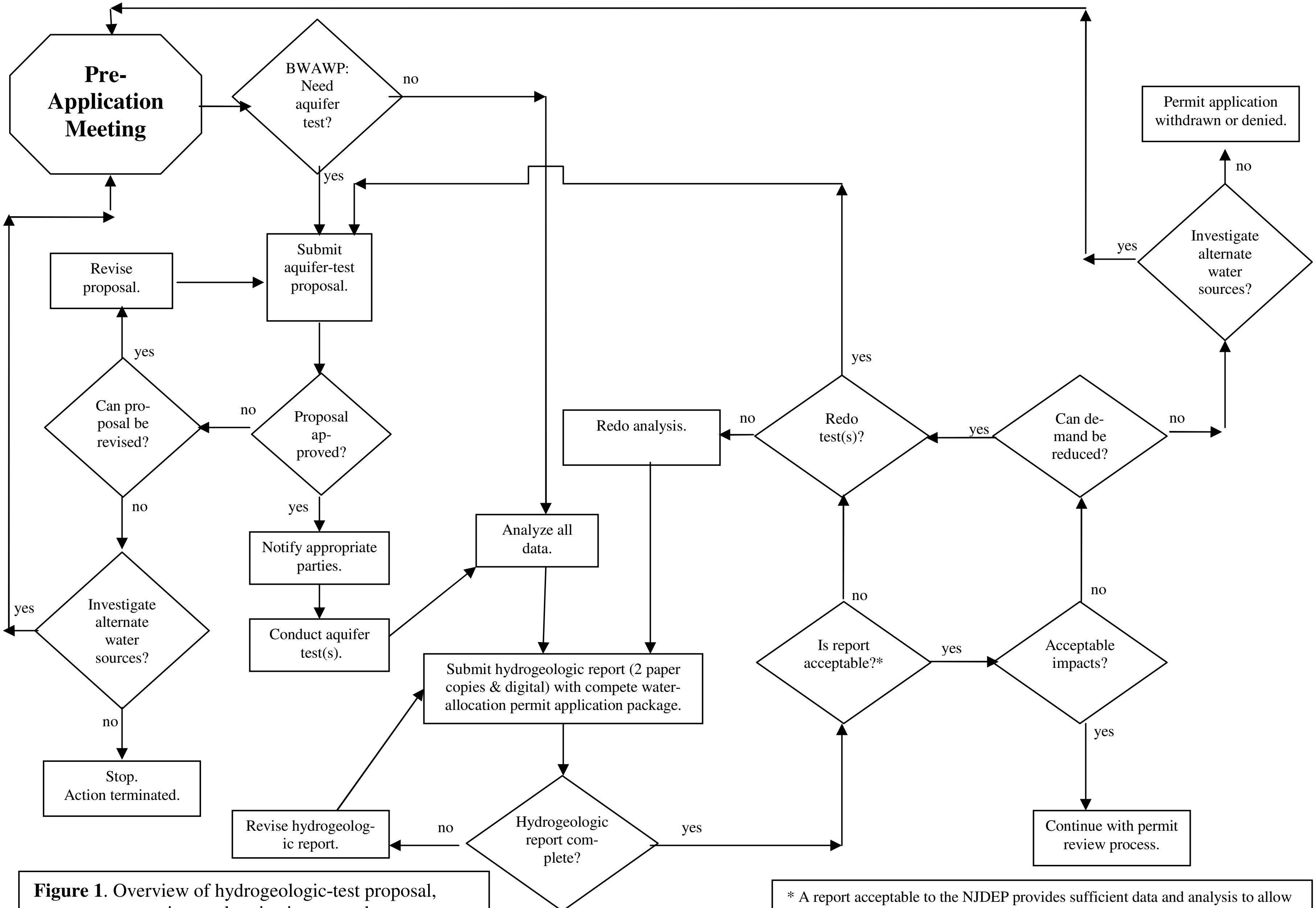

Figure 1. Overview of hydrogeologic-test proposal, reporting and reviewing procedures.

* A report acceptable to the NJDEP provides sufficient data and analysis to allow an accurate estimate of potential impacts of the proposed diversion.

II.C. Potential Impacts

N.J.A.C. 7:19 requires permit applicants establish that the proposed diversion is just and equitable and does not adversely impact the resource or other users of the resource. Adverse impact means an impaired flow rate, water level, or water quality (i.e. based on New Jersey primary and secondary drinking water standards at N.J.A.C. 7:10) for another diversion, or degradation of the water resources or natural environment of the waterways of the State as determined by NJDEP.

In order to determine if the new or increased diversion is "just and equitable" the applicant must determine the necessary hydrogeologic parameters and then quantify impacts of the diversion on other users. This report helps ensure that aquifer tests are designed and conducted appropriately and produce data that support an accurate analysis of potential impacts.

The water supplied to a well may come from one or more of three sources:

1) *Changes in storage* - Water will come out of storage in the aquifer and water levels decline.
2) *Interception* - The cone of depression around the well may intercept water in motion in the aquifer that would have discharged elsewhere.
3) *Induced recharge* - More groundwater may be induced to flow towards the well from adjacent aquifers or surface-water bodies due to the steeper hydraulic gradients associated with drawdown near the well.

Lowered water levels, interception and induced recharge have the potential to decrease water availability for other users, alter the migration of groundwater contamination, accelerate saltwater intrusion, decrease streamflow, and impact surface waters. If these potential impacts are a concern they must be considered in aquifer test design and evaluated in the hydrogeologic report.

Determining the impacts of a proposed diversion is generally a four-step process:

1) Determine the aquifer's hydrologic properties.
2) Quantify the changes in water levels, recharge and discharge the diversion will cause.
3) Quantify the impacts these changes will have at all points of concern.
4) Determine if the impacts are acceptable or unacceptable.

This report does not provide the standards by which the impacts are judged to be acceptable or unacceptable. These standards are provided in N.J.A.C. 7:19.

The following sections review some of the impacts that may result from a large groundwater diversion. These potential impacts will be discussed in the pre-application meeting to help guild test design and data analysis.

II.C.1. Groundwater Users

Diversion of water from a well lowers the water level in the aquifer. Drawdown is greatest at the pumping well and decreases with distance. This is called a cone of depression (fig. 2). At some distance the drawdown becomes insignificant. The zone of influence (ZOI) is the three-dimensional region which experiences a significant hydrologic impact attributable to a diversion. The extent of the ZOI is determined by the pumping rate and the hydrologic properties of the aquifer. This ZOI could be any number of shapes (i.e. drawdown patterns as mentioned in sections V.C and VIII.G below) based upon the hydrogeological setting.

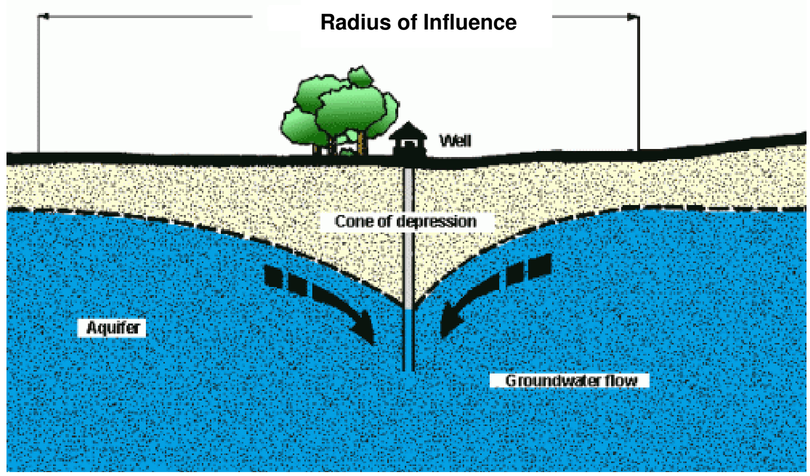

Figure 2. Cone of depression and zone of influence
(from web site groundwater.oregonstate.edu/under/wells)

In some cases, a well's ZOI may encompass pre-existing wells tapping the same aquifer and cause increased drawdown in them. This 'well interference' may or may not be significant depending on the amount of drawdown and characteristics of the pre-existing well. The regulations require that new diversions not adversely affect existing groundwater users. This may require monitoring water levels in or near other wells during all aquifer tests. This may also require numerical modeling of the cone of depression.

It is the applicant's responsibility to quantify the potential impacts to other groundwater users. The NJDEP will make a determination of whether or not the proposed groundwater diversion will result in adverse impacts.

II.C.2 Groundwater Contamination

Pumping near a groundwater pollution site may cause contamination migration. Additionally, new pumpage near an existing remedial-action project at a contamination site may interfere with the cleanup. The applicant must evaluate the potential of the proposed diversion to adversely interfere with any existing or planned remediation activities or to alter the path of a contamination plume.

The applicant must inventory all nearby groundwater pollution sites. The NJDEP maintains an inventory of these sites. This inventory, the known contaminated sites list, is available graphically through an internet mapping application (see section IV.B.)

In some areas groundwater pollution is widespread. These areas may be identified under one of three programs. Classification exception areas (CEAs) show geographically defined areas within which the New Jersey Ground Water Quality Standards (NJGWQS) for specific contaminants have been exceeded. Currently known extent (CKE) areas are geographically defined areas within which the local groundwater resources are known to be compromised because the water quality exceeds drinking water and groundwater quality standards for specific contaminants. A deed notice area is a geographically defined area within which soil remedial cleanup guidelines for specific contaminants have been exceeded. These three areas are available through an internet mapping application (see section IV.B.)

II.C.3. Saltwater Intrusion

Some areas of New Jersey have groundwater quality changes associated with saltwater intrusion. Saltwater intrusion may come from the ocean or from connate water already in or near an aquifer. The water may move laterally from a recharge area under the ocean, bay, tidal stream or saltwater marsh. It may leak upward from an underlying formation (upconing), or leak down from an overlying formation.

Saltwater intrusion may occur naturally due to changes in sea level. However, it is exacerbated by lowered water levels caused by excessive diversions too close to saltwater sources.

The U.S. Geological Survey (USGS) performs a survey of groundwater conditions in New Jersey once every five years and publishes maps which identify water levels within the major confined coastal plain aquifers. These maps also identify areas where elevated chloride levels are present in the aquifers. The most recently-published data are for the year 2003 (dePaul, Rosman, and Lacombe, 2009).

Pumpage near areas with water of elevated chloride concentrations may accelerate saltwater intrusion. Requests for new or increased diversions near such areas must address the possibility of inducing more salt water into the proposed pumping well or into other pumping wells, or increasing the rate at which salt water intrusion is occurring. All of the sources of saltwater listed above must be considered.

II.C.4. Streams

Groundwater discharge from the water table sustains stream baseflow (Winters and others, 1998). If the proposed diversion has the potential to reduce this baseflow the applicant must estimate the effect on nearby streams. This estimate must also include impacts upon surface water ecosystem, upstream dischargers, and downstream diverters and dischargers.

The applicant must address whether the proposed diversion will have a measurable effect on the hydrology and ecological viability of the stream. Reduction of flow can reduce the ability of a stream to assimilate discharges upstream and downstream of the proposed diversion, reduce the available supply to existing downstream users, cause reservoirs to increase releases to meet downstream passing flow requirements or reduce reservoir safe yield, and alter water temperature and ecology.

The applicant must analyze changes to the streamflow hydrograph, flow duration curve, and any streamflow statistics specified by NJDEP. If there are no streamflow records, the applicant must contact NJDEP in accordance with N.J.A.C. 7:19 to determine the procedures to be followed for obtaining stream flow records for a similar stream and adapting those records.

Any change in groundwater flow direction that would divert water from the drainage area of the stream can reduce stream baseflow. If the analysis indicates that the pumping will divert water from the drainage area of the stream, a quantitative assessment of the reduction in stream base flow and location of affected stream reaches must be made.

NJDEP's Division of Fish and Wildlife may review an application to determine if the requested diversion will affect stream flow critical to wildlife. NJDEP is currently evaluating an ecologically-based approach to setting monthly passing flows. This will require methods to estimate flows at ungaged sites. These methods are in development but are not currently (2012) implemented.

II.C.5. Lakes and Ponds

Surface-water bodies (generally lakes and ponds) may be affected by increased groundwater diversions. The proposed diversion may induce water to leak from surface water or it may intercept water that would otherwise have discharged to it. In some cases impacts of diversions on nearby surface water may be an important consideration. If the analysis indicates that the proposed diversion will reduce flow to a surface-water body the applicant must make a quantitative assessment of the reduction in inflow.

II.C.6. Sustainable water-resource yield

According to the Water Supply Management Act, “safe or dependable yield” or “safe yield” means a maintainable yield of water from a surface or groundwater which is available continuously during projected future conditions, including a repetition of the most severe drought of record, without creating undesirable effects.

As applied in New Jersey, the concept of safe or dependable yield primarily applies to surface-water sources, reservoir yield, and water distribution systems. This concept does not provide sufficient direction for practical application to groundwater diversions.

This concept of a yield that can be sustained during adverse conditions is here further qualified as the *sustainable water-resource yield*. The sustainable water-resource yield is the diversion rate that avoids unacceptable impacts on other groundwater and surface water users and the environment. This is evaluated by estimating the diversion that will not have adverse impacts on ecological flows, or create surface-water or groundwater overdrafts. Specifically:

1) Ecological flows, as defined at N.J.A.C. 7:19, are maximum, minimum and other statistical streamflow thresholds and frequencies (such as the minimum average seven consecutive day flow with a statistical recurrence interval of 10 years [MA7CD10 or 7Q10]) prescribed by NJDEP for the purpose of sustaining water-dependant ecology including, but not limited to, endangered species.

2) Surface-water overdraft means surface water diversion to the point of an undesired effect such as reduction in the MA7CD10 stream flow or other specific flow statistic, saline-water intrusion, or inability to meet permit-required ecological flows.

3) Groundwater overdraft means groundwater mining to the point of an undesired effect such as decline in available head to the base of an unconfined aquifer, reduction in the MA7CD10 stream flow or other specific flow statistic, decline in available head to the top of a confined or semi-confined aquifer, or saline-water intrusion.

II.C.7. Wetlands

Any structure located in a wetlands must receive a freshwater wetlands permit. A permit may also be required for a structure in the transition area of a wetlands. The NJDEP's Division of Land Use Regulation issues these permits.

Groundwater tends to be close to the surface under wetlands. Some plant communities, such as the endangered plant species swamp pink (*Helonias bullata*), are extremely sensitive to even small changes in groundwater levels (Laidig, Zampella and Popolizio, 2010). Excessive and sustained groundwater declines may contribute to changes in wetland composition and structure or possibly result in the loss of wetland plant habitat and animal species (Bunnell and Ciraolo, 2010; Laidig and others, 2010; Laidig, 2010). The NJDEP's Division of Land Use Regulation may review an application to determine if a requested groundwater diversion will adversely affect water levels under a wetland.

II.D. Overview

Planning, conducting, and analyzing an aquifer test involves a number of steps:

(1) Review of available geologic and hydrologic information.
(2) Pre-application meeting with NJDEP to learn of any specific restrictions or concerns.
(3) Develop and submit an aquifer-test proposal to determine the capability of the aquifer to supply water and to determine possible effects of proposed diversion on other users and the environment. Submit checklist with proposal.
(4) Revision and approval of the aquifer-test proposal.
(5) Sufficient notification to all parties of the upcoming aquifer test.
(6) Conduct the test under the controlled conditions defined in the aquifer-test proposal.
(7) Analyze all test data using the most appropriate methods of analysis. Estimate impact of the proposed diversion on other users and the environment.
(8) Prepare a hydrogeologic report that includes all data and analysis. Submit to NJDEP as part of water allocation permit package. Submit checklist with report.

This report contains detailed guidance in all of these areas below. However, this list may become outdated. As new concerns are recognized BWAWP may require additional reporting and testing conditions. Any additions will be discussed at the pre-application meeting.

II.D.1. Background geologic and hydrologic information

It is impossible to plan for an aquifer test without having some knowledge of site geology and general water-bearing properties of the aquifer. For example, a test of a limestone aquifer in northern New Jersey must be planned and conducted differently than one in a sand-and-gravel aquifer in southern New Jersey. Appendix A presents an overview of New Jersey's aquifers, but it is not a substitute for an experienced hydrogeologist.

It is the responsibility of the applicant or the applicant's representative to properly research available data. There is a wide range of geologic and hydrogeologic data available for New Jersey's aquifers. The N.J. Geological and Water Survey and the U.S. Geological Survey have published reports, maps, and data sets on the geology and groundwater resources of the State. Well logs and reported yields of nearby wells are especially important as they may indicate site-specific conditions which must be addressed.

Site-specific conditions must be considered within the context of regional geology. In some areas of the State local conditions may be quite different than the regional geology. It is advisable that the applicant research local well records and, if necessary, drill an exploratory well early in the process. This information developed during this initial research should guide the aquifer-test proposal.

The NJDEP makes available a robust environmental dataset on its internet-based environmental mapping tools (NJ-GeoWeb). These show public supply wells, streams and associated wetlands, critical habitat, and groundwater contamination along with other relevant concerns. NJDEP expects the applicant to use these tools to fully investigate site-specific environmental concerns. See section IV.B. for more information.

II.D.2. Pre-application meeting

BWAWP requires a meeting with the applicant or the applicant's representative before submission of a water allocation permit application. At this meeting, BWAWP and the applicant will exchange information on the proposed diversion and any special restrictions or requirements. For example, the applicant might be made aware of pumping restrictions on certain aquifers, such as water supply critical areas (section III.B.1). Another example is that the applicant might learn of the existence of environmental concerns that must be monitored during the test.

BWAWP expects that the applicant will have made use of the Water Allocation Availability Screening (WAAS) GIS tool before the pre-application meeting. This screening tool helps identify areas of concern and is required for Water Supply Allocation Permit Application administrative completeness. It represents one of several proofs necessary to assess probable water availability and identify permitting-process impediments.

The pre-application meeting saves the applicant a significant amount of time and money by ensuring that an appropriate water source is tested and that all tests are designed correctly.

II.D.3. Aquifer-test proposal

The DEP requires that the applicant develop an aquifer-test proposal. The proposal describes in detail the test protocol. It includes information on site geology, expected locations and screened intervals of observation wells, pumping rates, location of water discharge, length of test, and other relevant information.

The aquifer-test proposal must address all areas of concern expressed by the NJDEP during the pre-application meeting. The proposal must detail all monitoring locations and schedules. This includes, but is not limited to, monitoring of surface water, groundwater, water quality, water temperature, precipitation, tides and barometric pressure.

If the applicant discovers additional concerns while developing the test proposal, these should also be addressed in the proposal.

Appendix C is a checklist of the proposal's required contents. The applicant must complete and submit this checklist with the aquifer-test proposal.

II.D.4. Approval of the aquifer-test proposal

BWAWP must approve the aquifer-test proposal before the aquifer test can take place. There may be several revisions of the aquifer-test proposal before BWAWP issues final approval. Given the expense and effort involved with conducting an aquifer test, it is vital that the applicant conduct the test in a manner that will generate the data needed by BWAWP to answer the questions of concern.

The approved aquifer-test proposal acts as the blueprint of the aquifer test. Tests not conducted in accordance with the approved proposal may be rejected. Problems can occur during the test that prevent complete adherence to the aquifer-test proposal. BWAWP will review these situations on a case-by-case basis to determine if the available data are sufficient and acceptable. However, failure to collect adequate data may result in either rejection of the entire permit application or a redoing of the test. Not conducting the test in accordance with the test proposal will lengthen review times.

II.D.5. Notification

The applicant must give all relevant parties adequate notification of the start of aquifer test. NJDEP may wish to observe some tests or install additional monitoring equipment. Other parties (for example, local officials or nearby well owners) may need to be notified. In general, the applicant should issue a preliminary notification a month in advance, then a final notification a week in advance.

II.D.6. Hydrogeologic tests

Good hydrogeologic tests provide information about the groundwater system and potential impacts of groundwater diversions. Three different hydrogeologic tests may be necessary to fully evaluate the feasibility and impact of a groundwater diversion:

- step test
- single-pumping-well aquifer test
- multiple-pumping-well aquifer test

BWAWP requires a step test for all new public supply wells before any further aquifer test. BWAWP requires either a single-pumping-well test or a multiple-pumping-well test for allocation requests for new wells, increases in allocation for an existing pumping well, and requests for a larger pump size in an existing well. Under certain conditions both a single-pumping-well and a multiple-pumping-well test may be required. In cases where BWAWP determines that sufficient hydrogeologic data exists, the aquifer test may be waived.

The type, number and location of monitoring points is determined by the aquifer properties, expected pattern of drawdown, surface-water/groundwater interactions, nearby groundwater users, and environmental concerns. Tests in different locations with different concerns may have greatly different monitoring schemes.

It is critical that the tests be conducted under controlled conditions. This includes, but is not limited to, controlling pumpage at neighboring wells, keeping the diversion rate constant during the test, no significant water-table fluctuations due to precipitation, and continuous data measurements at numerous monitoring points. These conditions are explained below. Failure to achieve these requirements may result in data which do not adequately monitor the impact of the diversion. In such a case the test will not produce results that support an adequate estimate of the potential impact of the withdrawal.

II.D.7. Analysis and interpretation of data

Analysis of test results yields information on the aquifer characteristics that govern groundwater flow - transmissivity, storativity, vertical leakage, delayed yield, and anisotropy. However, different aquifers and test conditions require different analysis techniques. Appendix B presents a brief overview of analytical techniques and appropriate situations but is not an adequate substitution for a groundwater professional.

The applicant must also evaluate the diversion's possible effect on other aquifers, groundwater users, contaminated areas, surface-water bodies and environmentally sensitive areas as detailed above in section II.C.

BWAWP recognizes the need for flexibility under certain hydrogeologic conditions and site constraints. Extenuating circumstances may require adjustments to the approved aquifer-test proposal. The applicant must contact BWAWP and explain the necessary adjustment before starting the aquifer test.

II.D.8. Final hydrogeologic report

After all tests are conducted and analyzed, the final interpretive hydrogeologic report is submitted as part of the water supply diversion application. The final report must include a discussion of the field procedures, all data gathered, analysis of the data, and evaluation of the effect of the proposed diversion on the aquifer based on all other groundwater and surface-water users and areas of environmental concern. Unsupported statements are not acceptable.

Appendix B presents an overview of techniques for analyzing hydrogeologic test data. It is not comprehensive but covers the most common methods. Its primary purpose is to guide the applicant toward the most appropriate analytical method for particular hydrogeologic and testing situations. The analysis technique used should adequately and accurately address the test conditions.

The applicant must submit two paper copies and an electronic copy (in Adobe pdf format) of the final hydrogeologic report.
The applicant must submit all observed test data in electronic form. Section VIII.J. below describes the format for electronic data. The application package should not include lengthy data appendices on paper.

Appendix D is a checklist of the final hydrogeological report's required contents. The applicant must complete and submit this checklist with the paper report.

II.E. Previous editions

The first edition of this report was Technical Memorandum TM89-3 "Guidelines for preparing hydrogeologic reports for water-allocation permit application" (Hoffman and others, 1989). After use, this were revised and republished as Geological Survey Report GSR 29 (Hoffman and others, 1992).

This report is the third edition. It addresses additional concerns that have arisen since the earlier editions. As NJDEP becomes aware of additional environmental concerns these will be addressed in update sheets issued by BWAWP.

This edition also addresses specific topics and issues encountered by NJGWS and BWAWP that have complicated the planning, performance, monitoring and analysis of hydrogeologic tests. Some of these complications have created delays in test analysis and final determination on the permit request.

II.F. Currency

The rules, statues, website addresses, and the nomenclature mentioned in this report were valid at the time it was published. However, this information may change over time. The applicants must always follow the most recent rules, regulations and guidance. These are available from BWAWP.

The administrative details outlined in this report are for guidance purpose only and are designed to help applicants and other interested parties in the water allocation process. Full details are in N.J.A.C. 7:19.

II.G. Acknowledgements

The 1992 version of GSR29 was greatly improved by the assistance of numerous Bureau of Water Allocation and Well Permitting staff, especially Diane Zalaskus, Rachel O'Brien and Andrew Hildick-Smith. The comments of John Cagnassola and James Schultes were very informative and much appreciated.

The third edition builds upon the previous one. Many thanks to all the reviewers for their useful comments.

III. Other Requirements and Restrictions

All applicants proposing a new or increased diversion and proposing to perform an aquifer test should investigate the following issues for applicability. All of these issues must be satisfactorily addressed before the NJDEP can issue a final decision on an application.

This report is intended to assist those conducting tests to evaluate the aquifer as a water source, as well as possible impacts on other groundwater users. This is required by the Bureau of Water Allocation and Well Permitting in the Division of Water Supply and Geosciences. However, by proper coordination and planning, the applicant may be able to generate information during the aquifer test that may meet the requirements of other permitting groups, and regulatory agencies.

III.A. Permitting Requirements

A water-supply well will require a number of permits for construction, testing and operation. These are outlined below. BWAWP can provide additional guidance on these issues.

III.A.1. Well Permits

All wells drilled in New Jersey must be done in accordance with N.J.A.C. 7:9D-1 et seq. NJDEP's Bureau of Water Allocation and Well Permitting (BWAWP) oversees this requirement. A licensed driller must install the well. A licensed pump installer must install the permanent pumping equipment. The driller must also submit a well record to BWAWP with well location, construction details, and aquifer data after the well is completed.

BWAWP assigns a unique 10-digit well number to each well when the well permit is issued. The well permit number must be shown on all logs, data sheets, and other documents submitted in support for a hydrogeologic testing or a water allocation application. This step helps avoid confusion when analyzing data from multiple wells.

BWAWP requires a new well permit if the use of the well changes. Thus if a test well is converted into a production well, BWAWP requires that the applicant obtain a new well permit. This step results in a new well permit number for the same well. In cases where the use of a well has changed, and thus well permit number has changed, the applicant must include a correlation table detailing all changes in well permit number.

BWAWP requires that a master well driller install all public community supply wells. If the applicant intends to install a test well that may later be converted to a public community supply well then a master well driller must install the test well.

III.A.2. Permit-by Rule

BWAWP requires a short-term water-use permit-by-rule for aquifer tests in support of a new well where more than 100,000 gallons per day is being diverted for less than 31 days; the threshold is 50,000 gallons per day in the Highlands Preservation Area. This is used to track water use over the testing period.

III.A.3. Other Division of Water Supply and Geoscience Permits

Public water supplies are strictly regulated. Other Bureaus in the Division of Water Supply and Geoscience have additional permit requirements that apply to public supply wells. Any well that is used for public community water supply is subject to the New Jersey Safe Drinking Water Act (N.J.A.C. 7:10-1 et seq.). The Bureau of Safe Drinking Water (BSDW) requires permits for both the construction and operation of a new or modified well and also for any related treatment prior to placing the well into operation. A 24-hour pump test run at 120% of the design pump capacity may be required to be performed on a new public community supply well (including replacement wells). In some cases a 72-hour test, run at 100% of capacity, may be sufficient to satisfy the drinking water rules at N.J.A.C. 7:10-11.7(h). However, the applicant should contact BSDW, or its successor, to receive an official determination regarding the required testing procedures.

The Bureaus of Safe Drinking Water has additional regulations that affect public supply wells. Applicants must contact this Bureau for the steps required to under their regulations.

Copies of the New Jersey Safe Drinking Water Act may be obtained from the Division of Water Supply and Geoscience, or from the NJDEP's website at
http://www.nj.gov/dep/watersupply/g_reg.html

BWAWP recommends the applicant coordinate with the various programs in the Division of Water Supply and Geoscience to minimize, if possible, the required testing.

III.A.4. Other Permits

Depending on site-specific conditions, NJDEP may require additional permits before the applicant can conduct the aquifer test. In environmentally sensitive areas, such as tests conducted near a groundwater pollution site, NJDEP may require additional permits. These may include, but are not limited to, New Jersey Pollution Discharge Elimination System (NJPDES) permits for discharge of water, and wetland disturbance permits.

Aquifer storage and retrieval (ASR) projects require several additional permits as they are generally considered Class V injection wells under the Underground Injection Control

Program. Testing and long-term monitoring requirements for ASR wells are at N.J.A.C. 7:14A-8. The review process under N.J.A.C. 7:14A-8 is initiated through a Ground Water Protection Plan (GWPP) to confirm that Ground Water Quality Standards and Safe Drinking Water Standards are met under N.J.A.C. 7:9C and N.J.A.C. 7:10 respectively. If the source of the injected water is another aquifer, the applicant shall conduct additional testing for that diversion in accordance with N.J.A.C. 7:19-2.2.

Other agencies may require additional permits. These may include, but are not limited to, county and/or municipal well permits, access road construction, sediment control, and utility disruption, to name a few.

It is the responsibility of the applicant to identify and obtain all necessary permits before conducting a hydrogeologic test.

III.B. Restrictions

Certain areas within the State have water availability issues. Proposed diversion may either be limited or prohibited depending upon the location and source of water.

III.B.1. Water supply critical areas

The Water Supply Management Act (N.J.S.A. 58:1A-7) and Water Supply Allocation Rule (N.J.A.C. 7:19) selectively limits opportunity for new or increased allocations from affected aquifers within Areas of Critical Water Supply Concern. Currently there are two such areas in New Jersey. Critical Area 1 is in central New Jersey along the Atlantic coast and covers four critical aquifers, the upper Potomac-Raritan-Magothy, the middle Potomac-Raritan-Magothy, the Englishtown, and the Wenonah-Mt. Laurel. Critical Area 2 is in southwestern New Jersey and applies to all water-bearing units of the Potomac-Raritan-Magothy aquifer system. Each Critical Area consists of a depleted and threatened zone.

Figure 3 is an unofficial representation of the Water Supply Critical Areas. BWAWP maintains individual maps of each affected aquifer in each Critical Area. Proposed diversions outside but adjacent to a Critical Area must also be evaluated to determine if they will result in lowered water levels within a critical aquifer within a Critical Area.

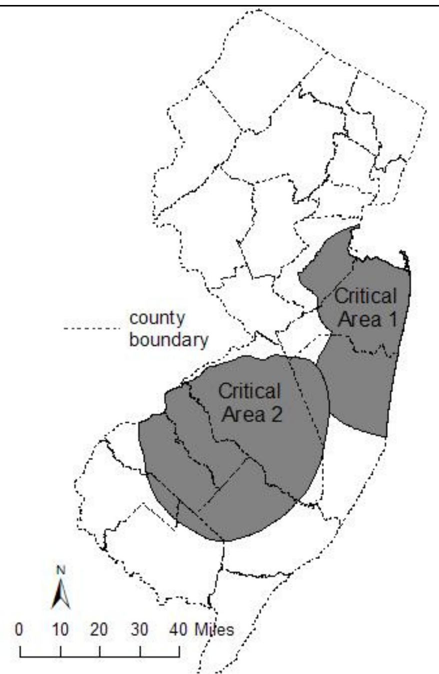

Figure 3. Water Supply Critical Areas

III.B.2. Water-supply reservoirs

BWAWP prohibits any surface water or groundwater diversion upstream of a water-supply reservoir that reduces the safe yield of the reservoir. This is because the reservoir already has a permitted safe yield and any new upstream diversion may not diminish this safe yield. In some cases, upstream diversions may be permitted if the water loss is counted against the reservoir's safe yield. This requires the approval of BWAWP and the reservoir operator.

This prohibition also applies to groundwater diversions upstream of a surface-intake that reduce that intake's yield.

III.B.3. Areas of limited water availability

In addition to the regional water-supply regulatory restrictions outlined above, there are numerous areas in the State with either aquifer and/or watershed-specific concerns. These water-availability issues may limit the amount of water that can be withdrawn or may even preclude any additional water diversions. BWAWP staff will discuss any such restrictions that may apply at the pre-application meeting.

III.C. Other Relevant Agencies

All applicants for a new or revised water allocation permit must investigate the following issues for applicability. All of these issues must be satisfactorily addressed before NJDEP can issue a new or revised water allocation permit.

III.C.1. Pinelands

The New Jersey Pinelands Protection Act of 1979 (N.J.S.A. 13:18A-1 et seq.) established the Pinelands Commission in order to protect and preserve the Pinelands ecosystem. The Pinelands Commission evaluates the ecological impacts of water diversions on the unconfined Kirkwood-Cohansey aquifer which underlies the Pinelands (fig. 4).

The Commission has developed the Pinelands Comprehensive Management Plan to guide and mitigate impacts on the ecosystem. All development activities, including water diversions, must be consistent with the Plan. The Commission issues a Certificate of Fil-

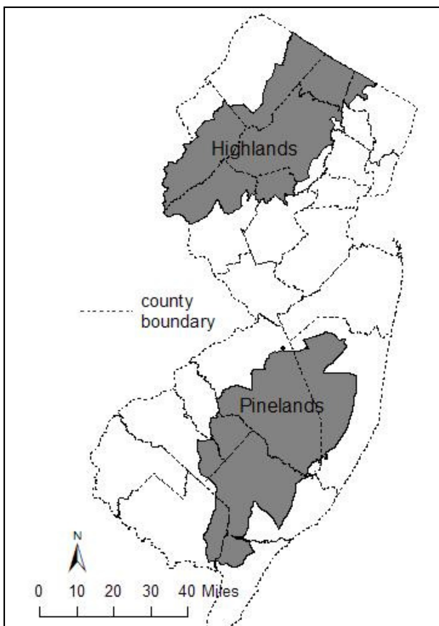

Figure 4. Highlands and Pinelands

ing for those activities that are consistent. The Pinelands Commission may also review proposed diversions outside of the Pinelands that have the potential to affect the Pinelands ecosystem.

NJDEP may not issue a water allocation permit that is inconsistent with the Pinelands Comprehensive Management Plan. The Pinelands Commission's web site is at http://www.state.nj.us/pinelands/index.shtml.

III.C.2. Highlands

The Highlands Water Protection and Planning Act of 2004 (N.J.S.A. 13:20-1 et seq.) established the Highlands Council. The Council, through the Highlands Regional Master Plan, regulates water resources within the Highlands Region (fig. 4). BWAWP's regulatory volume thresholds are halved in the Highlands Preservation Area, from 100,000 gpd to 50,000 gpd.

New and increased diversions in both the Highlands Preservation and Planning Areas must be consistent with the Highlands Regional Master Plan. NJDEP may not issue a water allocation permit that is inconsistent with the Highlands Regional Master Plan or the Highlands Act.

New or increased diversions within the Highlands Preservation area must apply for a Highlands Preservation Area Approval (HPAA) in accordance with N.J.A.C. 7:38, rather than a water allocation permit or permit modification unless the proposed diversion has been determined to be exempt from the Highlands Act. The water allocation process is an element of the HPAA in these cases. This requires a mandatory pre-application meeting. This process is outlined on NJDEP's Highlands web site.

NJDEP's Highlands web site is at www.state.nj.us/dep/highlands/. The Highlands Council's website is at http://www.highlands.state.nj.us/.

III.C.3. Delaware River Basin Commission

The Delaware River Basin Compact, including the Federal Government and the states of New York, Pennsylvania, Delaware and New Jersey, established the Delaware River Basin Commission (DRBC) in 1961. The DRBC oversees a unified approach to managing diversions and wastewater discharges without regard to political boundaries. All diversions and discharges must be in accordance with the Delaware River Basin Comprehensive Plan and Water

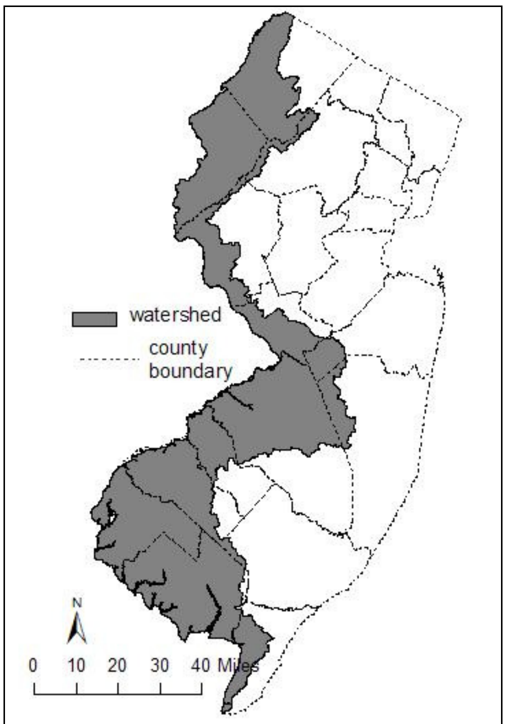

Figure 5. Delaware River and Bay watershed in New Jersey

Code.

The Delaware River Basin Commission's web site is www.state.nj.us/drbc/.

III.D. Notifications

The applicant may have to notify a number of organizations before conducting an aquifer test.

III.D.1. Aquifer-test proposal and reviews

The Bureau of Water Allocation and Well Permitting (BWAWP) is the lead agency on reviewing aquifer tests. They either issue the allocation permit or a denial letter. A BWAWP staff person is the primary contact for all communication with the applicant and his representative.

The NJGWS Bureau of Water Resources and Geoscience (BWRG) advises BWAWP. BWRG staff may assist at pre-application meetings, review aquifer-test proposals, and help review aquifer test reports. However, all communication should be made first through the BWAWP staff contact.

The applicant must notify both BWAWP and BWRG staff of the test dates at least 30 days in advance of conducting any tests. This is to allow staff the opportunity to conduct a site visit during the test.

III.D.2. Local health department and well owners

Applicants must notify the local Health Department and all well owners (including private well owners) within the estimated zone of influence of the test well. This notification must take place a reasonable period of time before the test starts. It is the applicant's responsibility to identify the wells within the estimated zone of influence.

III.D.3. Public notice and hearing on the application

As part of the approval process, NJDEP notifies nearby permit holders, municipalities and counties of the application. They are given an opportunity to comment on the application. If objectors emerge, NJDEP may conduct a public hearing to obtain additional information regarding any concerns. This may include concerns about the aquifer test. NJDEP addresses concerns in a comment response document issued after the close of the comment period.

IV. Information Tools

Information on the aquifers and water resources of New Jersey is readily available through NJDEP resources. Much of this information is available over the Internet via interactive mapping and data base query applications.

IV.A. Existing Well Information

NJDEP maintains a record of wells drilled throughout the State. This record is open to the public and may yield a significant amount of information on geologic units in a particular area. Electronic tools are available that can help identify wells in a particular area. A search of well records may yield detailed geologic logs. In addition, BWAWP offers a well search for identification of wells within a designated area. Details regarding procedures and fees can be obtained from the Well Permitting section at (609) 984-6831.

IV.B. Water Allocation Availability Screening Tool

The Water Allocation Availability Screening tool (WAAS) is a interactive mapping system. It is a web screening tool designed by the Division of Water Supply and Geoscience to assess probable water availability for a specified location. It can be used to identify permitting process impediments.

BWAWP expects that all applicants will have used the WAAS before the pre-application meeting.

IV.C. Interactive Mapping

Interactive mapping (I-Map) applications are a graphical approach to displaying data using an internet map service. The user specifies an area and which data layers are to be displayed and the resulting map appears on the screen. By zooming in and out, and changing the layers, a user may gather regional and site-specific information about a site of interest. Currently two I-Maps are useful in this context, NJ-GeoWeb and iMap-NJ Geology.

The NJ-GeoWeb application is designed to show general environmental data. It can display a wide range of environmental and cultural features (table 2). It is available at http://www.nj.gov/dep/gis/geowebsplash.htm. This internet mapping application will be updated with new layers as they become available. This application may eventually be replaced by more advanced applications.

I-Map NJ Geology is designed to show information on the geologic and hydrogeologic resources of New Jersey. It is available at http://www.nj.gov/dep/gis/ and at http://www.njgeology.org/. Table 3 lists the layers currently available for display in I-MapNJ Geology.

IV.D. Data Miner

Data Miner allows a user to retrieve data from NJDEP's data bases. These data bases contain selected permit conditions and data submitted by the regulated community. It also provides a number of reports on specific issues. Data Miner is available at:
http://www.nj.gov/dep/opra/online.html.

IV.E. New Jersey Geological and Water Survey

The New Jersey Geological and Water Survey (NJGWS) has published numerous reports on New Jersey geology and water resources and maintains a record of aquifer tests in its Hydroparameters Data Base. The NJGWS web site (at http://njgeology.org) allows for searches of published documents, many of which are available in digital form.

IV.F. U.S. Geological Survey

The U.S. Geological Survey (USGS) has published numerous reports on New Jersey geology and water resources, and has extensive data collection network. The USGS Publication warehouse (at http://pubs.er.usgs.gov/) allows for searches of published documents. The USGS state web page (at http://nj.usgs.gov/) provides access to both real-time and archived stream flow and groundwater data.

Table 2. Data layers in NJ-Geo Web*

Aerial Photos 1930	Landscape Project 3.0 - Vernal Habitat
Aerial Photos 1995/97	Legislative Districts
Aerial Photos 2002	Mid-Atlantic States
Air Monitoring Stations	Municipalities
Ambient Biomonitoring Network (AMNET)	Natural Heritage Priority Sites
CAFRA	NJEMS Sites
Category One Waters	NJPDES Discharge Points - Surface Water
Chromate Sites	NJPDES Regulated Facilities
Congressional Districts	Open Space (State)
Counties	Pinelands Boundary
Deed Notice Areas	Pinelands Management Area
Delaware and Raritan Canal Commission Review Zones	Place Names
Fish Index Of Biotic Integrity	Public Community Water Supply Wells
Groundwater Contamination Areas (CEA)	Quarter Quad Grid
Groundwater Contamination Areas (CKE)	Purveyor (water)
Highlands	Roads (Tele Atlas)
Historic Archaeological Site Grid	Roads (major)
Historic Districts	Sewer Service Areas
Historic Properties	Shellfish Classification
Impervious Surface % (2002)	Soils (SSURGO)
Known Contaminated Sites List	State Plan Centers
Land Use 1995	State Planning Areas
Land Use 2002	Streams
Land Use Change 1995-2002	Sub-Watersheds (HUC14)
Landscape Project 2.1 - Bald Eagle Foraging	Surface Water Quality Standards
Landscape Project 2.1 - Beach	Underground Storage Tanks Facilities
Landscape Project 2.1 - Emergent Wetlands	Urban Enterprise Zones
Landscape Project 2.1 - Forest	Water Bodies
Landscape Project 2.1 - Forested Wetlands	Watershed Management Areas
Landscape Project 2.1 - Grassland	Watersheds (HUC11)
Landscape Project 2.1 - Urban Peregrine	Well Head Protection Areas (Community)
Landscape Project 2.1 - Wood Turtle	Well Head Protection Areas (Non-Community)
Landscape Project 3.0 - Landscape Version	Well Program Grid
Landscape Project 3.0 - Species Based Patches	Wetlands (2002)
Landscape Project 3.0 - Streams	Zip Codes

*Current May 2010, at http://www.nj.gov/dep/gis/geowebsplash.htm

Table 3. Data layers in i-MapNJ GEOLOGY*

Abandoned Mines	Groundwater Recharge Areas
Aerial Photos 2002	Landslides
Ambient-Major ions	Magnetic Anomalies (gammas)
Ambient-Metals	Mid-Atlantic States
Ambient-Nutrients	Municipalities
Ambient-Pesticides	Physiographic Provinces
Ambient-Radionuclides	Place Names
Ambient-VOC	Public Community Water Supply Wells
Bedrock Aquifers	Quad Grid
Bedrock Geology	Quarries
Bedrock Geology Cross-sections	Roads (Tele Atlas)
Bedrock Outcrops	Sole-Source Aquifers
Bedrock-Surface Topography	Surficial Aquifers
Canals and Water Raceways	Surficial Geology
Counties	Surficial Geology Cross-sections
Dikes	Tidal Benchmark Network
Drought Regions	Topographic Images
Earthquake Epicenters	Watershed Management Areas
Faults	Well Head Protection Areas (Community)
Folds	Well Head Protection Areas (Non-Community)
Gravity Anomalies (1 mgal)	

* Current May 2010, at http://www.nj.gov/dep/gis/imapnj_geolsplash.htm

V. Aquifer-test proposal

NJDEP requires an aquifer test for most new requests for groundwater diversions. An aquifer test may also be required if an applicant requests an increase in permit diversion limits. The goal of the test is to provide sufficient information on the aquifer's ability to supply the requested water, potential impacts on the environment and other users, and influence on contaminated sites. To make sure the test is appropriate NJDEP requires that the applicant submit a test proposal and that this proposal be approved before conducting the test. The applicant must submit two paper copies of the aquifer-test proposal.

Appendix C is a checklist of items the aquifer-test proposal must address. This checklist may change as NJDEP's approach and responsibilities change. If this happens, the BWAWP will supply the most recent checklist which will supersede Appendix C. The applicant must complete and submit the checklist along with the aquifer-test proposal.

V.A. Justification

Aquifer tests provide the information that allows the applicant to quantify the impacts of a proposed diversion. Therefore it is vital that the tests be conducted properly in order to provide sufficiently-accurate information. It is NJDEP's experience that developing a thorough aquifer-test proposal results in better tests, better data, and better analysis. This provides for a better assessment of impacts to the environment and other groundwater users and a more efficient and timely permit review process.

The NJDEP may require a test to be redone if it is conducted improperly (too short, for example) or improperly monitored (ignoring a nearby contamination site, for example). Developing a thorough aquifer-test proposal, and following it, reduces the chance that the test will have to be redone thus saving the applicant time and money.

V.B. Description

BWAWP requires the applicant to develop and submit an aquifer-test proposal before conducting an aquifer test. The aquifer test may not take place before the proposal is approved. The aquifer-test-proposal approval process may require revision before final approval. The test must then be conducted in accordance with the approved proposal.

The aquifer-test proposal must:

1) Sufficiently describe the aquifer and justify the type of aquifer test proposed (see section VI.).
2) Address all of the appropriate design factors (see section VII.).

3) Include a description of monitoring and pumping wells, pumping schedule, monitoring locations and schedule, and other relevant factors.
4) Identify the environmental concerns and describe how the test will generate sufficient data to allow analysis of potential impacts.
5) Identify nearby users and present a test design that will yield sufficient information on aquifer properties to allow an estimate of the potential impact on them.

At the pre-application meeting BWAWP may identify additional areas of concern. The test proposal and the final report must address these issues. If the applicant later uncovers additional environmental factors then these must also be addressed appropriately.

BWAWP must approve the aquifer-test proposal before the aquifer test is conducted. Failure to obtain this approval increases the chance that the aquifer test will not generate sufficiently accurate and appropriate information. If the test does not result in sufficiently accurate and appropriate information at all points of concern then BWAWP may require the applicant to repeat the aquifer test.

The approved aquifer-test proposal acts as a detailed blueprint for the aquifer test. NJDEP expects that the applicant will conduct the test, and monitor impacts, as described in the approved aquifer-test proposal. Changes to the test procedure that decrease the accuracy of the data, or result in less monitoring than approved, increase the chance that the test data will not be able to support the required analysis. If this occurs BWAWP may require another test.

A step test is required before conducting the proposed aquifer test. This helps ensure that the pumping well can maintain the requested diversion rate during the aquifer test. Preferably the step test will have been conducted before the test proposal is submitted. If not, then NJDEP's approval of the test proposal will be conditional upon performing a step test and upon the step test proving that the pumping well can support the planned pumping rate during the drawdown test.

V.C. Estimated drawdown pattern

The applicant should, based on the best-available understanding of site-specific hydrogeologic features, create a generalized description of the expected drawdown pattern. This is based on those features which either impede or allow drawdown. This understanding is preliminary, and may change as additional wells are installed at the site and further field work is conducted. But this will help provide a framework that can guide installation of monitoring points for the aquifer test.

The estimated drawdown pattern, along with those factors which govern it, must be described in the aquifer-test proposal.

The following examples present some of the hydrogeologic features found in New Jersey that may affect the pattern of drawdown observed:

1) If a stream is a recharge source then a pumping well in an unconfined aquifer on one side of the stream may create less drawdown on the other side of it than if the stream were not there.
2) In a buried-valley aquifer, where the walls of the valley are much less permeable than the water-bearing sediments in the valley, the drawdown pattern may be truncated by the walls but exaggerated along the strike of the valley.
3) In a rock aquifer where water travels preferentially along either the strike and dip of the units, solution-weathered beds, and/or fractures, the drawdown pattern may be elongated in these directions. Conversely, units off strike and off dip may experience less drawdown.
4) If the semi-confining unit adjacent to a pumped aquifer has areas of greater and lesser permeability, then drawdown in the aquifer may be less where recharge is able to leak into the aquifer. Where this leakage occurs there may also be measurable drawdown in an overlying aquifer.
5) In areas with pre-existing pumping wells a new diversion may cut off recharge that had supplied one of these older wells. In this case the older well's drawdown pattern may alter as it captures recharge from other sources.

V.D. Changes after Approval

NJDEP's approval of the aquifer-test proposal usually occurs before all of the monitoring points have been installed. Occasionally, field work after approval of the aquifer-test proposal shows that one or more of the monitoring points will not yield the desired information during the aquifer test. In such cases the monitoring point needs to be changed. The applicant must document the conditions that require the change from the original monitoring location to the new. The NJDEP must be notified of, and give approval of this change before the aquifer test begins.

The goal of the aquifer-test proposal is to ensure that all areas of concern are appropriately monitored. The approved proposal is not a straight jacket that prevents alteration if field conditions are different than what was assumed. The applicant must ensure that the test generate sufficient information to allow an evaluation of potential impacts of the proposed groundwater diversion.

V.E. Waiver Request

BWAWP requires an aquifer test when there is insufficient hydrogeologic information to adequately predict the impact of the proposed diversion on other users and the environment. In some cases accurate hydrogeologic information exists (from previous tests or existing peer-reviewed, published and well-calibrated groundwater models) to allow an accurate prediction. If so, the requirement for an aquifer test may be waived. BWAWP, not the applicant, determines if sufficient hydrogeologic information exits. In some cases BWAWP may require supplemental testing to address site-specific issues.

A request to waive the aquifer-test requirement must come from the applicant. The applicant must show that sufficient data exist to allow adequate prediction of the proposed diversion's impact. If this request is approved, BWAWP will issue an aquifer-test waiver.

If a waiver is granted, the aquifer test does not need to take place. However, the applicant must still submit a hydrogeologic report that uses the existing information to adequately predict the impact of the proposed diversion on other users and the environment. In this case the hydrogeologic report will contain all of the sections discussed below except those dealing with the aquifer test procedure, data and analysis. The hydrogeologic report must include an estimate of the zone of influence and the groundwater diversion's impact. This hydrogeologic report must include an analysis of current groundwater flow patterns using the most current data available.

VI. Types of Aquifer Tests

This report covers three types of aquifer tests, step, single-pumping-well, and multiple-pumping-well. A step test is conducted on a proposed pumping well and does not require any observation wells. It generally takes less than a day to perform. A single-pumping-well test requires one pumping well and several properly located and screened observation wells and other monitoring points. It generally lasts 72 hours, but may be longer if needed. A multiple-pumping-well test involves multiple pumping wells with other observation points. It may last 30 days, or longer, if needed. NJDEP may require the applicant to conduct one or more of the three tests depending on local conditions, type of permit requested, environmental concerns, and availability of reliable hydrogeologic data

These tests are discussed in more detail below. However, this discussion is cursory in nature and does not substitute for a college-level or professional course in aquifer-test design and analysis. Proper interpretation of test data requires an understanding of the hydrogeologic system, test conditions, and appropriate analysis techniques. In order to correctly generate and interpret test data the applicant, or representative, must have a good understanding of proper field techniques, New Jersey hydrogeology, the assumptions underlying the analysis methods, and any limits to the analysis.

Aquifer test analysis may be complicated by many factors. Geologic conditions rarely match all of the assumptions required by the available analytical techniques. The hydrogeologist may need to evaluate the data using several methods and, based on professional judgment select the method which best approximates the hydrogeologic setting and hydraulic responses observed during the aquifer test. The applicant should then use conservative estimates of aquifer parameters in estimating the potential impact of the proposed diversion. Appendix B provides a summary of selected analytical methods appropriate for various hydrogeologic settings in New Jersey. The appendix does not replace a more detailed, formal study of the methodologies.

VI.A. Step Tests

The cost of pumping groundwater is a major factor in water supply. Maximizing a well's efficiency helps minimize costs. There are three steps to maximizing overall efficiency:

1) Design the most efficient well for the aquifer.
2) Select the most efficient pump for the well.
3) Operate the system at the most efficient pumping rate.

One parameter measured by the step test is the well loss factor. This is a measure of the friction caused as water moves through a well's gravel pack and screen into the well bore. The well loss is, roughly, the drawdown that would be observed in a well at a given pumping rate if friction were not a factor divided by the observed drawdown. The well loss is different at different pumping rates. Determining well loss is a necessary step in operating the well in the most efficient way.

A step test provides data that allow determination of well loss. For the purposes of these procedures, a step test is conducted to determine the appropriate discharge rate for the subsequent long-term aquifer test. NJDEP requires that a step test be conducted before a drawdown test. This is to ensure that the well will be able to maintain the desired pumping rate during the drawdown test.

If the applicant has already constructed observation wells for the 72-hour aquifer test, it is recommended that water levels be monitored in the near observation well during the course of the step test. Such data can be invaluable in confirming the results of the step test analysis and can provide backup data for the analysis of the 72-hour aquifer test.

The following procedures should be followed when conducting a step test, and analyzing the data:

VI.A.1. Select the pumping rate for each step

At a minimum, five equal pumping discharge steps must be selected, with the final step being equivalent to 120% of the applicant's maximum requested pumping rate. Starting with the smallest step, each successive step must be pumped at a constant discharge rate for a minimum of 90 minutes.

VI.A.2. Run the step test

Testing must be done in continuous steps with no pause between steps. If the pump fails during any step the test must be restarted at the lowest pumping rate after water levels in the well have recovered to within 95% of pre-test levels.

VI.A.3. Collect test data

The applicant must monitor the discharge rate at least at 10 minute intervals. Discharge rates must be monitored and maintained constant at each step. Water levels in the pumping well should be measured at least at 30 second intervals. [1]

Discharge should be expressed in units of gallons per minute and water levels in decimal feet. These data should be presented in graphical form in the hydrogeologic report, and supplied in digital form.

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[1] If the applicant has already installed observation wells NJGS recommends monitoring water levels in them during the step test. Such data can be invaluable for confirming the step test analysis and provide confirming and/or backup data for the 72-hour aquifer test.

VI.A.4. Calculate the efficiency of the well

There are several techniques available to calculate well efficiency from the results of a step test. The applicant must justify the technique selected and provide calculations and graphics illustrating the application of the technique. The well efficiency at the proposed pumping rate should be at least 70%.

VI.A.5. Determine stable yield

The well's stable yield is the pumping rate at which the water level in the well is at least 20 feet above the pump intake when the following factors have been accounted for:

1) drawdown in the well at the proposed pumping rate;
2) seasonal water-level fluctuations;
3) a reasonable assessment of the long-term decline in well efficiency due to routine operation.

If the well cannot support the desired pumping rate as a stable yield then the applicant may have to lower the requested rate.

This estimate of stable yield considers only drawdown in the pumping well; it does not consider any impacts on other users or the ecosystem.

Any proposed variation to the step test procedures listed above must be discussed with, and approved by, BWAWP.

VI.B. Single-pumping-well drawdown test

VI.B.1. Purpose

Single-pumping-well drawdown tests are the principal means NJDEP uses to assess hydraulic properties of aquifers and the potential impact that new groundwater diversions may have on the environment, existing users, and movement of contaminants. These tests consist of pumping a single well at a constant rate while monitoring water levels in nearby observation points. These points are typically monitoring wells installed specifically for the test, but may include shallow piezometers in wetlands and surface waters, existing wells operated by other users, and monitoring wells at nearby groundwater contamination sites. The monitoring points may be located in the aquifer being pumped or in a different aquifer. They may be tens to thousands of feet away from the pumping well. Exact locations and number of observation points depend on site-specific details of the hydrogeologic setting, environmental and/or health concerns, and other groundwater users.

As the goal of single-pumping-well tests is to determine aquifer properties and to assess potential impacts and risks, they require thorough planning. Some aspects of design are more easily determinable. For example, specifications as to the number, placement, and construction of observation wells focus on hydrogeology and fundamental assumptions of groundwater flow. Observation well construction differs for sand aquifers from that for rock aquifers. Section VII. describes in more detail specifications for observation wells, test duration, pumping rate, and other general aspects of test design.

Addressing site-specific factors is a vital component of aquifer-test design. For example, a nearby groundwater contamination site may have observation wells that need to be monitored during the test. This may require negotiation to gain site access, as well as special handling of probes inserted into the contaminated water. Water discharged during the test may require treatment. Or, a nearby production well may create water-level fluctuations. The applicant may have to monitor pumping rates and times at this off-site well in order to account for its influence on groundwater levels observed during the test.

Ideally, these site-specific issues should be identified and discussed at the pre-application meeting so that a test plan can be developed that will result in the collection of useful and pertinent data.

VI.B.2. Duration

The test well is usually pumped for 72 hours. Longer pumping times may be required (Section VII.C). The goal is to create a drawdown cone that supports an accurate estimate of the well's zone of influence. Additionally, the test should last long enough so that the impacts of any aquifer boundaries become apparent. NJDEP may require a longer test to determine impacts of the proposed diversion on points of concern that are not close to the well. This is especially true if the impacts cannot be reliably predicted using aquifer test models either due to limitations of the methods or uncertainty concerning the hydrogeology of the site.

VIB.3. Aquifer properties

Traditional analysis of an aquifer test uses time-drawdown data to predict aquifer properties and conditions. Based on the hydrogeology and hydraulic responses observed in the time-drawdown data, the investigator selects an analytic model from which to estimate aquifer properties. The analytic modeling techniques typically include straight-line fitting of time-drawdown data plotted on semi-logarithmic graph, curve-matching of various aquifer models to time-drawdown data plotted on log-log graph paper, and specially-designed computer programs that best-fit the user-specified aquifer model to the time-drawdown data.

All these analytic models contain certain basic assumptions and definitions concerning the physics of groundwater flow. Many of this report's requirements pertaining to observation well open-interval, number of observation wells, or constant pumping rate have been specified so that the aquifer test conforms with the assumptions and definitions required by the various models.

The estimate of aquifer properties that govern groundwater flow is based on analysis of drawdown data collected during the test. These properties may include transmissivity, storativity, recharge, vertical leakage, delayed yield, and anisotropy. The applicant must analyze test data using techniques designed for the specific type of aquifer and test conditions. Appendix B presents a short overview of analytical techniques and the situations appropriate for each.

VI.B.4. Hydrologic impacts

The applicant must assess hydrologic impacts based on the amount of drawdown during the test and the anticipated amount projected to be caused by the proposed diversion from the new well. The applicant must assess potential hydrologic impact using the aquifer properties and boundaries determined during the analysis of the aquifer test. In many cases, the analytic model used in the analysis can be used to project hydrologic impacts. In some cases the analysis of hydrologic impact may need to be evaluated with respect to specific features. For example, some regulatory authorities have adopted standards and thresholds concerning the amount of tolerable drawdown in specified environmentally-sensitive areas. Applicants should review any particular areas of concern, along with relevant standards, during the pre-application and test-proposal process and then address these concerns in the hydrogeologic report

The technical analysis must include the potential movement of groundwater using total potentiometric head. This assessment requires a surveying the elevation of each water-level monitoring point identified in the test plan according to the specifications indicated in appendix G. Hydrographs of water-level elevation and potentiometric contour maps then allow the applicant to assess the potential vertical and horizontal movement of groundwater. The applicant must use these maps to identify risks associated with the capture of contaminated groundwater and to determine the hydraulic relationships and potential changes in groundwater flux between aquifers, wetlands, and surface water bodies as a result of pumping the new well.

NJDEP understands that it is impossible to conduct a test that duplicates all conditions of concern. For example, a test conducted in an average summer may show insignificant drawdown under a nearby wetlands. During a drought when there is less recharge the same pumping rate may cause significantly more drawdown. Or, a test that lasts 3 days may or may not provide sufficient insight into what will happen after 3 months of constant pumping. However, in all cases, a good estimate of all relevant hydrogeological properties, combined with a test that duplicates actual pumping conditions, provides the best foundation on which to base predictions of the impacts of the proposed groundwater diversion.

VI.C. Multiple-pumping-well drawdown test

Well fields are clusters of wells relatively close to each other. The combined impact of the wells can be much greater than the impact of any single well. In many cases BWAWP issues limits on well field pumping volumes or aquifer-specific groups of wells, in addition to limits on individual wells.

In order to more accurately estimate environmental impacts, BWAWP sometimes requires multiple-pumping-well drawdown tests. These involve pumping several wells at once. These tests are designed to simulate the cumulative impacts that may be caused by diversions from the well field. A multiple-pumping-well test may be required instead of a single-pumping-well test, or in addition to one. If a single-pumping-well test is conducted first, it may indicate areas that may be threatened by well field operation. These sensitive areas should then be carefully monitored during the multiple-pumping-well test.

A multiple-pumping-well test consists of pumping two or more wells at a controlled rate for a specified amount of time. It is usually better to stage or phase-in the start of pumping at each well because the resulting jumps in drawdown allow a more-effective analysis. The total pumping rate should be equal to, or greater than, the rate proposed for the well field as a whole during normal operation. The test must be long enough to produce a drawdown cone that allows a valid estimation of the well field's impact under planned operation. The results of a multiple-pumping-well test may yield information on aquifer properties if it is carefully planned and executed.

Monitoring locations depend on site-specific conditions. A wide array of observation wells are needed to observe total extent of the drawdown cone. Nearby wetlands and ponds may require shallow piezometer nests to measure changes in vertical leakage. Nearby streams will require shallow piezometer nests and streamflow monitoring. If vertical leakage into the aquifer from overlying or underlying aquifers is of concern, then observation wells in these additional aquifers are needed.

In short, multiple-pumping-well test design is site-specific and dependent on the aquifer's hydrogeologic setting, nearby users, and areas of environmental concern. It is necessary that these factors be thoroughly discussed with BWAWP at the pre-application meeting and the aquifer-test proposal should adequately address all issues and concerns.

VII. Single-Pumping-Well and Multiple- Pumping-Well Test-Design Factors

There are a wide range of factors that influence single-pumping and multiple-pumping well test design. These include, but are not limited to, interference caused by other pumping wells, monitoring point locations, areas of environmental concern, measurement protocols, and test duration. "Cookie-cutter" requirements and procedures may not address all hydrogeologic situations. Each aquifer-test proposal must be tailored to fit the known and assumed hydrogeologic conditions at the pumping well's location. Accounting for these factors is critical in designing a test that will yield sufficiently thorough and accurate data.

NJDEP may reject the aquifer test if the applicant fails to collect sufficient data due to monitoring-system malfunction, incapacity to measure the full range of water-level fluctuation, or improper monitoring-system installation. If the data are not sufficiently thorough and accurate then the test will have to be redone. Thus aquifer test design is a critical component in conducting a successful aquifer test.

The following sections provide guidance on aquifer test design based on the experiences of BWAWP and BWRG over the last 25 years of reviewing, and sometimes rejecting, hydrogeologic reports.

VII.A. Nearby pumpage

Analysis of drawdown can yield estimates of aquifer properties. If there are other wells active during the test then the observed drawdown may include impacts of these additional wells. This is called well interference. Analyzing the cumulative drawdown, without accounting for well interference, may yield inaccurate estimates of aquifer properties.

It is thus necessary that the applicant identify all nearby pumping wells. The test proposal must detail the potential for well interference and list the steps that will be taken to account for and eliminate or minimize any impacts.

Preferably, all nearby wells will not pump during the aquifer test. They will shut down before the background period and not resume until after the recovery period. Under certain conditions (such as public supply needs and groundwater remediation activities) this may be impractical. When well interference cannot be eliminated, the applicant is responsible for monitoring of withdrawal rates and operation times, and then accounting for it when estimating aquifer properties.

In short, the applicant is responsible for identifying all external influences that may impact the aquifer test and to adequately address these potential impacts. Failing to do so may result in an unacceptable test and an inadequate analysis.

VII.B. Observation wells

Correct placement of observation wells is perhaps the most critical factor of a successful single-pumping-well or multiple-pumping-well tests. This includes a sufficient number of wells, located not only at appropriate distances from the pumping well, but also completed at appropriate depths. The number of wells, and the distance and depth of each, is a function of the type of test being conducted, the potential impact areas, and the hydrogeology. The more complex the aquifer and potential impacts, the greater the number of observation wells needed.

It is necessary to thoroughly examine observation well placement at the pre-application meeting, and then continue to re-examine the placement as additional information is revealed during the initial field investigation. Improper observation-well placement has a great potential to invalidate the results of an aquifer test.

Specifying the number and placement of observation wells requires a preliminary understanding of site hydrogeology and anticipated impacts. Developing this understanding may require one or more test wells, geologic mapping, and literature searches.

As a general rule, observation wells should not be too close to the pumping well if they are monitoring drawdown in the unit being pumped. The rule of thumb is that they should be at least at least 150% of the aquifer's saturated thickness away from the pumping well. For very thin or thick aquifers this may be modified.

There is no easy way to place an upper limit on the maximum distance an observation well can be. If a hydrogeologic boundary is thought to be a barrier to the propagation of the drawdown cone, then a well just on the other side of that barrier may be sufficient to prove this. But if drawdown observed during the test proves the boundary is not a barrier then the test may have to be redone with additional wells further away.

In cases where vertical leakage (water entering the aquifer from overlying or underlying units) is important, observation well clusters are required at appropriate depths and distances to provide information on how the proposed diversion may impact other units.

In sedimentary bedrock aquifers the extent of water-bearing units often corresponds with that of bedding, hence the placement of observation wells should take into account bedding attitude and bedrock structure. Wells that tap the same bed as the production well may experience more drawdown than wells located in beds not directly connected to the pumping well. Vertical fractures may allow drawdown to propagate between beds. This may create drawdowns at depths and distances that are not immediately intuitive.

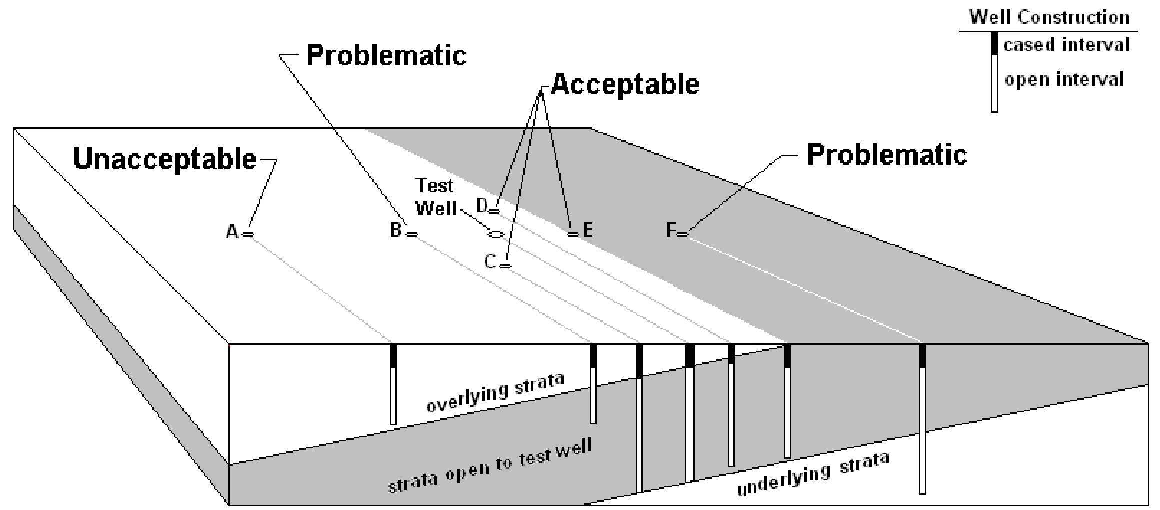


Figure 6. Observation wells in a sedimentary bedrock aquifer.

Figure 6 shows the general principals of observation well placement in a bedrock aquifer typical for the Newark Supergroup formations. The penetrated interval concept illustrated here should be followed in all rock aquifer where bedding and structure can be defined. Drawdown from the test well (fig. 6) propagates through a dipping water-bearing formation and impact distant wells at different depths. Observation wells C, D and E are open only in the unit being pumped by the test well and are at acceptable locations. Wells B and F are open both in the unit being pumped but also in either the overlying or underlying unit. Water levels in wells B and F will be an average of the levels in the two units each well is open to. This averaging seriously violates the assumptions of the analytic models used that estimate aquifer properties based on observed drawdowns. Thus situations posed by example wells B and F should be avoided. Well A is open only to the unit overlying the water-bearing unit being pumped. It will provide no information on water levels in the pumped unit and will not readily provide data useful in evaluating horizontal anisotropy within the pumped aquifer. Well A could provide information on vertical fluxes and vertical anisotropy, but this information may or may not be needed for a given site. These cases show that knowing the subsurface structure is critical to correct placement of observation wells and that design must fit the purpose for which the observation well is constructed.

VII.C. Test periods

Single-pumping-well and multiple-pumping-well aquifer tests consist of three periods, background (before pumping starts), pumping, and recovery (after pumping stops). The aquifer-test proposal must clearly specify the duration of each period.

VII.C.1. Background period

Measurements during the background period provide baseline conditions. The impact of the pumping is the change from this baseline. At some sites, water levels may fluctuate due to natural phenomenon (for example, heavy rains, long-term recovery after a drought, or tidally-induced fluctuation in a water-table aquifer near the ocean). Human-caused fluctuations (for example, drawdown due to day-time pumping by public supply wells with night-time recovery) may also complicate the data record.

In some cases specific monitoring locations or ambient conditions may require a longer period of background monitoring. This may include, but is not limited to, streamflow, water-table elevation, and precipitation. BWAWP will address these issues on a case-by-case basis. The background period must be long enough to allow accurate definition of any fluctuations and provide the ability to correlate them with a source. If these fluctuations are properly identified and accounted for then, in most cases, their effect can be removed from the data record. A sufficiently-long background period is key to this process.

All monitoring points that are measured during the drawdown period must also be measured during the background period. Experience has shown that more frequent measurements are more useful than less frequent ones. Also, synchronizing all monitoring devices to the same start time and frequency schedule simplifies later data analysis.

The background period should be followed immediately by the pumping period.

VII.C.2. Pumping period

During the pumping period water is withdrawn from one or more wells at a controlled rate. The beginning of the pumping period marks the end of the background period. The goal is to create a drawdown cone that can be analyzed for aquifer properties and provide data on potential impacts on the environment and other groundwater users.

A 72-hour pumping period is sufficient in many cases. Shorter periods may be suitable for confined aquifers with minor leakage from other aquifers. Longer periods may be required in some hydrogeologic settings. For example, pumping periods longer than 72 hours may be needed in thick, unconsolidated Coastal Plain aquifers with patchy semi-confining units to determine if the aquifer is semi-confined (leaky) or unconfined (with delayed yield). Longer durations may also be needed in unconfined and fractured rock settings to assess specific issues.

Single-pumping-well tests sometimes, but not always, consist of a 72-hour background period, a 72-hour pumping period, and a 72-hour recovery period. Longer periods may be needed to adequately assess the natural hydrogeologic conditions or if the potential environmental impacts are slow to develop. In some cases BWAWP has required 30-day pumping periods and background and recovery periods of a week or more.

During the pumping period it is vital to tightly control the rate of pumpage. Additionally, the pumped water must also be discharged where it will not be captured by the well's drawdown cone and thus incorrectly appear to be an additional recharge source. This 'short circuit' situation will invalidate the test results.

The pumping period should be followed immediately by the recovery period.

VII.C.3. Recovery period

When the pumping well(s) is shut down, water levels begin to rise. The rate at which water levels recover can provide significant information on aquifer properties.

The recovery period usually lasts a minimum of 24 hours. The total length of the recovery periods may be some set time duration (such as the same length of the drawdown period) or keyed to a certain amount of water-level rise (such as 90% recovery in all observation wells). The exact condition that governs the length of the recovery period is to be set either at the pre-application meeting or during the aquifer-test proposal approval process.

Well interference from nearby withdrawals will complicate estimates of water-level recovery. For this reason pumping in the immediate vicinity of the test should be kept constant so as to control well interference. Water-level recovery is based on removing any well interference from the data record.

In some cases observations made during the background and pumping periods may identify previously-unknown fluctuations. In these cases extending the recovery period and increasing the measurement sampling rate may help identify the source of fluctuations.

VII.D. Pumping rate

An aquifer test's pumping rate should simulate, as much as possible, the planned operation of the well. If, however, a higher instantaneous rate is necessary in order to pump the requested maximum monthly allocation, this higher pumpage rate may be required by BWAWP.

Information from any preliminary short-term well tests, such as step tests, is usually useful in indicating what pumping rate a well can maintain. A step test is required to determine well efficiency, adequacy of well development and the well’s stable yield. (These tests are discussed above.) The analysis and results of the step test should clearly show that the pumping well can maintain the proposed pumpage for the duration of the aquifer test. Pumping at rates higher than the aquifer can support will not be approved by BWAWP.

Analysis of these preliminary tests, along with other hydrogeologic, regulatory and institutional considerations, leads to an estimated maximum pumping rate. This is usually the rate BWAWP will require be used during the aquifer test.

A side consideration is that for all public community supply wells an additional test is required at a test pumping rate "20% above the designed pumping rate for 24 hours, or 100% of the requested rate for 72 hours in some cases" (N.J.A.C.7:10). In some cases, designing an aquifer test accordingly may eliminate the need for a second aquifer test for new public community supply wells.

VII.E. Maintaining and measuring the pumping rate

Maintaining a constant pumping rate is an important factor in a successful aquifer test. Almost all analysis techniques assume a constant pumping rate. A varying rate will result in less accurate estimates of aquifer properties. For this purpose, the rate must not vary by more than 10% over the course of the test. Greater fluctuations in the pumpage rate will hinder an accurate analysis of the water-level data and may be a basis for rejecting the aquifer test outright.

Several measuring procedures are available for determining the volume of water pumped from the well. Procedures include, but are not limited to, flow meters (propeller meter), totaling flow meters, weirs, orifice weirs and flumes (fig. 7).

Figure 7. Arrangement of orifice weir and vertical piezometer tube for measuring discharge of pumping well. (Photo by S. W. Johnson.)

At a minimum, the applicant must accurately measure the discharge rate every 10 minutes during the first hour of the test and every 60 minutes thereafter. NJDEP recommends using an ADR to continually monitor and record pumping rates while using a second method as a backup. This will also allow comparison between methods.

A decrease in discharge from the pump will normally occur with increasing drawdown as the pump works against a greater hydraulic head and increasing friction in the system. These losses must be compensated for in order to maintain a constant discharge. Experience has shown that adjustments in pumping rate are more accurately accomplished by regulating a gate valve in the discharge pipe rather than changing the speed of the pump.

If, for some reason, the pump must be turned off during the test, it must be restarted within 10 minutes. No more than one 10-minute break should be allowed for every six hours of pumping. No halting of the pump is allowed during the first hour of the test. If the pump is halted during this period for any reason the test must be restarted after allowing water levels in the pumped and observation wells to return to within 95 percent of levels at the end of the background period. The applicant must report all shutdown incidences during the pumping test with accurate recording of the time of pumping cessation and resumption.

VII.F. Discharge of pumped water

Water pumped from a well must be discharged where it cannot infiltrate into the ground and flow back to the pumping well or influence water levels in an observation well during the duration of the test. If the pumped water were to be 'recycled' this would create the appearance of recharge to the aquifer where none actually exists. In some cases (for instance, a deep aquifer with an overlying confining unit) this may not be a concern. In other cases (a carbonate rock aquifer with minimal overburden and sinkholes; a shallow, unconfined sand aquifer) this could be a significant issue.

For tests of an unconfined aquifer, the discharge water may have to be piped to a storm drain or discharged to a surface-water body a significant distance downstream of the test site. It is especially important that the discharge water not be added to a surface-water body upstream of a surface-water monitoring point.

Discharging water too close to the pumping well may significantly alter the natural hydrogeologic conditions. This may create the need for another, better designed, aquifer test.

VII.G. Water-level monitoring specifications

VII.G.1. Justification

Water levels measured during aquifer tests are the primary data used to assess aquifer properties, evaluate potential impacts, identify hydrologic phenomenon, and monitor for interference from extraneous sources. For these reasons, NJDEP requires accurate and comprehensive water-level measurements during an aquifer test.

VII.G.2. Requirements

The following general requirements apply to all water-level measurement locations that are specified in the NJDEP-approved aquifer test plan, or are specified as a conditions of a water allocation permit:

1) An automatic data recorder (ADR) is required for most monitoring points.
2) The sampling schedule must follow the schedule in the approved aquifer-test proposal.

3) Manual measurements are required to verify the ADR readings and to calibrate in case of instrument drift during the test. They also provide a way to correlate the ADR values with the vertical datum.
4) The applicant must supply accurate elevations of all monitoring locations. Elevation standards are provided in appendix G.

VII.G.3. Synchronization

All ADRs must have a synchronized time. Without this it is impossible to correlate the pumping with observed drawdowns at distant points. This also requires accurate times for the beginning of the pumping and recovery phases of an aquifer test. All manual measurements taken must also have an accurate timestamp.

VII.G.4. Frequency

NJDEP recommends using ADRs with a constant sampling frequency and to not change the sampling frequency during the test. To minimize human error the constant sampling frequency should be set at the beginning of the background period. If this proves impractical the frequency should be constant during the pumping and recovery periods of the test. BWAWP recommends data collection every 30 seconds at observation wells completed in the pumped aquifer as modern digital ADRs can easily handle this volume of data. Any data that does not contribute significantly to the results (such as long durations where the water levels do not change) can be parsed out before final analysis. It is better to collect too much data during the test than too little. Table 4 presents recommendations on water-level measurement frequencies for various site types monitored during aquifer tests.

ADRs have become increasingly reliable, affordable and capacious. NJDEP recommends monitoring all water levels with ADRs and an appropriate probe. Manual water-level measurements should be collected throughout the test for QA/QC and calibration. This is discussed below in the section on probes.

The aquifer-test proposal must specify the sampling frequency at all monitoring points. This must be approved by the NJDEP before the aquifer test begins.

VII.G.5. Units of measurements

The applicant may collect water-level data in the field in any relevant or appropriate unit. The original data should be included in the submitted digital data. However the applicant must report all water levels as an elevation in decimal feet above mean sea level (msl). The digital submission must include documentation that shows how the original measurements were transformed into water-level elevations.

Table 4. Monitoring frequencies during the aquifer test.

Site Type	Purpose of Monitoring	Frequency[1]	Applicability
Observation wells completed in test aquifer	Time-drawdown data for aquifer characterization	≤ 10 min for background period[2], 30 seconds for pumping and recovery periods	All single-pumping-well and multiple-pumping-well tests.
Observation wells completed in overlying or underlying aquifer	Water-level data to indicated degree of hydraulic connection with other aquifers	≤ 10 minutes	All single-pumping-well and multiple-pumping-well tests.
Pumping well	Measure rate of diversion	≤ 10 minutes for first hour of pumping period, ≤ 60 minutes thereafter.	All single-pumping-well and multiple-pumping-well tests.
Existing wells potentially affected by new diversion	Measure impact on existing users	≤ 10 minutes	All single-pumping-well and multiple-pumping-well tests.
Nearby pumping wells impacting the aquifer being tested	On and off times of interference pumping	Accurate monitoring of pumping times, with rates.	Nearby high-capacity wells.
Streambed piezometers	Measure potential depletion of stream discharge	≤ 10 minutes	Where hydrogeology indicates stream may be directly impacted by the aquifer test
Wetlands piezometers	Determine water-table decline in wetland habitats.	≤ 10 minutes	Where hydrogeology indicates that wetlands water-table may decline during aquifer test
Stream discharge	Measure potential depletion of stream discharge	≤ 10 minutes	Where hydrogeology indicates stream may be directly impacted by the aquifer test
Surface-water monitoring	Measure effect of groundwater drawdowns on surface water	≤ 10 minutes	Where hydrogeology indicates surface water may be directly impacted by the aquifer test
Precipitation	Impact of recharge on water levels	≤ 24 hours	Typically unconfined and semi-confined aquifers.
Barometric pressure	Impact of pressure changes on water levels	≤ 60 minutes	Typically semi-confined and confined aquifers.
Tide monitoring	Remove tidal loading from aquifer test data	≤ 10 minutes	Confined aquifers in coastal areas and beneath barrier islands.
Water temperature	Identify sources of recharge to the well	≤ 10 minutes for first hour of pumping period, ≤ 60 minutes thereafter	In pumping well and nearby potential sources of recharge.

[1] The sampling frequencies recommended in this table may be modified depending on site-specific conditions. Applicants may proceed with a less-frequent sampling frequency only with NJDEP approval.

[2] Adequate planning, preparation and time must be allowed for change of ADR programming from background to test monitoring frequency in order to reduce the inevitable time gap between the end of one monitoring frequency to another. If this is not the case, all periods of the test should be monitored at 30-second intervals. All monitoring times must remain synchronized.

VII.H. Static Water Levels

If the aquifer test is in support of a major modification of an existing groundwater diversion permit then the applicant may already have water-level data at existing production wells. Generally, under a water allocation permit a permittee is required to report static water levels in the production wells. The static water level is the elevation of water in the well after it has been rested for at least 12 hours.

If available, the applicant must include these static groundwater levels, and an analysis of them, in the aquifer-test proposal and hydrogeologic report. The analysis must evaluate seasonal and long-term changes to groundwater levels and what these changes indicate with respect to the sustainability of the diversion.

The following data must be part of the static-water-level analysis:

a. Surveyed elevations, in feet, of the measuring point (MP) relative to NAVD 1988. Standards for measuring elevation are provided in appendix G.
b. The method used to collect the static-water levels. This may be air line, transducer and data logger, weighted chalk and tape, calibrated electrical, drop-line tape, or other appropriate method.
c. All static-water levels must be accurate to the nearest hundredth of a foot.
d. The initial static-water level when the well was drilled, if available.
e. The date and time of each observation.
f. A hydrograph showing the elevation of all static water levels.
g. Determine if static water levels are consistently changing and what effect any change may have on public community water supply wells, public non-community water supply wells, nearby domestic and agricultural wells, contamination sites, surface water, areas of environmental concern, and salt-water fronts within the well's zone of influence (ZOI). If the ZOI is unknown assume a 1-mile radius in a confined aquifer and a 0.5 mile radius in an unconfined aquifer.
h. Static water-level data must also be submitted electronically (disk) in two-column format ASCII files, water-level collection date (month, day, year) and static-water level in feet at well.

VII.I. Wetlands Monitoring

If wetlands monitoring is required then the following sections apply.

Diversion of groundwater from an aquifer may damage the wetland ecosystem and affect species dependent upon this ecosystem. Hydrologic impacts to wetlands consist of transient or permanent lowering of the water table in aquifers connected to wetlands, loss of stream flow where wetlands are fed by surface water, reduction in free-standing water surface levels or loss of groundwater seepage at seepage-fed wetlands.

The applicant must identify potentially impacted wetlands through on-site documentation, through a Letter of Interpretation obtained from the Department's Land Use Regulation Program, or through mapping from the Department's Landscape project, available through the Department's I-Map project at the Department's web site:

http://www.nj.gov/dep/gis/newmapping.htm

VII.I.1. Assessing Hydrologic Impact

The applicant must, by direct hydrologic testing, determine if the proposed diversion has the potential to affect a wetland. During the hydrogeologic testing the applicant must measure the amount of drawdown that occurs beneath the wetlands as well as changes in surface-water levels within the wetlands. The hydrogeologic report must include the results of the wetlands monitoring and a projection of the amount of drawdown that would occur beneath the wetlands as a result of the proposed diversion. This analysis must address:

1) The hydrogeologic framework and its influence on the potential hydrologic connection between the aquifer and wetlands.
2) The relationship among groundwater levels in the aquifer, surface-water diversions and wetlands.
3) The results of any monitoring conducted during the testing of groundwater levels at wetlands.

It is imperative that the aquifer test result in sufficiently thorough and accurate data that provide answers to these questions.

VII.I.2. Monitoring Plan

If the proposed diversion may affect a nearby wetlands, the submitted aquifer-test proposal must include a section for a proposed wetlands monitoring plan. The plan must address the hydrogeologic setting in which the wetlands occurs, the sub-surface geology of the aquifer and its relationship to the wetlands, and the relationship between groundwater levels and the wetlands. The final hydrogeologic report must include all data collected for wetlands monitoring, as well as a discussion of the monitoring plan if its implementation was modified from that which was submitted in the aquifer-test proposal.

The length of the test must be sufficient to allow hydrologic effects to be detected, should they occur. BWAWP usually requires a pumping period of 72 hours. Background and recovery periods of seven days are usual in order to determine water-level trends controlled by atmospheric pressure and precipitation. Tests should not be performed immediately after a period of notable precipitation or a notable dry period.

The following are key components to an approvable wetlands monitoring plan proposal:

1) Any action which may affect the status of a wetlands or its buffer zone must be reviewed by the Bureau of Freshwater Wetlands Permits.
2) Measurements during the background, pumping and recovery periods must be taken in accordance with the approved aquifer-test proposal. All measurements must have an accuracy of 0.01 foot. Results must be reported (electronically) in units of decimal feet.
3) Continuous, digital, water-level measurements must be collected in all observation wells. Readings are to be taken in accordance with the approved aquifer-test proposal. Water-levels readings should be taken by "hand measurements" (electronic tape or equivalent) at least daily. The precise time of these hand measurements should be recorded, along with the coincident reading on the water-level recorder.
4) A precipitation gage must be installed at the test site to measure precipitation in accordance with the approved aquifer-test proposal.
5) Surveyed elevations of all monitoring points.

VII.I.3. Observation Wells

The applicant must install a sufficient number of groundwater piezometers to detect drawdown and the effects of precipitation. This requires a piezometer nest (minimum of two piezometers co-located but with screens at different depths) in or immediately adjacent to each wetland of interest. This will provide an evaluation of vertical fluxes and how this changes over the test. A third observation well or piezometer must be installed at a remote location, outside the projected zone of influence of the pumping well, to monitor ambient fluctuations in the water table. Observation wells must have an open interval of a minimum of one foot in length, be completed in a permeable stratum, and must be developed using air, a surge block, or pump to ensure responsiveness to water-level fluctuations. The applicant must conduct a falling- or rising-head permeability test on each observation well to determine if it functions efficiently.

VII.J. Stream monitoring

If BWAWP requires stream monitoring then the following sections apply.

Stream discharge measurements can be an important part of a water allocation permit application and hydrogeologic report. The discharge data may determine the presence and magnitude of streamflow depletion as a result of a groundwater diversion. Streamflow depletion may result in lowered inflows to downstream reservoirs and intakes, less baseflow in the stream, lowered water levels in wetlands, earlier on-set of downstream passing flow restrictions, and adverse impacts on aquatic ecology and water quality. The data may also help estimate the amount of water available for capturing or skimming, to estimate runoff or a curve number for a drainage basin, or to quantify an appropriate passing flow. Measuring stream discharge is not a simple task and collection of the data should be limited to cases where it can be successfully and accurately collected and where it will provide meaningful results.

Determining if a groundwater diversion will result in streamflow depletion is perhaps the most complicated use of stream discharge measurement since it involves both an understanding of the local hydrogeology and the ability to accurately measure stream discharge. The timing, magnitude, and duration of the depletion, if any, is a function of many factors. These include, but are not limited to, the hydrologic connection between the aquifer being pumped and the stream, the hydrogeologic properties of the aquifer(s), streambed conductance, distances between the diversion and the stream, volume diverted, and antecedent conditions.

The preferred way to determine if streamflow depletion is occurring is to measure stream discharge directly. Unfortunately, observing and/or quantifying streamflow depletion can be difficult, particularly during a 72-hour aquifer test. Complications include, but are not limited to:

1) Full impact of the pumping may take longer than a short-term aquifer test to develop. In such cases a long aquifer test (30 days or more) may be required.
2) The volume of depletion may be small compared to the discharge in the stream.
3) The volume of depletion may be small compared to typical discharge measurement error.
4) The impact of the diversion may be spread among different streams.
5) Antecedent trends may mask the impact.

Significant streamflow depletion is likely to be observed during a 72-hour aquifer test only where the well is close to the stream, the magnitude of the diversion is a large percentage of total stream flow, the antecedent period has been dry, and the aquifer is hydraulically directly connected to the stream. In many instances changes in water levels in piezometers installed in the stream bed, or in groundwater gradients may provide evidence of the depletion. Site-specific hydrogeologic conditions must guide the approach taken to address the issue.

BWAWP will determine on a case-by-case basis if measurement of stream discharge, stream stage, or streambed piezometers are needed. This may occur either at the pre-application meeting or during the aquifer-test proposal approval process.

Even if streamflow depletion is not observed during the 72-hour aquifer test, it might occur during the normal use of the requested diversion. This potential impact must be addressed as part of the hydrogeologic report.

VII.J.1. Data Collection Criteria

The following conditions apply to aquifer tests where NJDEP determines that the proposed diversion has the potential to adversely diminish the discharge of nearby streams and is measurable.

1) The applicant must install ADRs and probes to continuously measure the hydraulic head beneath the streambed bottom (in a piezometer) and above it (stream stage measurements in a stilling well).
2) If the proposed diversion is greater than 30% of the estimated lowest monthly mean flow in the nearby stream the applicant must install equipment to continuously measure streamflow.
3) If there are established USGS streamflow gages immediately downstream BWAWP may allow these may be used instead of installing streamflow equipment. This is evaluated on a case-by-base basis.
4) The applicant must monitor surface water level (stage and/or piezometers) and surface water discharge (if required) for a minimum of two weeks prior to the start of an aquifer test. For three days prior to the beginning of the aquifer test and for the first three days of the pumping period there must be no measurable increase in stage and discharge due to precipitation. It is the applicant's responsibility to schedule the background and pumping periods, as far as possible, so as to conform to these fair weather requirements. For pumping periods longer than 3 days, NJDEP may waive the no measurable change in stream stage and discharge requirement providing that fair-weather conditions have been met for the background and early pumping periods.

VII.J.2. Data Measurement Devices

VII.J.2.a. Piezometers

Hydraulic head measurements below the bottom of streams must be made using piezometers. The piezometer must be installed a minimum of five (5) feet below the bottom of the stream. The applicant must exercise good judgment to ensure that the piezometer well screen is placed into hydraulically conductive earth materials within the practical limitations of the site geology and bottom conditions. The piezometers must be developed using airlift, surge block, or pumping to ensure hydraulic responsiveness. A slug-injection or removal test must be performed to assess responsiveness of the piezometers. The piezometers must be sited at a location where anticipated drawdown from the aquifer test is likely to be greatest. For sand and gravel aquifers this location is generally at a point in the stream closest to the test well. For rock aquifers this location will likely be where preferential flow zones intersect the stream bottom. The applicant must provide the location and elevation of the piezometers and elevation of vertical reference points according to the surveying requirements specified in Appendix G.

VII.J.2.b. Discharge Measurements

For groundwater diversions, the stream-discharge measurement site must be located far enough downstream to measure the full impact (i.e. downgradient of the zone of influence). The applicant must use established techniques and procedures for measurement of open-channel flow such as weirs, flumes, or calibrated stage-discharge relationship (Rantz and others, 1982). The downstream discharge measurement location should also be chosen at a location suitable for the stream discharge measurement technique. Typically, this includes linear flow and a stable channel and stream bottom, but the specific method will guide location selection.

If there is an established USGS streamflow gage immediately downstream BWAWP may allow to be used for discharge measurements. This gage must be close enough to the pumping well so that the estimated impact on streamflow is not masked by additional water entering the stream.

If the discharge measurement techniques require water-level readings or stage measurements the applicant must install a stilling well and ADR to monitor discharge on a continuous basis. An elevation measuring point must be established on the stilling well, and if artificial controls such as weirs or flumes are used, the parts of those devices referenced for flow calculation. The location of the discharge measurement site and elevation of vertical reference points must conform to the Surveying Requirements specified in Appendix G.

VII.J.2.c. Stage Measurements

The applicant must monitor water levels in streams using a stilling well. A reference point elevation must be established on all stilling wells and their location must be established according the Surveying Requirements in Appendix G. Where the applicant is required to install a piezometer into a stream bottom, the stilling well must be next to the piezometer.

VII.J.3. Surface-Water Monitoring Data Analysis

The applicant must analyze the data collected during the hydrologic testing period and determine the amount of drawdown that has occurred beneath the bottom of the streams, changes in stage in stream, and changes in streamflow. The analysis should account for ambient trends such as recession in water levels and discharge, precipitation and its impact on water levels and discharge, and impacts from upstream diversions, pumping, and discharges. The applicant must address whether the proposed diversion will diminish stream baseflow either by diversion of surface water or reduction of groundwater seepage.

VII.K. Lakes and Ponds

If BWAWP requires the applicant to monitor lakes and ponds then the following sections apply.

Surface-water bodies include lakes, ponds, reservoirs, and may also include tidal bodies. Groundwater diversions may cause surface water to leak to the underlying aquifer, or may intercept groundwater that would otherwise discharge to the water body. BWAWP will base the decision to monitor surface water for drawdown on the likelihood that the proposed diversion will lower the surface-water level. Factors considered in this determination include the volume and proximity of surface water relative to the proposed diversion. Depending on the site conditions, monitoring with an ADR and/or staff gage may be needed. Aquifer tests should be conducted while the surface water is free of ice to allow for an accurate measurement of water level.

VII.K.1. Monitoring with an ADR

An ADR provides a detailed record of fluctuations in surface-water level during an aquifer test. Accurate measurements are important because even small changes in the water level over a large surface area can equate to a large volume of water being diverted to the pumping well.

Monitoring with an ADR is appropriate:

1) When a preliminary analysis indicates drawdown in the surface-water body may occur.
2) To determine whether a surface-water body outside the expected area of influence of the pumping well has responded to the pumping.
3) To monitor whether the water body is receiving discharged water from the pumping well.

For ease of monitoring, the ADR can be installed into the water from a dock or other structure accessible from land. However, the site should be chosen to accommodate the total anticipated drawdown without being moved during the test.

The following provisions apply if an ADR is required for surface-water monitoring:

1. The frequency of data collection in a surface-water body must be chosen in consideration of the hydrogeologic conditions of the test site. For most aquifer tests, a sampling frequency of every 10 minutes is adequate. In all cases, the frequency of data collection in surface-water bodies must follow the schedule in the approved aquifer-test proposal.
2. Where waves may interfere with water level measurements the water levels must be measured using a stilling well. A reference point elevation must be established on all stilling wells and their location must be established according to the surveying re-

quirements in appendix G. Stilling wells for monitoring tide should be located as close as possible to the aquifer test site.

3. A staff gage must be installed to provide a backup system for the ADR. The gage should be calibrated to .02 ft. intervals and readings made to the nearest .02 ft. Manual readings of the staff gage must be made daily during the background portion of the test, and twice each day at approximately 12-hour intervals for the pumping and recovery phases of the test.
4. Visual documentation of the surface-water level should be obtained at a minimum, 1) prior to the start of the test, 2) at the end of the pumping phase, and 3) at the end of the recovery phases. The photographs should be taken from the same vantage point and clearly show the surface-water body in relation to its bank, contain a digital date, and, if possible, include the staff gage.
5. Aquifer tests should be conducted while the surface water is free of ice so that an accurate measurement of the water level can be made.
6. Monitoring surface-water levels for a longer-duration test may require a more durable setup for installation of an ADR, such as a stilling well. If a longer-term test is to be performed, monitoring details should be discussed with the NJDEP during the pre-application process.

VII.K.2. Monitoring with a staff gage (ponds and lakes only)

On ponds and lakes, a staff gage may be sufficient to monitor potential changes in surface-water level. Staff gages are practicable where more than one pond is present or for obtaining "control" data at a surface-water body outside the area where drawdown is expected to occur. Where staff gages are used independent of an ADR, monitoring frequency should be, at a minimum, daily during the background phase of the test, and twice each day at approximately 12-hour intervals for the pumping and recovery phases of the test. A summary of monitoring frequency is shown in table 4.

VII.K.3. Collecting surface-water temperature data

BWAWP may require water-temperature monitoring of the surface-water body to assess groundwater/surface-water interaction. Refer to section VII.O. for water-temperature monitoring requirements.

VII.K.4. Precipitation and climate data

To interpret surface-water-level trends the applicant may need to obtain precipitation, air temperature, and possibly other climatological data. This data may be collected at the test site or obtained from a nearby regional weather station. Refer to section VII.M. for detailed information on the requirements for obtaining climate data.

VII.L. Barometric-pressure effects

Changes in barometric pressure affect water levels in observation wells screened in confined aquifers (Furbish, 1991). Barometrically-driven water-level changes are generally not large enough to impair the analysis of time-drawdown data from observation wells that are properly constructed and located. However, where a distant well is monitored for a confined-aquifer test, barometrically-driven water-level changes may be mistaken for impact from the pumping test. In these cases it may be necessary to remove the barometric effect to properly estimate the drawdown. This requires an estimate of that aquifer's barometric efficiency. The barometric efficiency is based on observed water-level fluctuations due solely to changes in barometric pressure. Clark (1967) presents the procedure typically used for estimated barometric efficiency. Gonthier (2007) gives an example of this use.

Unless there is a compelling reason for the applicant to address the relatively minor water-level fluctuations associated with barometric impacts, there is seldom a need to be concerned with this issue.

A correlation of barometric and water-level data may be a useful means for determining if an aquifer is confined or unconfined. Unconfined aquifers do not exhibit responses to changes in barometric pressure. The aquifer under study must not be impacted by extraneous pumping and the duration of ambient water level/barometric monitoring should be about 2 weeks.

If a weather station is nearby barometric measurements may be available from the National Weather Service. The applicant must establish the availability of such data before the test begins.

VII.M. Precipitation Monitoring

Accurate site-specific precipitation data may be a necessary component of a successful aquifer test. Precipitation can significantly impact water-level data monitored in surface-water bodies, streams, and water-table aquifers. Water-level fluctuations due to precipitation can mask the changes in stream discharge and drawdown caused by pumping of the test well. The testing of wells in water-table aquifers should only occur when weather forecast calls for fair conditions. On-site precipitation monitoring is required to insure that minor rainfall events do not compromise the accuracy and usefulness of the aquifer test data.

The hydrologic response to a precipitation event depends upon the timing, intensity, and duration of the event as well as the site’s specific physiographic setting and antecedent conditions. Without accurate on-site precipitation data it is extremely difficult to characterize the system's hydrologic response to the precipitation and thus account for its impact on observed water levels. The collection of precipitation data can be the difference between a successful test and one that requires repeating.

VII.M.1. Data Collection Criteria

Precipitation intensities and totals can vary greatly over short distances. Thus the applicant must collect on-site precipitation data for all unconfined or semi-confined aquifer tests or when the diversion could potentially affect wetlands, streams, ponds or other surface-water bodies, which is often the case in New Jersey. Data must be collected for the same period that water-level data are collected. Hourly and daily precipitation totals, accurate to the nearest tenth of an inch, are required. This requires a tipping bucket rain gage or equivalent. Currently a tipping bucket rain gage, data collection logger, and computer software can be purchased for under $500.

BWAWP does not require precipitation monitoring for truly confined aquifers where potential impacts to wetlands, streams, ponds or other surface-water features are not a concern. In confined aquifers where the diversion is in the vicinity of the outcrop (<= 1 mile) BWAWP will decide on a case-by-case basis if precipitation monitoring is required. This will depend upon the hydraulic properties of the aquifer and confining unit, distance to the outcrop, other available environmental data, and professional judgment.

In general, any test which monitors water levels in either the unconfined aquifer or in a surface-water body will require precipitation monitoring.

VII.M.2. Rain Gage Installation

A tipping bucket rain gage should be placed in an open area without overhead or adjacent structures that could intercept precipitation. Typically, the gage should be no closer to an obstruction (man-made or natural) than four times the height of that obstruction. The gage should be as close as possible to the surface-water feature or to the pumping well if no surface-water features of interest exists. The orifice of the gage must be in a horizontal plane, open to the sky, and above the level of in-splashing and snow accumulation. Typically, tipping buckets are sited on level ground covered with short grass or gravel about 3 feet above the ground surface. Instructions for siting a precipitation gage are in American Association of State Climatologists (1985), U.S. Environmental Protection Agency (2000) and World Meteorological Organization (2008).

VII.M.3. Analysis of Precipitation Data

Precipitation data can be used in several ways related to aquifer testing and hydrologic report development. NJDEP will use it primarily to determine the potential cause of unexplained water-level rises. The precipitation data may also be used to develop estimates of site-runoff (using the curve number approach or other similar methods). The real-time data can be used along with discharge or storage data to estimate rainfall-runoff relationships. These relationships can then be used with historic precipitation data to determine the range of runoff to a storage reservoir or available for skimming and storage. The development of these relationships typically meets the Department's requirements of the use of the lowest quality water for the intended use, N.JA.C. 7:19.

Every effort should be made to schedule an aquifer test when fair weather is forecasted. NJDEP fully understands the uncertainty of weather forecasts and will make every reasonable effort to work with data that are impacted by precipitation.

VII.M.4. Data Accuracy and Submission Procedures

Precipitation data must be collected with instruments that are accurate to a tenth of an inch and capable of determining hourly and daily precipitation totals. The applicant must submit electronic data in the form of comma-delimited text files to BWAWP with the hydrologic report. The files must contain no headers and two columns. The first column must contain serial date and time and the second column must contain precipitation total in decimal inches. The hydrogeologic report must include separate files for the daily and hourly precipitation data.

VII.N. Tidal Effects

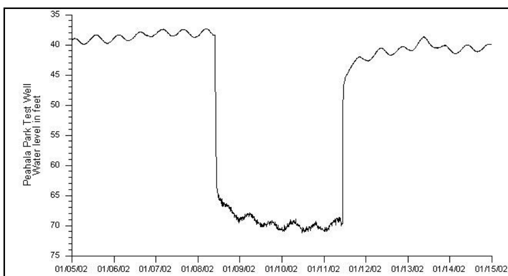
Tidal cycles can significantly affect groundwater levels. Tidal fluctuations occur in the confined Coastal Plain aquifers that extend in subsurface beneath bays, estuaries, and the ocean. For aquifer tests conducted near coastal areas and on the barrier islands (Long Beach Island, for example), tidal fluctuations can interfere with the interpretation of drawdown and recovery data. Careful background monitoring of tide and water-level in the test observations allows for the development of filtering procedures. This will then permit the analysis for aquifer properties using conventional aquifer test methods.

It is essential to have precise time and tide heights at the aquifer test site. Generally, the existing network of tide monitoring sites is too sparse. Also, the timing of tide in back bays and estuaries can be significantly different from that on the open ocean. In these areas, tide height and timing is strongly affected by wind, river discharge, and proximity of inlets to the open ocean.

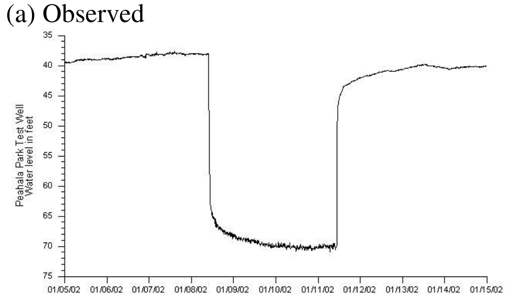
Where tidal changes cause a measurable change in groundwater levels the applicant is responsible for monitoring the tide. The monitoring point should be in tidal surface water at the closest location to the test site. When monitoring tides, NJDEP requires a stilling well to reduce unwanted water-level fluctuations due to wave-action. If the water body's floor is composed of permeable sand, then a pipe with a drive-point well screen pushed into the bottom can make a suitable stilling well. Otherwise, it may be necessary to attach the stilling well to a nearby pier or piling. In this case, a length of 2-inch PVC casing can make a suitable stilling well.

BWAWP requires synchronized ADRs to record the tide and water level in the aquifer test observation wells. The sampling frequency of the data logger monitoring the tide should be at the same frequency as for the aquifer test observation wells. A background-monitoring period of three days (6 full tidal cycles) should provide enough data to develop tidal correction factors, providing that water levels in the test aquifer are not significantly affected by other factors. Interference and/or pumping stress prior to the background period may require a longer duration of background monitoring to establish water-level trends and to eliminate uncertainty in the development of tidal correction factors.

The simplest correction for tidal fluctuation requires the calculation of tidal efficiency and time-lag factors for each of the aquifer test observation wells. The tidal efficiency is essentially a ratio that determines how much a change in water-level in the aquifer is caused by a change in tide. The time-lag is a measurement of the phase delay between the tide and the sympathetic water-level fluctuations recorded in the observation wells. Erskine (1991) provides a good example of the tidal fluctuations in an aquifer and how tidal efficiency and time-lag vary with distance from tide. Trefry and Johnston (1998) demonstrate the calculation of tidal efficiency and time-lag in relation to processing of data for standard aquifer tests analysis. Serfes (1987) presents an example from coastal New Jersey. These references also show how tidal analysis can be used to estimate hydraulic properties of the aquifer, such as hydraulic conductivity and hydraulic diffusivity (ratio of transmissivity to storativity). In general, the greater the transmissivity and the lower the storage coefficient the further inland the tidal effects reach.



(a) Observed



(b) Corrected for tidal effects.

Figure 8. Tidal correction of groundwater levels, Peahala Park, New Jersey. (a) Observed; (b) corrected for tidal effects. (Data courtesy of Pete Demicco.)

Figures 8 shows drawdown measured during an aquifer test in Peahala Park, Long Beach Township, Ocean County, New Jersey. Nearby tidal monitoring allowed an analysis that revealed an estimate tidal efficiency estimate of 0.33 with a time lag of 225 minutes between peaks in tide and peaks in groundwater levels. Using the tidal data, the raw drawdown data (fig. 8a) were corrected for tidal effects (fig. 8b). The corrected water levels are ready for further analysis.

<u>VII.O. Water-Temperature Monitoring</u>

Changes in groundwater temperature during an aquifer test can provide insight into site hydrogeology and groundwater flow paths. Contrasts between surface-water and groundwater temperature can aid in determining whether a pumping well is pulling water from a lake or stream. In fractured-rock aquifers, borehole temperature trends may provide information on the fracture connectivity of water-bearing zones (Nicholson, 2006, 2009) Groundwater temperature change occurs in the bore hole as flow to the well is derived from a different water-bearing zone, at a different temperature, when pumping occurs.

For some aquifer tests, the DEP may require temperature monitoring. In general, temperature monitoring will be required 1) in tests designed to assess potential impacts of pumping on surface water or 2) to better define the fracture network and recharge areas for a pumping well in a fractured-rock aquifer. The monitoring may require measuring temperature of both surface water and ground water. Many modern probes are designed to simultaneously monitor for water levels and temperatures and modern ADRs can easily handle the amounts of data required.

VII.O. 1 Method for surface-water impacts

When temperature monitoring is required to assess potential impacts to surface water, the following specifications apply:

1) The applicant must monitor temperature in water pumped during the test. This should be done in the well bore, not in the water discharged at the surface. The monitoring schedule should be the same as used for monitoring water levels.

2) Observation wells and piezometers provide additional sites for collecting groundwater temperature data. Measurements made at these locations provide background data on water temperature in the aquifer, or serve as additional locations to monitor the movement of water from the surface-water body to the pumping well.
3) Any surface-water body monitored with a probe and ADR for water level must also be monitored for temperature. Deeper bodies of water may show temperature stratification. Care should therefore be taken to obtain a representative sample of the overall surface-water temperature by placing the instrument at the appropriate depth and location.
4) A surface-water body manually monitored throughout the test does not need to have a probe and ADR installed for temperature monitoring. However, manual measurements of temperature are recommended at the same frequency as manual water-level measurements. As detailed above, a representative sample of the overall temperature of the surface-water body should be obtained.

VII.O.2 Method for fractured-rock aquifers

When temperature monitoring is required to assess fracture interconnections, the following specifications apply:

1) An ADR capable of both water-level and temperature monitoring must be installed in all observation wells in fractured rock. Temperature data collection should be at the same frequency as water-level data collection.
2) Because temperature changes may be subtle, as small as hundredths of a degree, all thermometers used must be capable of temperature resolution of 0.01°C with an accuracy of +/- 0.1°C. They must also be calibrated correctly according to manufacturers specifications.

VII.P. Probe specifications

A probe, also called a transducer, measures a physical property. In this context, the probe usually measures pressure. This can be converted into the depth of water above the probe. Change in pressure corresponds to change in water levels. The automatic data recorder (ADR) queries the probe at set intervals and records the measured pressure. In some cases the ADR is in a box at the surface and is connected to one or more probes by cables. In newer systems, the ADR is actually part of the probe and installed below the water surface. A cable runs from the probe/ADR assembly to the surface where it can be connected to a portable computer for data downloads.

The following discussion applies to probes regardless of where the ADR is located.

VII.P.1. Selection of ADR probes

An ADR probe monitors the pressure of the water above it. Probe sensitivity generally decreases with the amount of pressure it can withstand. The lesser resolution of higher-pressure probes may not capture subtle variations in water levels that lower-pressure probes could distinguish. For that reason, it is important to use a probe appropriate to the anticipated water-level fluctuations. A 100 psi probe should not be used if a 15 or 30 psi probe can withstand the water-level fluctuations.

VII.P.2. Vertical placement of probes

The applicant is responsible for anticipating the range of water-level fluctuation that will occur during aquifer testing and for ensuring that the probes in the water-level monitoring system will measure that full range of water-level fluctuation. At the beginning of the test each probe must be installed at a depth below the greatest drawdown anticipated during the test at that monitoring location. The probe will dangle in air if the water level drops too far. A 'hanging probe' will yield no useful data. If this probe is in a critical location it may require repeating the aquifer test.

The applicant must be careful to not overpressure the probes. This happens if the probe is inserted at too great a depth below the water surface. This may lead to the unacceptable distortion of any collected data as well as damage to the probe.

The submitted report must include the technical specifications for each probe as well as the depth at which it was installed.

VII.P.3. Thermal equilibrium

Just after a probe is installed it will gradually warm or cool to meet the water's temperature. During this process the probe readings may be inaccurate. Most manufacturers recommend that data collection not start until the probe temperature has reached thermal equilibrium with the water. This can take between 30 and 60 minutes. This concern is especially important for any analog probes where temperature can affect its physical properties. It is not as significant a concern for solid-state, digital probes.

VII.P.4. Accuracy/resolution/precision

Different probes have different levels of accuracy, resolution and precision as well as different maintenance and operation requirements. The applicant must maintain and operate each probe, following manufacturers recommended specifications, so as to produce the most accurate readings possible.

VII.P.5. Calibration

Over days or weeks a probe's reading may slightly change even if the depth of water above the probe doesn't. This may be due to instrument drift. For this reason the applicant must take calibration data to allow checking for, and compensating for, instrument drift.

A calibration data set consists of two near-simultaneous water-level readings. One is from the probe, as recorded by the ADR. The other is a manual measurement of water level, with an accurate timestamp. During background periods up to three days long the applicant should collect a calibration data set every 24 hours, including the start and stop of the period. More frequent measurements are preferred. For background periods longer than 3 days the applicant should collect a calibration data set at least once a week, then every 24 hours for the three days before the pumping period begins. During the pumping period the applicant should collect a calibration data set every eight hours. For the first day of the recovery period the applicant should collect a calibration data set every 12 hours. After that, collect a data set every 24 hours.

This specification assumes a check of ADR operation every day during the pumping and recovery phases. Whenever an ADR is installed, removed, or accessed to examine its operation a calibration data set should be collected.

For long-term water-level monitoring, (two months or longer) ADR operation should be checked and calibration data should be collected on a monthly basis.

After the test, during data processing, all calibration data sets are compared. The value reported by the probe and recorded by the ADR is converted into an appropriate water level, to the nearest 0.01 feet, relative to the datum used in the test. The simultaneous manual reading of depth to water level is also converted into a water level to the nearest 0.01 feet, relative to the same datum. The calibration data for each monitoring location must be tabulated and submitted with the data-logger measurements.

Hopefully the calibration values agree throughout all phases of the test. If they instead diverge with time then this instrument drift must be compensated for. In such cases the manual reading is assumed to be more accurate and the probe values are adjusted by an appropriate amount. The submitted report must address any instrument drift and supply sufficient details to show all compensation steps.

VIII. Hydrogeologic Report

The hydrogeologic report must include detailed information on the site's hydrogeologic setting, test specifications, collected data and analysis. The following sections detail the information to be included in a technically complete report.

VIII.A. Maps

The hydrogeologic report must include a number of maps that allow NJDEP to evaluate the site in context. These maps must be at scales appropriate to the level of detail required to clearly show the relevant information.

In general there are two sets of maps, regional and detailed. Each set may have more than one map in order to clearly show the required features.

The regional maps are at 1:24,000 (quadrangle scale) or more detailed. These maps show locations of the proposed new diversion and all other nearby diversions. These maps will also show surficial and bedrock geology, surface-water bodies, nearby groundwater pollution, and other areas of environmental concern. They will include appropriate cultural features (such as roads) and political boundaries. If there are mapped well head protection areas in the area these must be included. One regional map must show estimated regional groundwater flow paths.

Detailed site maps must be at an appropriate scale, but certainly more detailed than 1:24,000. They must show locations of all pumping and observation points during the aquifer tests, nearby pumping wells, and the location of the discharged water. If there are geological details that are not clearly shown on the regional map then they must be shown on a detailed map. A topographic map is required that also shows nearby surface-water bodies, streams, and areas of environmental concerns. One site map must show cultural features, such as buildings, roads, and political boundaries. The report must include two detailed maps showing the groundwater potentiometric surface, the first of conditions during the background period and the second of conditions at the end of the pumping period.

VIII.B. Existing Geologic and Hydrogeologic Data

Geology governs groundwater flow. It is critical to understand the distribution of, and relationships between, geologic units at the site and their transmissive properties. Without this knowledge of hydrogeologic properties, one cannot develop a sufficiently-accurate understanding of groundwater flow patterns. This understanding is necessary for estimating the impact of a new or increased diversion.

The hydrogeologic report must describe in sufficient detail the geologic and hydrogeologic setting. Important sections are discussed below.

VIII.B.1. Published reports

Numerous State, Federal and privately-developed reports discuss regional hydrogeology throughout New Jersey. Site-specific research should start with this published material. Field research can then be directed towards filling data gaps.

VIII.B.2. Hydrogeologic setting

The hydrogeologic report must include a thorough description of the site's hydrogeologic setting. This will include aquifer and confining-unit thicknesses, areal extent, outcrop areas, and relationships to other aquifers. It must also include a discussion of the expected recharge area of the water that would supply the requested diversion.

VIII.B.3. Aquifer properties

The hydrogeologic report must include a summary of the site's aquifer properties. This includes all known values of aquifer hydraulic conductivity, transmissivity, storage coefficient, thickness, and any other relevant aquifer characteristics. It must compare results from aquifer tests conducted for the current permit application to aquifer properties developed previously.

The hydrogeologic report must include a map of the regional groundwater flow pattern. This helps identify recharge and discharge areas, hydraulic heads in the various aquifers, and geologic controls on groundwater flow. Regional maps are based on a combination of field data, well-record data, and sound hydrogeologic assumptions.

The hydrogeologic report must include a detailed maps of groundwater levels at the site at the end of the background period and at the end of the pumping period. This maps are based on site-specific data collected during these periods.

VIII.B.4. Confining-unit properties and boundary conditions

Confining units overlying and underlying the aquifer can exert a profound effect on the aquifer. Impermeable units can prevent local recharge or discharge (perhaps inducing recharge or discharge in more distant areas) and prevent vertical migration of pollutants or salt water. Leaky, semipermeable units may allow limited vertical flow. The thickness, vertical hydraulic conductivity, and areal extent of the confining units are of great importance. The hydrogeologic report must include all available information relevant to the confining units in the vicinity of the proposed diversion site, including any results generated by analysis of data gathered during the current investigation.

VIII.B.5. Data on other formations

Other formations in the stratigraphic column may affect the aquifer being pumped. For this reason the hydrogeologic report must include information on the hydraulic characteristics, areal extent, water levels, nearby pumpage, known leakage, and other relevant factors in these neighboring formations. Of special interest are data bearing on the potential for hydraulic interconnections between all water-bearing units at the site.

VIII.C. Other wells nearby

The hydrogeologic report must inventory public-supply and major pumping wells regulated by BWAWP yielding more than 100,000 gallons per day (70 gpm) within 5 miles of the proposed diversion. (This cutoff rate value is 50,000 gpd (35 gpm) in the Highlands Preservation Area unless the proposed activity is exempt.) The inventory must include wells for public supply, groundwater remediation, irrigation, public non-community, and agriculture.

This inventory must include all relevant information (including but not limited to owner, well name, well permit number, aquifer, total depth, depth of screen setting, pump setting, pump capacity, allocation permit number, and allocation permit volume limits). These data are on file with BWAWP. The hydrogeologic report must include appropriate scale maps displaying the location of these wells.

The hydrogeologic report must include all public community wells with an allocation permit within five miles of the site, regardless of the permitted volume.

The aquifer test must include an inventory (and map) of all domestic wells within a 1-mile zone of the proposed well. This inventory must summarize in table form all relevant available data for each domestic well. It must also inventory major subdivisions (50 or more homes) between one and three miles of the site. For these major subdivisions it is it is acceptable to locate, on a map, the subdivision and give the total number of wells and their average well depth. The inventory for each of these more distant subdivisions does not need to be as detailed as that done for domestic wells within 1 mile of the site.

BWAWP's files contain information on well permits and well records. The files are available for public review. Applicants should contact BWAWP to make an appointment in order to view the records.

VIII.D. Details of all test and monitoring wells

The hydrogeologic report must include construction data of all wells pumped and monitored during the aquifer test. This includes permit information, drilling date, location in state plane coordinates, well log, total depth, pump setting, screen and casing specifications and all other pertinent data. This must be presented in a concise table. If a well had a change in permit number, both old and new numbers must be included.

The hydrogeologic report also must include the technical specifications of the permanent pump, along with the pump's performance curve and proposed installation depth. If these data are not available at the time of application they should be submitted when available..

If the well has been pumped previously, its performance history is needed, including pumping rates and drawdowns from any previous aquifer tests. If the well has been geophysically logged by downhole methods, or by a video log, these logs are also required in an appropriate format.

The hydrogeologic report should include any other factor which might affect the performance of the well and/or pump, such as age and redevelopment techniques.

VIII.E. Sustainable Water-Resource Yield

The hydrogeologic report must include an estimate of the aquifer's sustainable water-resource yield. This is the amount of water the aquifer can produce that is available continuously during projected future conditions, including a repetition of the most severe drought of record, without creating undesirable effects. (See section II.C.6 for more details.)

All diversions create drawdown and intercept water that otherwise would have discharged elsewhere. The sustainable water-resource yield of an aquifer is based on linking an analysis of the impacts of diversions to a determination of the limits of acceptable impacts.

If the determination of sustainable water-resource yield includes impacts on other users and the ecosystem then a detailed analysis is required. In some cases it may be impossible to define this yield before completing a detailed site study. In some cases NJDEP has made estimates of the aquifer’s sustainable water-resource yield by analyzing the water-supply abilities of the combined surface water/unconfined aquifer system.

Once a well is in production it is clear that the sustainable water-resource yield of the aquifer has been exceeded if water levels do not stabilize in a pumping well but rather continue to decline.

VIII.F. Estimated aquifer parameters

The goal of an aquifer test is to yield information on the aquifer's ability to transmit and store groundwater. These aquifer parameters are then used to predict the impact of the requested diversion on other users and the environment.

The hydrogeologic report must include the estimated aquifer parameters and substantiate these values by presenting the worksheets, graphs, and calculations that led to the parameters. It must discuss the interpretations made about the aquifer at the applicant's site, including storage conditions (confined, leaky, or unconfined), flow conditions (isotropic or anisotropic), and lateral boundary conditions (infinite acting, constant head, or no-flow) observed during the course of the test. Observed drawdown characteristics should be reconciled with the hydrogeologic setting and the narrative should explain why the analysis technique chosen is appropriate.

If the aquifer parameters are the result of a software program's best-fit approach then the hydrogeologic report must identify the program and include graphs showing the data and best fit.

VIII.G. Zone of influence

The zone of influence (ZOI) of a pumping well defines an area that experiences an effect attributable to that pumping well. This concept is easy to state but is in practice difficult to quantify.

The ZOI is a three-dimensional area whose shape is governed by the site's hydrogeology. In a water-bearing unit which meets all theoretical conditions of an ideal isotropic confined aquifer, the ZOI extends an infinite distance from the pumping well. The aquifer receives no recharge and a pumping well will eventually influence all parts of the aquifer.

In a strict sense, no water-bearing unit in New Jersey meets all of the requirements of an ideal confined aquifer. All aquifers have a source of recharge, perhaps an outcrop area many miles away, or slow leakage from an adjacent unit. However, if the recharge is sufficiently slow or far away then the aquifer will appear to be confined for the duration of a test.

ZOI calculations are not the only indicator of those areas subject to adverse effects. BWAWP reserves the right to establish areas of significant impact outside a calculated ZOI. An example of a significant impact area outside the calculated ZOI may be a specific time-based well head protection area capture zone which includes known groundwater contamination.

There are many methods to estimate the ZOI. These can generally be divided into two categories - modeling and analytical.

A modeling approach to estimating the ZOI requires building a numeric groundwater flow model that accurately reproduces the hydrogeologic features of the site. This will include a detailed representation of the transmissive and storage properties of all units, along with recharge and discharge points. This model can be run first without and then with the proposed pumpage. The difference in simulated groundwater levels then shows the ZOI.

The analytical approach uses one or more equations to predict the drawdown that will result from the proposed diversion. This approach is much more simplistic than the modeling approach but may be justified in some cases. Analytical approaches include:

1) The Jacob distance-drawdown approach based on steady-state drawdown in an confined aquifer.
2) Extrapolations of the distance at which a specified drawdown will occur at a specified time. This requires a transient-drawdown methodology appropriate to the aquifer.
3) Assume an average recharge rate near the well and determine the size of a drawdown cone that will intercept sufficient recharge to supply the pumping rate.

The author of the hydrogeologic report must use best professional judgment to determine an appropriate ZOI. NJDEP recommends a conservative approach, using methods and parameters that will result in protection of the groundwater resource.

VIII.H. Water Quality Concerns

A pumping well alters groundwater flow paths. If this alteration intersects a region of groundwater contamination then the proposed diversion may spread the contamination. The test results must provide insight into this possibility and the hydrogeologic report must address it.

VIII.H.1. Groundwater contamination

The hydrogeologic report must inventory nearby groundwater contamination sites. It must address the possibility that the requested groundwater diversion will adversely affect any nearby remediation efforts, or increase the spread of contamination.

VIII.H.2. Saltwater intrusion potential

Pumpage near areas with water of elevated chloride or sodium concentrations may accelerate saltwater intrusion. The hydrogeologic report must evaluate the potential of the proposed diversion to induce saltwater into the proposed pumping well or into other pumping wells, or increasing the rate at which salt water intrusion is occurring. In this context salt water is defined as water containing a chloride concentration in excess of 10,000 mg/L (N.J.A.C. 7:19). This intrusion may come from the ocean or from connate water already in or adjacent to the pumped aquifer. The water may move laterally from a recharge area under the ocean, bay, tidal stream or saltwater marsh. It may leak upward from an underlying formation (upconing), or leak down from an overlying formation containing salt water. All possible sources of saltwater must be addressed in the hydrogeologic report.

VIII.I. Groundwater modeling

In some cases the applicant may submit a groundwater model that simulates the impacts of the pumping well. This may be done as part of the hydrogeologic report and be based on results of the aquifer test. Or, it may be done in lieu of an aquifer test if NJDEP agrees that sufficient hydrogeologic data exit to support the modeling effort.

The following items are required when submitting a groundwater flow or transport model. They are necessary in order for the reviewer to evaluate the applicability and accuracy of the model and its results.

1) A thorough discussion of the objective of the groundwater model and its applicability and validity in assessing issues related to the permit application.
2) A description of the modeling software used to develop the model.
3) A detailed description of the conceptual model used in generating the numerical groundwater model including geologic/hydrogeologic framework, hydrologic boundary conditions, groundwater/ surface-water interaction, ground or surface-water diversions and all factors pertinent to understanding the flow system. This includes all existing data (such as well logs and aquifer test results) that form the basis for the development of the model.
4) A description of the numerical model and modeling analysis including the type of model used (steady state or transient, flow or transport, 3-D, number of layers, etc.), model input parameters, and any assumptions or simplifications used in modeling the flow system. All methods for calculating input parameters must be reported.
5) Model data presented in a map format. For each model layer, a figure(s) showing the model area, grid and input parameters overlain on a topographic base map. The figure(s) should clearly show:
    a. zones of equal hydraulic conductivity (horizontal and vertical), transmissivity, vertical leakance, storativity, and recharge,
    b. boundary conditions such as river or constant head cells,
    c. wells simulated in the model, and
    d. any other parameter used in the model at a scale appropriate to clearly convey the information.
6) Digital copies of all model input data sets and all model simulations used in the analysis.
7) A description of the modeling results for all simulations including:

   a. model calibration criteria and a discussion of how simulated water levels and flows meet these criteria,
   b. maps showing the piezometric surface and groundwater flow directions in each model layer,
   c. comparison of measured and simulated groundwater/surface-water elevations,
   d. a water budget for the modeled area.
8) The results of sensitivity analyses to assess the uncertainty in chosen model input parameters.
9) Any limitations of the model in its intended application.

VIII.J. Electronic Data Submission Standards

The hydrogeologic report must supply all figures, tables, and data sets in electronic format. This includes raw data collected during the test and processed data for analysis. The data collected must be checked for errors and inconsistencies, summarized in narrative and tabular form, and submitted in digital form. Specific requirements include:

VIII.J.1. Digital Field and Processing Notes (Test Metadata)

An aquifer test will generate data from a number of monitoring points, measured by a variety of techniques, and perhaps reported in different units. The hydrogeologic report must include a section with details on data collection. This is the metadata section. The metadata section should also be submitted electronically.

The metadata section includes, but is not limited to, information on well elevations, well descriptions, probe placement depths, make, model and psi/depth rating of the probe, barometric compensation steps and equipment (if required), test parameters, transducer related problems, data collection problems, pumping well setup, discharge measurement setup, orifice diameters (if used), automated discharge measurement device make and model, pumping well problems, pumping rate changes and rate change times, data losses, download problems, access problems, general test problems, pumping failures, etc.

NJDEP also requires a second metadata section that describes processing steps. This will describe in detail barometric compensation, antecedent-trend processing, other problems requiring compensation, elevation conversions, raw data file formats, ADR software name and version, data file names, processing dates, processing software and methods, known data errors (data loss, transducer drift, apparent failures, gaps) and omissions. The goal is that the reviewer can recreate the steps taken to transform the raw data into the processed data that are the basis for the analysis.

VIII.J.2. Raw ADR Data Files

The raw data observed in the field must be submitted in two forms:

1) The hydrogeologic report must include in digital form all unprocessed data files. These are generated by the all ADRs used during the test and may include data from probes monitoring water levels, discharge, temperature, precipitation, and barometric pressure. These files should be in the native format created by the ADR manufacturer. The hydrogeologic report must indicate the manufacturer's software and/or firmware version in the metadata file describe above.
2) The raw data files must be translated into a two-column format ASCII file of elapsed test time (in decimal minutes) and observation (in an appropriate unit). These files must be clearly named so as to indicate which observation point they apply to. They must include all appropriate header information in the file.

VIII.J.3. Unified Data Processing File(s)

In order to create data sets suitable for analysis the applicant must process the raw data into one or more unified data processing files. These processing files must also be submitted in digital form with the hydrogeologic report. It is the responsibility of the applicant to ensure that the data submitted from and aquifer test is assembled in a clear and un-ambiguous manner. It should be possible for anyone to review the data in its proper hydrologic context and in its proper sequence.

The submitted digital data must include a MS Excel ™ compatible file that contains all observed water levels. All water-level data should be presented relative to the common datum (NGVD, 1988). All water-level data should also be presented as calculated drawdown from static levels in that observation point. If barometric, tidal, antecedent trend, instrument drift, or other adjustments were made on the observed data appropriate steps should be evident in the file. All observations must include appropriate timestamps. The timestamps should include true date and time, serial dates, and run time. Timestamps for all monitoring points must be synchronized.

The digital file should include hydrographs of observed water levels data versus time for all monitoring points throughout all phases the test. As appropriate, the hydrographs should also indicate daily precipitation data from any on-site meteorological station or nearest station, barometric measurements (if required) and the start and stop times of test pumping and any significant changes in pumping rate (e.g. figure 9).

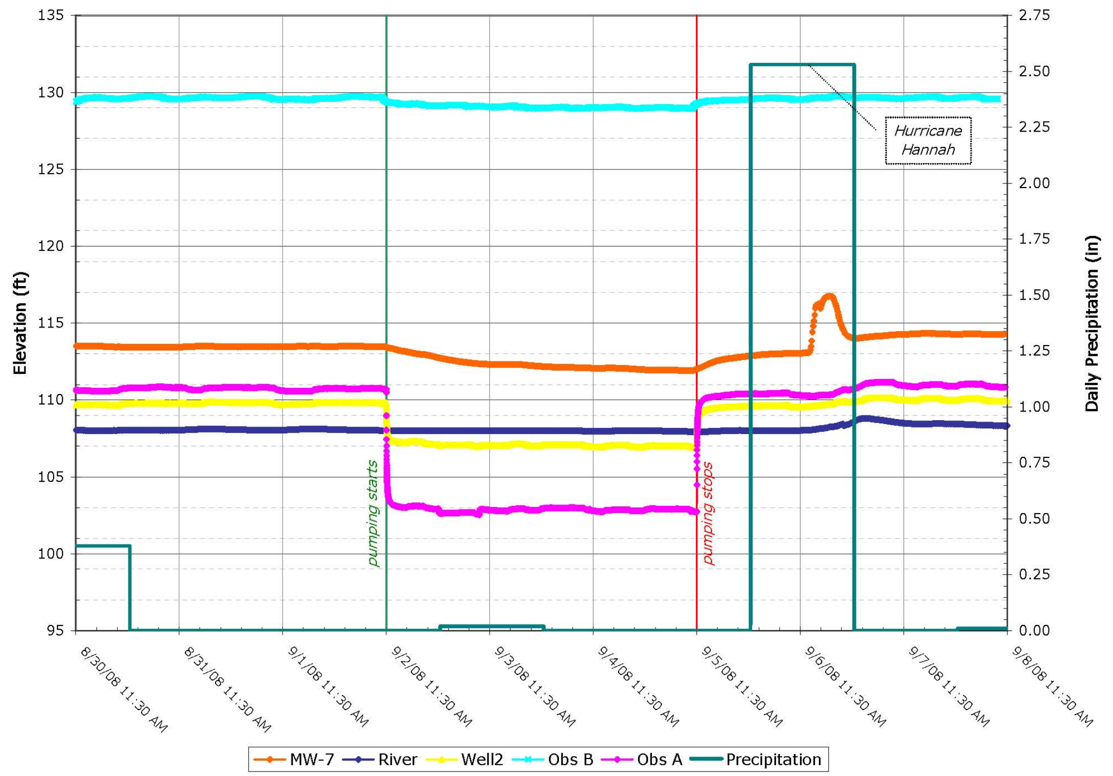


Figure 9. Water levels and precipitation hydrographs observed during the test of TW-3 in Milford, New Jersey.

The submitted digital data must include a MS Excel™ compatible file that contains the data on pumping rates. This will include processed ADR discharge measurements and any manual measurements of discharge, or manometer measurements. This must include any processing steps taken to convert the reported ADR values into a discharge rate (in gpm). All observations must include appropriate synchronized timestamps. The timestamps should include true date and time, serial dates, and run time.

These data may be included in the unified water-level data processing file if they are clearly marked as discharge data.

VIII.J.4. Media

The digital files must be included with the application on Windows™ PC-compatible media. NJDEP prefers data CDs (CD-ROM, CD-R, CD-RW) or DVDs (DVD-ROM, DVD-/+R, DVD-RAM, DVD+/-RW).

Digital files may be compressed using the ZIP[2] compression format in order to reduce the size of the submitted data. If file compression is used, all raw ADR data must be placed in a clearly indicated ZIP archive and all processed data files (including ASCII drawdown files) must be placed in a second, clearly indicated ZIP archive. Disk spanning archives are acceptable but disks must clearly indicate that they are part if such an archive and must clearly indicate the archive disk order.

<u>VIII.K. Wetlands</u>

If BWAWP has indicated the proposed diversion's impact on wetlands is a concern then the hydrogeologic report must contain the data, analysis and interpretation used to evaluate this impact. In general, this will include:

1) Measured drawdown in designated wetland area(s).
2) Location of the predicted zone of influence in relation to the designated wetland area(s).
3) Any change in groundwater-flow direction, measured or predicted, that results in water being diverted from a wetland area. Contour maps showing water levels and groundwater-flow directions a) prior to pumping, b) at the end of the pumping phase, c) after recovery has occurred, and d) under long-term operating conditions at proposed diversion. Changes in location of a groundwater or surface-water divide as a result of the pumping must be indicated on the map.
4) Potential impacts to wetlands and sensitive wetland species based on analysis of test results, including any adverse impact. The appropriate State and Federal regulations governing wetlands and wetland species should be consulted to make this determination.
5) Other relevant data, results and analysis.

<u>VIII.L. Streams</u>

If BWAWP has indicated the proposed diversion's impact on streams is a concern then the hydrogeologic report must contain the data, analysis and interpretation used to evaluate this impact. In general, this will include:

1) Measurement of stream flow and levels with analysis of any changes.
2) Comparison of stream levels to changes in vertical fluxes.
3) Any visual observations of a decrease in stream flow or level.
4) Analysis of any changes in temperature in pumping well as compared to stream temperature.

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[2] The ZIP format should not be confused with Iomega ZIP™ disks. Iomega ZIP™ disks are a type of digital media and any data submitted on these disks shall be rejected. The ZIP data compression program is widely available on the Internet.

5) Comparison of the zone of influence to the stream.
6) Other relevant data, results and analysis.

VIII.M. Lakes and Ponds

If BWAWP has indicated the proposed diversion's impact on surface water (lakes and ponds) is a concern then the hydrogeologic report must contain the data, analysis and interpretation used to evaluate this impact. In general, this will include:

1) Measurement of surface-water levels with analysis of any changes.
2) Comparison of surface-water levels to changes in vertical fluxes.
3) Any visual observations of a decrease in surface-water levels.
4) Analysis of any changes in temperature in pumping well as compared to surface-water temperature.
5) Comparison of the zone of influence to the surface-water.
6) Other relevant data, results and analysis.

VIII.N. Threatened and endangered species

If BWAWP has indicated the proposed diversion's impact on threatened and endangered species is a concern then the hydrogeologic report must contain the data, analysis and interpretation used to evaluate this impact. In general, this will include:

1) Location of the predicted zone of influence in relation to the designated threatened and endangered species habitat.
2) Any change in groundwater-flow direction, measured or predicted, that results in water being diverted from an area hosting threatened or endangered species. Contour maps showing water levels and groundwater flow directions a) prior to pumping, b) at the end of the pumping phase, c) after water-level recovery has occurred, and d) under long-term operating conditions at the proposed rate of diversion. Changes in location of a groundwater or surface-water divide as a result of the pumping must be noted on the map.
3) Potential impacts to threatened and endangered species based on analysis of test results, including any adverse impact. The appropriate State and Federal regulations governing threatened and endangered species should be consulted to make this determination.

IX. Aquifer Storage and Recovery

Aquifer storage and recovery (ASR) refers to the practice of injecting water into an aquifer for later recovery. The source of the injected water may be a different aquifer, a surface-water source, a combination of the two, or even water purchased from another purveyor. The goal is to inject water during a wet or off-peak period and withdraw it during a dry or peak-demand time to supplement other water sources. If successfully implemented, purveyors may meet peak demands with greater ease and perhaps reduce stress on the environment and other groundwater users.

Applications for ASR wells must be accompanied by additional information that documents the hydraulic testing (N.J.A.C. 7:19-2.2). The testing and analysis must allow a feasibility analysis of the ASR well in addition to evaluation of potential hydrologic impacts on other water users and the environment. Due to the additional regulation of ASR wells (see section III.A.4 above) the pre-application meeting for these projects must include BWAWP, the Bureau of Non-Point Pollution Control and the Bureau of Water System Engineering.

An aquifer test designed for an ASR system should follow the techniques outlined in this report in regard to the number and placement of monitoring locations, data collection, and reporting requirements. The test and hydrogeological report must also address additional requirements relevant to ASR wells.

IX.A. Injection and diversion rates

The applicant must design and conduct the test to simulate the proposed ASR cycle. Rates and duration of injection and diversion volumes must be in proportion to the proposed use of the ASR system. The test's injection period (aquifer storage period) must provide data to evaluate the aquifer's capability to accept and retain the planned injection rate and volume of water. The pumping portion of the test should replicate a recovery period. It must provide data to evaluate the aquifer's ability to supply water at the proposed peak capacity without creating de-watering conditions within the aquifer.

The associated change in the local and regional water levels must to be identified to analyze any impacts on nearby users in the storage zone.

Some ASR facilities use multi-year “water-banking” to balance storage and recovery volumes. For such facilities, the aquifer test should be conducted at rates equivalent to the actual volumes of water to be injected and recovered during a maximum monthly period in the multi-year scheme.

IX.B. Geochemical analysis

The chemical compatibility of injected water with native groundwater at the site is a critical operational component. Geochemical data from current ASR systems show that injected water, especially if treated with corrosion inhibitors, may react with native groundwater and aquifer materials. This may increase the potential for trace element and radionuclide mobilization during storage of water in the aquifer.

The selection of an appropriate storage zone is integral in minimizing the impact of mixing of different chemistry waters. This is particularly true for aquifers containing saline water. ASR systems where the geochemistry of the injected water and the native aquifer are similar provide the highest recovery efficiency.

IX.C. Water-level monitoring

The potential of the aquifer as a competent storage zone needs to be identified to ensure that there is significant confinement to prevent pumping impacts from stratigraphically higher or lower aquifers. The degree of confinement is also important to protect the storage zone from any contaminant migration. Thus during the test the applicant must monitor any overlying and underlying units, as appropriate. This will help determine if the injected water has the potential to leak out of the aquifer.

NJDEP will require long-term water-level monitoring in all aquifers affected by ASR systems.

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Appendix A. Types of Aquifers

An aquifer is a saturated hydrogeologic unit able to yield significant quantities of water to a well or spring. Aquifers are commonly classified as unconfined, confined, or semi-confined. This classification is based on the hydrologic properties of the units overlying and underlying the aquifer and by the physical processing governing the release of groundwater storage to the well. Water levels in these three types of aquifer respond differently to pumping.

Additionally, aquifers are classified by hydrogeologic characteristics. This classification differentiates aquifers by lithology and focuses on the attendant porous attributes present in various rock types and unconsolidated deposits. Lithology also defines important attributes such aquifer geometry, extent, and uniformity of physical properties. On this basis, aquifers are broadly classified as unconsolidated or consolidated.

Not understanding the hydrogeologic setting may lead to the use of an inappropriate test and/or an inappropriate analytical technique. Even worse, it may result in not monitoring the appropriate response, thus making the test a waste of time and money.

A.1. Confined Aquifers

A confined aquifer is overlain and underlain by relatively impermeable units through which groundwater flow is nonexistent or negligible. All voids in the aquifer are filled with water at a pressure greater than atmospheric. The potentiometric head in the confined aquifer is at a level higher than the top of the aquifer.

During the aquifer test the potentiometric head in the confined aquifer remains above the top of the aquifer; no dewatering of the aquifer occurs. Recharge to the aquifer from overlying or underlying units is minimal. Pumping of the test well reduces the fluid pressure within the aquifer. In response the aquifer releases water by consolidation of the aquifer skeleton and by expansion of water within the aquifer pore space.

A.2 Semiconfined Aquifers

A semiconfined aquifer is similar to a confined aquifer except that the overlying and/or underlying confining units cannot be considered to be impermeable. The permeable overlying and/or underlying unit is called an aquitard. Enough water flows vertically through the aquitard to be a significant source of recharge to the aquifer. This vertical recharge is called leakage and must be accounted for in analyzing aquifer test data. The source of the leakage is more commonly another aquifer above and/or below the aquifer being tested, however in some hydrogeologic settings, the source of leakage can be the aquitard(s). Like a confined aquifer, all voids in the semiconfined aquifer are filled with water which is at a pressure greater than atmospheric and the potentiometric head is above the top of the aquifer.

During an aquifer test the rate of leakage depends upon the permeability of the aquitards and the difference in hydraulic head between the aquifer being tested and the aquifer(s) supplying leakage. At the beginning of the aquifer test water produced by the test well is derived from storage in the semiconfined aquifer, again due to consolidation of the aquifer skeleton and by expansion of water within the aquifer pore space. As pumping continues, the lowering of head produces a vertical hydraulic gradient between the pumped aquifer and the overlying or underlying aquifer(s) and the rate of leakage increases with test time. With continued pumping, the leakage rate can approach the withdrawal rate of the test well, indicating that most of the pumpage is then being derived from storage in aquifers above or below the semiconfined aquifer.

A semiconfined aquifer can be recognized in at least three ways. (1) Lithologic information on the aquitards may indicate they will allow some leakage. (2) Water-level changes in the aquitards or aquifers directly overlying or underlying the test aquifer may indicate a hydraulic connection. (3) The observed time-drawdown data in the aquifer may indicate an additional water source. If the hydrogeologic setting, water-level data, and drawdown response fit a theoretical semiconfined-aquifer type curve, then the aquifer probably is semiconfined.

A.3. Unconfined Aquifers

An unconfined aquifer is bounded above by the water table, not an impermeable unit. The potentiometric head in the aquifer is at the elevation of the water table. During the aquifer test the water table falls in response to pumping. The decline in water level is the draining of water from the pore space in the aquifer. The draining process doesn't occur instantaneously and persists for a period of time, resulting in a temporary flattening in the pattern of time-drawdown data. The flattening of the time-drawdown data is called delayed yield. As the test proceeds into late-time, the rate of water draining from the pore space above the new water table position will diminish and the time-drawdown data will resume a pattern similar to that observed in confined aquifers.

If the saturated thickness of the aquifer changes by less than 5 percent during the course of an unconfined-aquifer test then the late-time data may be suitable for analysis by a confined-aquifer method. This decision is at the discretion of the hydrogeologist analyzing the data. Otherwise, the change in saturated thickness of the aquifer caused by drawdown during the test must be accounted for in the analysis of the data.

As a general principle, it is always advisable to attempt to fit observed data to both confined and semiconfined type curves. This lessens the probability of neglecting any vertical leakage.

A.4. Unconsolidated Aquifers

Unconsolidated aquifers are generally gravel and sand deposits interbedded with relatively minor amounts of silt and clay. The materials may be compacted somewhat, but lithification due to cementation is minor or absent. The deposits retain much of their original intergranular porosity. Vertical permeability of an unconsolidated aquifer can be strongly influenced by any continuous silt or clay layer in the deposit. Overall permeability is more generally influenced by depositional environment (e.g. marine, estuarine, glacial), hence existing geologic mapping and reports can be invaluable in the characterizing the uniformity of aquifer properties, areal extent, and degree of confinement.

A.5. Consolidated Aquifers

In a consolidated aquifer, the grain are cemented or compacted into a firm and cohesive mass. Consolidated aquifers are also called bedrock aquifers. Consolidated aquifers can be made up of igneous, metamorphic, or sedimentary rock.

Secondary porosity is generally the prime mechanism for groundwater movement in consolidated aquifers, though primary porosity may be present in some clastic sedimentary rocks. The porosity of consolidated aquifers tends to be much lower than that of unconsolidated aquifers. Joints and other fractures are the most common source of secondary porosity. In carbonate rock aquifers, chemical dissolution is another source of porosity, enlarging fractures and/or beds through which groundwater flow can be significant.

The distribution and orientation of the secondary-porosity structures can be the dominant factors controlling the hydrogeologic response of consolidated aquifers. The most common phenomena observed during aquifer tests of consolidated aquifers are anisotropy and complex responses in storage behavior. These must be accounted for in order to accurately estimate the water-supply properties of the aquifer.

An additional complication is that these secondary structures may affect drawdown patterns. Some tests in consolidated units in New Jersey have shown preferential drawdown which can be related to bedrock structure commonly available from existing maps. For example greater water-level fluctuation in a distant observation well that is on bedding strike than in a closer well that is off bedding strike can be commonly observed. An analysis of drawdown that does not consider the underlying geologic complexity will produce incorrect estimates of aquifer properties. These incorrect properties are not useful in accurately predicting pumpage impacts.

Appendix B. Types Of Aquifer Tests

An aquifer test consists of withdrawing water at one or more wells and measuring the response at one or more monitoring points. Analysis of this response can yield information on hydrogeologic parameters if an appropriate test is conducted under controlled conditions.

The following sections provide an overview of the types of aquifer tests and some of the assumptions required by the analysis techniques. This section is not a substitute for a thorough grounding in hydrogeologic analysis techniques.

B.1. Steady-State and Unsteady-State Aquifer Tests

Aquifer tests are divided into two types, steady state and unsteady state. This is based on rate of change in drawdown observed in the pumping well and/or observation wells.

In a steady-state test, the test well is pumped at a steady rate and water levels are monitored until they have stabilized. All pumped water is produced by water flowing laterally or vertically towards the pumping well. Steady-state water levels are more readily achieved during a long test (e.g. 30-days) but water levels can stabilize during the course of a 72-hour aquifer test in some hydrogeologic settings. Commonly data from steady-state tests are used in a distance-drawdown analysis method, which requires data from more than one observation well.

It is unclear exactly when water levels in a well reach a steady (or equilibrium). If the aquifer being tested is a true confined aquifer, then it will theoretically never reach equilibrium. From a practical point of view when the rate of drawdown has slowed to inches per day the water level could be considered to be close to steady state and steady-state analysis methods may be used to provide estimates of aquifer properties such as transmissivity.

An unsteady-state test utilizes drawdown data gathered during the fall of water levels immediately following the start of the pump. Usually the data are plotted for one well at a time showing observed drawdown against elapsed time. The tests are said to be unsteady-state tests because the water levels continue to decline with pumping. In an unsteady-state test the changing water level from one well can be analyzed to yield aquifer properties using the appropriate methods. Modern computer analysis with these methods allow for the analysis of drawdown from multiple observation wells simultaneously, which provides for a more rigorous assessment of aquifer properties and conditions.

With respect to determining steady-state or unsteady-state conditions, no specific rate of decline is established here to define stabilization. A judgment that stabilization has been reached is a decision based on the slope of the time/drawdown plot(s). One popular standard is an average decline in water level in an observation well of 1 to 1.5 inches per hour. Another is if drawdown has been less than 6 inches over a six hour period. By testing equilibrium versus nonequilibrium solutions on the data, the applicant can determine if the correct assessment has been made.

Good reference for the theory, design, and analysis of aquifer tests are Bentall (1963a, 1963b), Ferris and other (1962), Kruseman and other (1990), Lohman (1972), Reed (1980), Stallman (1971), and Walton (1987).

B.2. Testing of Bedrock Aquifers

The theory underlying the aquifer tests mentioned above assumes that the aquifer is homogeneous and, usually, isotropic. This is frequently not the case for fractured-bedrock aquifers. An additional limiting factor is that most analytic methods are best suited for aquifers which have well defined overlying and underlying boundaries. In a consolidated formation which may be several thousand feet thick, the effective aquifer thickness can be open to question. The depth of the pumping well or penetrated stratigraphic interval may be an appropriate surrogate for aquifer thickness. Defining the top, bottom, and areal extent of bedrock aquifer is an important step toward analyzing an aquifer test in consolidated aquifers.

Because of these limiting factors, the analytical techniques developed for confined, unconfined and semiconfined conditions are most accurately applied to unconsolidated aquifers. A separate set of solutions is available for fractured bedrock aquifers.

B.3. Choice of Testing Methodology

This report is not a rigid guideline requiring one specific technique to use in each situation; often more than one method is available. Tables B1, B2, and B3 list analytical techniques that are appropriate under various hydrogeologic conditions. Each technique is applicable under specific sets of assumptions. The applicant should attempt to verify that the assumptions associated with a technique are appropriate to the field situation and should discuss the application of the method and estimated aquifer properties in the hydrogeologic report.

B.4. Assumptions and Common Violations

All methods of analyzing aquifer-test data require some assumption as to the hydrogeologic nature of the aquifer and the nature of the test. In the real world the assumptions are rarely entirely satisfied. However, if the assumptions are close enough then the results from the analysis technique provide useful insights into the water-bearing properties of the aquifer.

Aquifer-test analysis methods typically assume initial and boundary conditions, many of which are applicable to a specific type of aquifer. A few of these basic assumptions concern conditions which are common to most methods and for which procedures in these guidelines are designed to address. Violations of these basic assumptions either by failing to recognize certain field conditions or by not following some of the procedure recommended herein can thwart a meaningful analysis of the aquifer test data and provide misleading conclusions about the aquifer properties or impacts from a proposed diversion.

B.5. Pre-test water levels

Most aquifer test analysis methods assume that potentiometric surface is horizontal and that water levels are neither rising nor falling. In addition, leaky aquifer methods also assume that the pre-test hydraulic head in the aquifers which are sources of leakage is the same as that in the test aquifer. Common problems with this assumption concern previous pumping stress, water-level rise caused by recharge, water-level decline caused by groundwater recession, and tidal forcing. The background water level monitoring allows for assessment of the pre-test water levels by which it may be determined that the aquifer is recovered from previous pumping stress (or testing) or to establish water-level trends such as groundwater recession which may be needed to correct drawdown in unconfined aquifers. In unconfined aquifers, aquifer testing should be conducted during a period of fair weather to avoid water-level rises due to precipitation and recharge. Tidal forcing in confined aquifers coastal areas may require an extended period of pre-test monitoring and analysis to correct drawdown as described in Section VII.N of this report.

B.6. Partially-Penetrating Wells

If the pumping well fully penetrates the confined aquifer then groundwater flow towards the pumping well is horizontal. For the purposes of these procedures, a well is considered to fully penetrate the aquifer if it is screened through 80 percent or more of the aquifer's saturated thickness. If it is screened through a smaller percentage, vertical flow in the aquifer may affect water levels in nearby observation wells. If the pumping well does not meet the criteria for a fully penetrating well, then the aquifer-test-analysis method used should be appropriate to a partially-penetrating well situation.

In general, the closest observation well should be no closer than 1.5 times the saturated thickness of the aquifer to avoid problems associated with vertical water flow near the well screen. Ideally partial-penetration can be taken into account some aquifer with relative uniform hydraulic properties, however, if the test well screened interval contains much layering and variation in texture (grain size) than screening the observation wells over the same interval of aquifer is recommended. Partial penetration can be effective in unconsolidated aquifers with a well-defined top and bottom but are generally ineffective in consolidated aquifers where the water-bearing zones are poorly defined or where the test well and observation may be completed in different water-bearing zones (heterogeneous aquifers). In sedimentary bedrock aquifers, observation wells should be constructed with their open interval corresponding to the same stratigraphic interval as the test well.

B.7. Variable Discharge Rate

One assumption often violated is that there is no variation of the pumping rate during the aquifer test. However, a constant pumping rate is very hard to achieve. For the purpose of these procedures if the pumpage does not vary by more than 10 percent during the test it can be considered to be at a constant rate.

To hold the pumping-rate variation to a minimum it is recommended that the pump work against a partially closed discharged valve. This valve can be progressively opened to maintain a constant discharge rate as the pump output falls off due to the extra lift required as the water level drops. A valve also permits varying the output to reduce the effects of mechanical or electrical variations.

If the pumping rate does vary significantly, a suitable methodology must be used to analyze the data. For a confined aquifer, where the saturated thickness does not change, the principle of superposition can be used to account for variation in pumpage rates. For more detail see Eden and Hazel (1973) and Jacob (1947).

The step test is a special case of the variable-discharge-rate aquifer test. This test is performed in order to analyze the efficiency of the well at different pumping rates. For more detail see Brereton (1979), Clark (1979), Labadie and Helweg (1975), Lennox (1966), Nahm (1980), Rorabaugh (1953), Sheahan (1971), and Sternberg (1968)

B.8. Delayed Yield

In an unconfined aquifer water is discharged from storage as the water level declines. This change in storage does not occur instantaneously, but is prolonged by the time required to drain openings above the saturated zone. Delayed yield is the transient process that releases water to the pumping well due to water table decline. Delayed yield should be considered and accounted for in all unconfined aquifer tests.

Delayed yield flattens out the time-drawdown curve and may suggest a steady-state condition. Ideally, once delayed yield is over, water levels should drop again signaling the cessation of drainage from the parts of the aquifer above the position of the water table during pumping conditions. Detecting the cessation of the delayed yield period may require extending the length of the tests, sometimes to many days. If lengthening the test is not practical, the delayed yield response should be evaluated by an alternative method in order to assess long-term drawdown.

B.9. Lateral Aquifer-Flow Boundaries

If an aquifer test is conducted near an aquifer boundary the water-level fluctuations may show an effect due to boundary effects. A no-flow boundary (one which contributes no groundwater flow) increases drawdown. These boundaries can show up as a sudden water-level decline in one or more observation wells or can appear as an ever-steepening time-drawdown curve on semi-log plots. If a no-flow boundary is suspected in the aquifer test data, an analysis should conducted to determine the location of the boundary and its hydrogeologic cause. In rock aquifer tests, care should be exercised not to confuse a no-flow boundary with time-drawdown behavior caused by dual-porosity response.

A constant head boundary (such as a perennial stream) may contribute significant recharge to the aquifer, lessening drawdown. Such a boundary is usually seen in the time-drawdown data by a sudden stabilization of water levels. Analysis should be conducted to determine the location of the constant-head boundary and its relation to nearby surface water bodies. Again care should be taken to determine that the stabilization of water levels is caused by a constant head boundary and not leakage from an underlying aquifer.

Boundaries such as these may be taken into account using image wells and the principle of superposition. It is unwise to ignore the impact of such boundaries as they can strongly impact estimates of aquifer properties and the impact of a proposed diversion. No-flow and constant head boundaries are covered in many basic groundwater-texts.

B.10. Anisotropic Aquifers

An aquifer whose hydraulic conductivity systematically varies with the direction of groundwater flow is said to be anisotropic. Vertical anisotropy, which typically arises from the layering of geologic deposits, is commonly quantified when conducting analyses involving partial penetration, and in leaky or unconfined aquifers. In rock aquifers horizontal anisotropy may be the most important factor governing groundwater flow. Horizontal anisotropy may be suspected on the basis of geologic evidence or from the magnitude and direction of drawdown obtained from an aquifer test. In some geologic settings it may be caused by a combination of bedrock structure and layering, where the greatest magnitude of groundwater flow and drawdown coincides more or less with bedrock strike. In other settings, the frequency and orientation of water-conducting fractures may be the determining factor for predicting the direction of maximum groundwater flow or drawdown impact.

Quantifying anisotropy is an important step in developing new water sources in rock aquifers, particularly if the new well may impact other users or cause the new well to draw in contaminants. At some sites, the geologic setting may provide conflicting indications for predicting the direction of maximum groundwater flow, hence the aquifer test must be designed to produce meaningful data in order to quantify horizontal anisotropy. A minimum of three observation wells are needed to quantify horizontal anisotropy (see Table B3). In addition, the open interval for the three observation wells should be the same as the stratigraphic interval open to the test well as shown in Figure 6. The open-interval design of the observation wells must take into account bedrock structure. Ideally, the observation wells should be located about 1.5 times the aquifer thickness from the pumping well, but this may be difficult at sites with steeply dipping beds.

The layout of the three observation well array also has an additional specification in that the bearing from the test well to each observation well must be different. For example on Figure 6, Well D is along bedrock strike, Well E is orthogonal to strike, and Well C is along a 45 degree angle with the strike direction. If geologic evidence suggests a direction for the highest rate for groundwater flow, then that should be used in the planning of the observation well location. For example if a compilation of fracture data indicates a dominant trend of N25E, then observation wells located along each bearing N25ºE , N70ºE, and S65ºE would provide a suitable array. Lastly for anisotropy analysis using the three well minimum, the bearing one proposed monitoring locations should not be 180 degrees from that of either of the other two observation wells; in other words, a well along N25ºE and another along S25ºW would not be acceptable. Grimestad (1995) is a good reference for horizontal anisotropy analysis.

B.11. Multiple-pumping-well Tests

In a confined aquifer the principle of superposition can be used to analyze the effect of several wells pumping simultaneously. Theoretically, the total drawdown is the simple sum of the drawdown caused by each individual pumping well. Superposition can be used to predict the combined impact of several wells pumping in the same aquifer providing that a previous single-well aquifer test as been conducted at that site. If the wellfield is located in a particularly poor or complicated aquifer where different pumping wells mutually interfere with one another, it may not be possible to predict the dependable yield of the wellfield or the sum of the impacts at a given well. Under such conditions a multiple well pumping test is usually recommended.

The strength of a multiple-pumping-well test is that it measures actual drawdown under anticipated everyday operating conditions. The usual goal of a multiple-pumping-well test is not necessarily to estimate aquifer properties but to estimate drawdowns during real-world conditions. Thus, analysis of these tests is often a matter of plotting drawdowns and analyzing actual effects, rather than engaging in a formal mathematical treatment.

B.12. Fractured-Rock aquifers

In many bedrock aquifers, the unfractured rock can be largely impermeable. Instead, fractures and other structural features in the in the rock provide the major conduits for movement of fluids.

Most analytic techniques used to analyze drawdown in a fractured-rock aquifer focus on a dominant characteristic or feature zone, with boundaries or other aquifer properties idealized and assigned constant values. Some approaches conceptualize fractures as important for movement of groundwater, but relatively insignificant as reservoirs of groundwater storage. These methods assume the bulk of groundwater storage comes from the aquifer matrix. Other approaches consider groundwater storage in both the fractures and in the aquifer matrix.

Table B3 highlights methodologies that address specific features of fractured-rock aquifers, such as anisotropy, effect of storage release, and contrasts in transmissivities of the bulk aquifer matrix and fractures. Originally developed for analysis or granular aquifer, these methodologies have partial application in fractured-rock settings where the tests conditions do not seriously compromise the boundary conditions specific in the conventional analysis of transmissivity and storativity.

Other methodologies listed in table B3 are analytical techniques directed at phenomena customarily observed in fractured-rock aquifer. The double-porosity models address the relative roles of fractures and the aquifer matrix (or "block") as sources of groundwater storage. The release of water from these sources results in a time-drawdown response which appears similar to the delayed-yield response of an unconfined aquifer. The single-fracture models focus on interaction of the aquifer matrix and a fracture penetrated by a production well. For wells located on a fracture or fracture system, the early time-drawdown data often exhibit a diagnostic half-slope (0.5) on a log-log plot.

Sauveplane (1984) and Houlden (1984) provide an overviews of these analytic methods and examples of their application.

In some cases fractured rock aquifers may be analyzed as unconfined aquifer because they exhibit similar time/drawdown characteristics. During the early part of a test the fractures contributes water to the well. During the midsection part, pores and smaller fractures are dewatered, leading to the appearance of delayed yield. During the later part of the test water comes to the well from fractures farther away.

Much work has is available on the analysis of fractured-rock aquifer tests. As examples, see Boulton and Streltsova (1977, 1978), Gringarten (1982), Gringarten and Witherspoon (1972), Hantush (1966), Houlden (1984), Jenkins and Prentice (1982), Neuman and others (1984), Papadopoulos (1965), Sauveplane (1984), and Way and McKee (1982).

B.13. Solution-Channeled Limestone and Dolomite Aquifers

Fractured, solution-channeled limestone and dolomite rocks pose specific hydrogeologic conditions. Weathered carbonate rocks normally contain cavernous zones developed as a result of chemical dissolution along joints, bedding planes, and other planar surfaces.

Solution mechanisms in carbonate rocks favor the development of larger openings at the expense of smaller ones. Thus, some of the analytical methods that focus on long, well developed fractures may be particularly applicable to solution-channeled aquifers. The block-and-fissure model used to describe fractures rock aquifers may be particularly useful in carbonate aquifers where solution-channel development is significant.

Carbonate rocks can be highly anisotropic and nonhomogeneous on a localized scale, but may behave more homogeneously on a regional scale. In many cases solution-channeled aquifers behave like fractured-rock aquifers and can be analyzed as such. In general, methods that recognize water table and/or leaky artesian conditions may be extremely useful in analyzing aquifer tests in fractured and solution-channeled carbonate-rock aquifers.

B.14. Analytical Technique Selection

Tables B1, B2 and B3 present numerous analysis techniques. In practice, a much smaller number of tests have proven to apply to almost all aquifer tests reviewed by the NJ Geological Survey. Occasionally these methods have been applied using image wells (to simulate aquifer boundaries or variations in pumping rates), by large-well-bore modifications (to account for well-bore storage), multiple pumping wells, or by partial-penetrating well modifications.

The NJ Geological Survey maintains a data base with information on aquifer tests reviewed in house. Table B4 shows the reported test methodology for the 272 entries in this data base in March 2009. Over half of the tests (140) were analyzed using the Hantush methodology for transient data in a semiconfined aquifer with no storage in the aquitard.

Before the widespread adoption of personal computers, hydrogeologists would plot data by hand on graph paper and then, using a light table, try to match the data to a variety of type curves (for example, Reed, 1980). Today's hydrogeologists tend to have one or more software programs that can automatically match the data to a small selection of digital type curves.

Real-world aquifer tests seldom match the all the conditions imposed by analytic models and methods analyses used to create the type curves. However, most aquifer tests produce responses that are close enough so that analysis techniques produce acceptably accurate estimates of aquifer parameters and thus impacts on other users and the environment.

Table B1. Types of aquifer-test analyses for 'uncomplicated' situations

All entries modified from Kruseman and DeRidder, 1979, who describe and reference all of the methodologies.

Assumption: Aquifer is homogenous, isotropic, areally infinite, and of uniform thickness. Pumping and observation wells fully penetrate and screen the aquifer. Prior to pumping the piezometric surface is horizontal. Discharge rate is constant and storage in the well can be neglected. Water removed from storage is discharged instantaneously with decline of head.

<table>
<tr><th rowspan="2">AQUIFER TYPE</th><th colspan="3">SOLUTION</th></tr>
<tr><th>Type</th><th>Name</th><th>Method</th></tr>
<tr><td rowspan="5">confined</td><td>steady-state</td><td>Theim</td><td>calculation</td></tr>
<tr><td rowspan="4">unsteady-state</td><td>Theis</td><td>curve fitting</td></tr>
<tr><td>Chow</td><td>nomogram</td></tr>
<tr><td>Jacob</td><td>straight line</td></tr>
<tr><td>Theis recovery</td><td>straight line</td></tr>
<tr><td rowspan="7">semiconfined</td><td rowspan="3">steady-state</td><td>DeGlee</td><td>curving fitting</td></tr>
<tr><td>Hantush-Jacob</td><td>straight line</td></tr>
<tr><td>Ernst modification of Theim method</td><td>calculation</td></tr>
<tr><td rowspan="4">unsteady-state</td><td>Walton</td><td>curve fitting</td></tr>
<tr><td>Hantush I</td><td>inflection point</td></tr>
<tr><td>Hantush II</td><td>infection point</td></tr>
<tr><td>Hantush III</td><td>curve fitting</td></tr>
<tr><td>unconfined with delayed yield</td><td>unsteady-state</td><td>Bulton</td><td>curve fitting</td></tr>
<tr><td>semiconfined with delayed yield</td><td>unsteady-state</td><td>Bulton</td><td>curve fitting</td></tr>
<tr><td rowspan="5">unconfined</td><td>steady-state</td><td>Theim-Dupuit</td><td>calculation</td></tr>
<tr><td rowspan="4">unsteady-state</td><td>Theim*</td><td>calculation</td></tr>
<tr><td>Theis*</td><td>calculation</td></tr>
<tr><td>Chow*</td><td>calculation</td></tr>
<tr><td>Jacob*</td><td>calculation</td></tr>
</table>

*Solutions for the confined, unsteady-state case can be applied to the unconfined, unsteady-state case only if the drawdown is modified by an appropriate factor. See Kruseman and DeRidder, 1979, for more detail.

Table B2. Types of aquifer-test analyses for 'complicated' situations

All entries modified from Kruseman and De Ridder, 1979, who describe and reference all of the methodologies.

Assumptions: Aquifer is homogeneous, isotropic, areally infinite, and of uniform thickness. Pumping and observation wells fully penetrate and screen the aquifer. Prior to pumping the piezometric surface is horizontal. Discharge rate is constant and storage in the well can be neglected. Water removed from storage is discharged instantaneously with decline of head

MODIFIED ASSUMPTION	AQUIFER TYPE	SOLUTION		
		Type	Name	Method
aquifer crossed by one or more fully penetrating recharge boundaries.	confined or unconfined	steady-state	Dietz	calculation
		unsteady-state	Stallam	curve fitting
			Hantush	straight line image
aquifer homogeneous, anisotropic and of uniform thickness	confined or unconfined	unsteady-state	Hantush	calculation
			Hantush-Thompson	calculation
	semiconfined	unsteady state	Hantush	calculation
Aquifer homogeneous and isotopic but thickness varies exponentially	confined	unsteady-state	Hantush	curve fitting
prior to pumping the potentiometric surface slopes	unconfined	steady-state	culmination	calculation point
		unsteady-state	Hantush	curve fitting
discharge rate variable	confined or unconfined	steady-state	Cooper-Jacob	straight-line
			Aaron-Scott	straight-line
			Sternberg	straight-line
			Sternberg recovery	straight-line
partially penetrating pumping well	confined	steady state	Huisman correction I and II	calculation
			Jacob correction	calculation
	semiconfined	steady-state	Huisman correction I and II	calculation
	unconfined	steady-state	Hantush correction	calculation
	confined	unsteady state	Hantush modification of Theis	curve fitting
			Hantush modification of Jacob	straight line
two-layered aquifer with semipervious dividing layer	semiconfined	steady state	Huisman-Kemperman	nomograph and curve fitting
			Bruggeman	straight line

Table B3. Analytic solutions for tests in fractured rock and karst settings.

Conventional methods addressing anisotropy:
The following methodologies were developed to determine anisotropy in a horizontal aquifer. For application in fractured rock aquifers, it is assumed that aquifer's behavior approximates that of a porous medium. Standard methodologies and their applicable assumptions are used to obtain values of transmissivity and storage, from which anisotropy is calculation.

Aquifer type(s)	Phenomenon Modeled	Method of Solution	Reference	Minimum number of wells for calculations
confined, homogeneous	2-D anisotropy	curve fitting or straight line with calculation	Papadopoulos (1964)	three
leaky and nonleaky, homogeneous	2-D anisotropy	curve fitting or straight line with calculation	Hantush (1966), Neuman and others (1984), Grimestad (1995)	three
homogeneous and heterogeneous, horizontal and vertical anisotropy, partial penetration	3-D anisotropy	curve fitting and with calculation	Way and McKee (1982)	four

Special methods addressing phenomena of fractured rock and karst aquifers:
The double porosity models focus upon the release of groundwater storage from the fracture system and the aquifer matrix; transmissivity is assumed constant and the bulk of groundwater storage is in the aquifer matrix. The single-fracture is models focus upon the interaction of the aquifer matrix and a fracture penetrated by a production well; the fracture functions as a highly transmissive extension of the well but, ideally, does not contain storage; all storage is derived from the aquifer matrix.

Aquifer type(s)	Phenomenon Modeled	Method of Solution	Reference	Remarks
confined, homogeneous, isotropic	double porosity block and fissure storage	curve fitting	Boulton and Streltsova (1977)	fractured rock or karst aquifers
unconfined, homogeneous, isotropic	double porosity block and fissure storage	curve fitting	Boulton and-Streltsova (1978)	fractured rock or karst aquifers
confined, matrix is homogenous and isotropic; fracture and aquifer system strongly anisotropic	pumping well penetrates vertical or horizontal fracture	curve fitting	Gringarten and Witherspoon (1972); Gringarten (1982)	analysis for pumping well data only
confined, matrix is homogenous and isotopic; fracture and aquifer system strongly anisotropic	pumping well penetrates vertical fracture	straight line	Jenkins and Prentice (1982)	analysis for hydraulic diffusivity; estimate of storativity from other methods needed to solve for transmissivity.

Table B4. Number of analyses, by analysis methodology, in NJGWS data base, March 2009

Methodology	#
Unconfined aquifer methodologies	
Neuman (unconfined)	38
Boulton & Gambolati (unconfined, transient)	12
Gambolati (unconfined, transient, late-time (B curve) analysis)	1
Confined aquifer methodologies	
Theim (confined, steady-state)	1
Theis (confined, transient)	43
Chow (confined, transient)	1
Jacob (confined, transient)	3
Theis recovery (confined transient)	1
Papadopulos-Cooper (confined, large-diameter, pumped well)	8
Semiconfined aquifer methodologies	
Hantush Jacob (semiconfined, transient)	140
Hantush I (semiconfined, transient)	1
Hantush (semiconfined, transient, storage in aquitard)	2
Fractured bedrock aquifer methodologies	
Gringarten & Witherspoon (confined, homogenous, isotropic)	1
Barker Generalized Slab Fracture-Fissure (double-porosity model)	5
Boulton & Streltsova (confined, homogenous, isotropic)	15
SUM:	272

Appendix C. Checklist for aquifer-test proposal submission

This checklist will be reviewed during the pre-application meeting. The applicant must also supply the completed checklist with the aquifer-test proposal. Check the box to indicate that each item has been addressed. Add the page, table or figure number to show where in report the item appears.

Submitting all required information is <u>not</u> a guarantee that the proposal will be approved For example, if the proposal doesn't include sufficient monitoring locations or frequency the proposal may be rejected.

<u>Appears in Text</u>

- Summary of current allocation, if applicable (p. ___)
  - Proposed diversion (mgy, mgm, gpm) (p. ___)
  - Proposed diversion from each specific source/aquifer, if relevant (p. ___)
- Geologic & hydrogeologic setting
  - General description (p. ___)
  - Identify geologic units/aquifers(p. ___)
  - Discuss aquifer setting (confined, leaky, water table) (p. ___)
  - Evaluate potential sources of water (leakage, outcrop areas, surface water, storage) (p. ___)
  - Identify geologic features and boundaries that will govern groundwater availability and flow (p. ___)
  - Evaluate potential of aquifer for isotropy/anisotropy and how this may affect tests (p. ___)
  - Summary of currently-available aquifer parameters (p. ___)
- Identify areas of environmental concern, as appropriate
  - Wetlands (p. ___)
  - Streams (p. ___)
  - Ponds (p. ___)
  - Threatened and endangered species (p. ___)
  - Nearby pollution sites (p. ___)
  - Other (p. ___)
- Identify other users, as appropriate
  - Nearby groundwater users with allocation permits (p. ___)
  - Nearby groundwater users without allocation permits (private wells) (p. ___)
  - Downstream surface-water users (p. ___)
  - Downstream passing flows (p. ___)
  - Downstream discharges (p. ___)
  - Other (p. ___)
- Description of proposed aquifer test(s)

  - Duration of all periods (p. ___)
  - Pumping rate (p. ___)
- Discussion of all monitoring points, as appropriate
  - Groundwater (distances & depths) (p. ___)
  - Surface water (p. ___)
  - Streamflow (p. ___)
  - Temperature (p. ___)
  - Tide (p. ___)
  - Precipitation (p. ___)
  - Barometric pressure (p. ___)
  - Other (p. ___)
- Other pumpage in area (rates, distances) (p. ___)
- Discussion of other regulatory concerns, as appropriate
  - Critical areas (p. ___)
  - Pinelands/Highlands/DRBC (p. ___)
  - Areas of special water resource concerns (p. ___)
  - Other (p. ___)
- Discussion of any water-quality limitations (p. ___)
- Discussion of discharge location with monitoring frequencies

<u>Tables</u>

- Current wells with construction and permit information (table ___)
- Proposed wells with screened/open intervals (table ___)
- Summary of current allocation, if applicable (table ___)
- Monitoring schedules at all monitoring locations (table ___)
- Nearby water users with allocation permits (table ___)
- Nearby public and private wells, with construction features and estimated draw-down (table ___)

<u>Regional Maps</u> (all at 1:24,000 or more detailed)

- Proposed well locations (fig. ___)
- Existing well locations (fig. ___)
- Location of proposed well discharge (fig. ___)
- Surficial geology (fig. ___)
- Bedrock geology (fig. ___)
- Surface-water bodies (fig. ___)
- Nearby areas of environmental concern (fig. ___)
- Other relevant features (fig. ___)

<u>Detailed Site Maps</u> (at appropriate scale)

- Pumping well location (fig. ___)
- Proposed well locations (fig. ___)

- Existing well locations (fig. ___)
- Location of proposed well discharge (fig. ___)
- All monitoring locations (fig. ___)
- Surface-water bodies and streams (fig. ___)
- Nearby areas of environmental concern (fig. ___)
- Building locations (fig. ___)
- Other relevant features (fig. ___)

Appendix D. Checklist for aquifer test analysis submission

Applicant must supply this checklist with all aquifer test reports. Check the box to indicate that each item has been addressed. Add the page, table or figure number to show where in report the item appears.

Submitting all required information is not a guarantee that the requested allocation will be approved. For example, if the monitoring wells were incorrectly installed or monitored the test may not have produced sufficient information for an adequate estimate of the impact. If the data and analysis do not support an adequate evaluation of the proposed diversion's impact on other users and the environment then another test may be required.

Discussion of Current and Proposed Allocation

- Summary of current allocation, if applicable (p. ___)
- Proposed diversion, overall and new source (mgy, mgm, gpm) (p. ___)
- Pump capacity and actual pumpage rate at all new sources (p. ___)

Location of Proposed Diversion

- County and municipality (p. ___)
- Street address, lot and block (p. ___)
- HUC14, WMA (p. ___)
- Location (X and Y) in State Plane Coordinates (NAD83, US Feet)

Site Geology and Hydrogeology

- Geologic setting (p. ___)
- Description of aquifer and confining units (p. ___)
- Available hydrogeologic data (p. ___)
- How geologic structures affect groundwater flow (p. ___)
- Identify recharge/source area for proposed groundwater diversion (p. ___)
- Identify discharge area for groundwater intercepted by proposed diversion (p. __)

Test Details

- Pumping well details (p. ___)
- Observation well details (p. ___)
- Details of all monitoring points (p. ___)
- Sampling frequency (p. ___)
- Copy of test waiver (if appropriate) (p. ___)

Discussion of Observations

- Observed drawdowns (p. ___)
- Comparison of manual to ADR water levels with discussion of any discrepancies (p. ___)
- Observed impacts at other monitoring points (p. ___)
- Details of all monitoring points (p. ___)
- Sampling frequency (p. ___)
- Details on raw data processing (See text for details.) (p. ___)

Aquifer Test Data Analysis

- Selected analysis method (p. ___)
- Narrative of aquifer test method and its appropriateness to aquifer (p. ___)
- Estimated aquifer parameters by hydrogeologic unit (p. ___)

Estimated Impacts of Allocation on other Users

- Nearby allocations (p. ___)
- Nearby domestic wells (p. ___)
- Zone of influence calculations (p. ___)
- Estimated dependable yield (p. ___)
- Downstream surface-water users (p. ___)
- Downstream passing flows (p. ___)
- Nearby contamination sites (p. ___)
- Other (p. ___)

Impact on areas of environmental concern, as appropriate

- Wetlands (p. ___)
- Streams (p. ___)
- Ponds (p. ___
- Threatened and endangered species (p. ___)
- Other (p. ___)

Groundwater Quality Concerns

- Nearby pollution sites (p. ___)
- Saltwater intrusion (p. ___)
- Other (p. ___)

Discussion of other regulatory concerns

- Critical areas (p. ___)
- Pinelands/Highlands/DRBC (p. ___)
- Areas of special water-resource concerns (p. ___)
- Other (p. ___)

Tables

- Summary of current allocation, if applicable (table ___)
- Monitoring schedules at all monitoring locations (table ___)
- Details of pumping well(s) (table ___)
    - Pump capacity and depth
    - Aquifer
- Details of nearby water users with allocation permits, with distance to pumped well (table ___)
- Details of nearby private wells with distance to pumping well (table ___)
- List of all digital files and description of what each contains (table ___)

Table of observation and production well construction information (table ___)

- Current permit number
- Previous permit number (if applicable)
- Name of well used in accompanying report
- Municipality & county
- Location (X and Y) in State Plane Coordinates (NAD83, US Feet) (survey or GPS)
- measuring point elevation (NAVD 1988) (survey or GPS)
- Date drilled
- Well depth/finished depth
- Screened/open interval
- Distance each observation well is from the pumping well
- Azimuth, measured clockwise from due north, of a line running from pumping well to observation well
- Other pertinent construction and location information

Table of other monitoring locations (table ___)

- Name of monitoring location used in accompanying report
- Municipality & county
- Location (X and Y) in State Plane Coordinates (NAD83, US Feet) (survey or GPS)
- Measuring point elevation (NAVD 1988) (survey or GPS)
- Distance of monitoring location from the pumping well
- Azimuth, measured clockwise from due north, of a line running from pumping well to monitoring location
- Other pertinent construction and location information

Figures

- Observed groundwater water levels (fig. ___)
- Observed drawdown (fig. ___)
- Comparison of manual to ADR water levels (fig. ___)
- All other monitoring data (fig. ___)
- Pumpage vs time (fig. ___)
- Drawdown analysis for aquifer parameters (fig. ___)
- Observed precipitation
- Surface-water levels vs. time

Regional Maps (all at 1:24,000 or more detailed)

- Proposed well locations including monitoring locations (fig. ___)
- Location of proposed well discharge (fig. ___)
- Nearby pumping wells with any well head protection areas (fig. ___)
- Surficial geology (fig. ___)
- Bedrock geology with faults and folds (fig. ___)
- Geologic cross section showing all relevant units (fig. ___)
- Nearby areas of environmental concern (fig. ___)

Detailed Site Maps (at smaller scale than 1:24,000)

- Pumping well location (fig. ___)
- Location of well discharge (fig. ___)
- All monitoring locations (fig. ___)
- Nearby areas of environmental concern (fig. ___)
- Nearby pumping wells with any well head protection areas (fig. ___)
- Groundwater potentiometric map during background period (fig. ___)
- Groundwater potentiometric map at end of pumping period (fig. ___)
- Notable buildings
- Topography

Digital Data (on CD readable by a Windows-based PC, see text for details)

- Raw data files for all observation points (from data loggers)
- Summary worksheets with all groundwater levels (See text for reporting details.)
    - Time-drawdown data converted to consistent units for all data.
    - All water levels converted to feet above NDVD 88
    - Clear identification of data from background, pumping and recovery periods.
- Worksheets with precipitation, barometric pressure, streamflow, surface water levels, temperature and other measurements. (See text for reporting details.)
- Table of well construction information
- Table of other monitoring locations
- Other data sets more appropriate for digital copy than paper

Appendices

- All well records and permits
- Geophysical logs
- Radius well search
- Water-quality data

Appendix E. Contact Information

New Jersey Department of Environmental Protection

Office	Phone Number*	Web site*
Division of Water Supply & Geoscience		
Bureau of Water Allocation and Well Permits	(609) 292-1702 v (609) 633-1231 f	http://www.nj.gov/dep/watersupply/
Bureau of Water System Engineering	(609) 292-2957 v	http://www.nj.gov/dep/watersupply/
Bureau of Safe Drinking Water	(609) 292-5550 v	http://www.nj.gov/dep/watersupply/
New Jersey Geological and Water Survey	(609) 292-1185 v (609) 633-1004 f	http://www.njgeology.org/
Land Use Regulation	(609) 984-3444v	http://www.nj.gov/dep/landuse
NJPDES	(609) 292-9977v	http://www.nj.gov/dep/dwq/
Non-Point Pollution Control	(609) 633-7021v	http://www.nj.gov/dep/dwq/bnpc_home.htm
Bureau of Endangered and Nongame Species	(609)292-9400 v	http://www.nj.gov/dep/fgw/ensphome.htm
Freshwater Wetlands	(609) 777-0454 v	http://www.nj.gov/dep/landuse/fww.html

* Correct as of June 2012

Other Government Agencies

Agency	Phone Number*	Web site*
Delaware River Basin Commission	(609) 883- 9500 v (609) 883-9522 f	http://www.nj.gov/drbc/
Highlands Council	(908) 879-6737 v (908) 879 4205 f	http://www.highlands.state.nj.us/
Pinelands Commission	(609) 894-7300 v (609) 894-7330 f	http://www.state.nj.us/pinelands/
U.S. Geological Survey, N.J Water Science Center	(609) 771-3900 v (609) 771-3915 f	http://nj.usgs.gov/

* Correct as of June 2012

Appendix F. Acronyms and Abbreviations

Acronym/Abbreviation	Full Name
ADR	automatic data recorder
ASCII	American Standard Code for Information Interchange
ASR	Aquifer storage and recovery
BSDW	Bureau of Safe Drinking Water
BWAWP	Bureau of Water Allocation and Well Permits
CEA	Classification exception area
CKE	Currently known extent
DRBC	Delaware River Basin Commission
DWSG	Division of Water Supply and Geosciences
ft	foot
gal	gallons
gpd	gallons per day
KCSL	known contaminated sites list
mgal	million of gallons
mgm	million gallons per month
mgy	million gallons per year
msl	mean sea level
NAD 1983	North American Datum of 1983
NAVD 1988	North American Vertical Datum of 1988
N.J.A.C.	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJGWS	New Jersey Geological and Water Survey
NJGWQS	New Jersey Ground Water Quality Standards
NJWSA	New Jersey Water Supply Authority
ZOI	zone of influence
USGS	U.S. Geological Survey

Appendix G. Surveying and GPS Standards

I. Justification

NJDEP requires that applicants provide information to determine if a proposed groundwater diversion will interfere with other water users, promote saline intrusion into aquifers, spread groundwater contamination, or interfere with groundwater remediation activities. This requires expressing all relevant water-level data in terms of total hydraulic head. The calculation of hydraulic heads and gradients requires that the location and elevation of all sites of interest share common horizontal and vertical datums. Precise location and elevation referencing of hydrologic measurements has long been standard practice for data published by the U.S. Geological Survey and is required by the Department's Site Remediation Program for monitoring wells.

II. Requirements

All wells, piezometers, staff gages, and stream discharge measurement sites used to gather hydrologic data for water allocation aquifer tests or required for long-term monitoring as a condition of a permit must be located horizontally and vertically according the following standards:

II. A. Horizontal location

1. All well location coordinates must be mapped within 10 feet of the actual location. The mapping method used must have horizontal accuracy of at least five meters.

2. Horizontal data points must be submitted in New Jersey State Plane coordinates using the North American Datum of 1983 (NAD 1983), in accordance with the Department's Mapping and Digital Data Standards at N.J.A.C. 7:1D Appendix A, using units of United States survey feet.

3. Location information collected in latitude and longitude must be converted to New Jersey State Plane coordinates.

4. Well locational information must be reported using one of the following methods
    a. Global Positioning System (GPS). GPS data must be obtained in accordance with Department standards set forth at N.J.A.C. 7:1D Appendix A. More information on GPS is available on the Department's Bureau of Geographic Information Systems' web site at http://www.nj.gov/dep/gis/. The GPS coordinates must be collected as close as possible to the as-built well location. GPS receivers used for GIS data collection must be either mapping grade or resource grade receivers that meet the standards in N.J.A.C. 7:1D Appendix A; or

b. Survey. All surveyed coordinate locations for an as-built well must be established by a Professional Land Surveyor.

II. B. Elevation

1. The elevation of all monitoring points must be surveyed by or under the direction of a Professional Land Surveyor

2. Elevation measuring points must be referenced to mean sea level using the North American Vertical Datum of 1988 (NAVD 1988).

3. The measuring point elevation established on a well casing or a staff gage must be surveyed to the nearest hundredth (0.01) foot. Elevations are to be determined by double run, three wire leveling methods using balanced sites, commencing from a well-marked and described point. This beginning point must either be derived from Federal or State benchmarks if not more than 1,000 feet from the site or from an alternate datum approved by the Department. Tolerances should meet third order standards, which are 0.05 feet x $(\text{mile})^{1/2}$. For sections less than 0.1 mile, the standard must be 0.02 feet.

4. A permanent water level measurement mark must be etched or scribed onto the top of the inner well casing or top of staff gage to allow for accurate, consistent and comparable water level measurements over time.