MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

WATER USE PROGRAM

AQUIFER PERFORMANCE TEST GUIDANCE

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ACRONYMS

APT Aquifer Performance Test

ARI Adverse Resource Impact

ASTM ASTM International (formerly American Society for Testing and Materials)

BE Barometric Efficiency

CSM Conceptual Site Model

EGLE Michigan Department of Environment, Great Lakes, and Energy

LQW Large Quantity Withdrawal

MCL Michigan Compiled Law

NAVD North American Vertical Datum

PFAS Per/Poly-fluoroalkyl Substances

ROI Radius of Influence

RP Reference Point

SSR Site-Specific Review

TOC Top of Casing

WMA Water Management Area

WRD Water Resources Division

WUAU Water Use Assessment Unit

WWAP Water Withdrawal Assessment Program

WWAT Water Withdrawal Assessment Tool

INTRODUCTION

An Aquifer Performance Test (APT), also known as an aquifer pumping test, is a short-term (usually 24-72 hours) test where the groundwater elevations in a single or multiple observation wells are monitored to measure how the aquifer(s) respond to the stress of pumping a high capacity well referred to in the Water Use Program as an LQW. Changes in water level data from the APT are used to determine aquifer properties like transmissivity and storage coefficients that are used by EGLE to assess potential environmental impacts of LQWs using tools like the WWAT, SSRs, or the alternative analysis under MCL 324.32706c, or in support of a permit application under MCL 324.32723. The purpose of this document is to provide guidance on APT methodology approved by EGLE WRD WUAU to evaluate the hydrogeologic situation of a proposed groundwater LQW. The APT is one tool in determining the potential for the proposed LQW to cause an ARI. Responsibility for APT thoroughness, accuracy of the data, and appropriateness of the analyses techniques lies with the applicant and the applicant's consultant.

Discussing the APT ahead of time may increase the likelihood the APT will produce useful results. Applicants and/or consultants may submit an aquifer pumping test work plan to the WUAU prior to conducting a test if local hydrogeology warrants deviation from this guidance. Should you wish to discuss the APT ahead of time, please contact WUAU staff, information can be found at Michigan.gov/WaterUse.

PART A. APT PREPARATION

APT design is based on site-specific geological and hydrogeological conditions onsite. Documentation showing completed baseline data collection steps outlined in Part A should be summarized into a report and provided to the WUAU for review as a part of the SSR, MCL 324.32706c alternative analysis, or permit application processes. Additional information regarding documentation required is provided in Part D. Important data to compile prior to the APT include:

1. **Geologic Setting -** Available geologic data should be reviewed before designing the aquifer test. Two-dimensional geologic or hydrostratigraphic cross-sections or alternate CSM should be completed to gain an understanding of the hydrologic framework including the thickness, extent, and characteristics of the aquifers and aquitards in the test area. Geologic datasets may be found through the Wellogic well database. The location of anticipated geologic boundary conditions should be identified and documented. This knowledge should be used in conjunction with well logs from the pumping and observation wells at the site to select proper test design. The location and screened intervals of the pumped well and observation wells or piezometers should be included in the CSM and submitted alongside test data and analysis, see Part D for additional details.

2. **Time of Year/Weather -** The APT of unconfined aquifer wells should be conducted during a time of average or below average seasonal stream flow conditions; that is, when baseline groundwater gradients have not been significantly altered by events such as spring runoff or heavy rainfall. This typically eliminates the months of March, April, and May. APTs for confined aquifers or bedrock wells may be conducted during any month of the year. Rainfall that occurs during the test must be measured to the nearest 0.01 inch and recorded daily or hourly during collection of background groundwater data, during the APT, and during the recovery period. Excessive rainfall may require extension or rescheduling of the test.

3. **Determine the Groundwater Gradient and Flow Direction -** Groundwater elevations should be used to estimate groundwater gradient (horizontal or vertical, as needed). This information can be used to confirm proper water disposal methodology or identify sensitive hydrologic features. Topography should not be the only source of information used to identify groundwater flow direction(s). Surface water elevation(s) can be included as potentiometric surface elevation data if the surface water in question is determined to be hydraulically connected to the applicable aquifer.

4. **Establish the Barometric Pressure Trend -** APT performed in confined aquifers will require collection of water level and barometric data prior to and during the test to calculate BE to assist in drawdown interpretation. Measurements should be collected and recorded on an hourly basis (at a minimum) for 24 hours. If the APT is performed in an unconfined or leaky aquifer setting, BE measurements should be collected for 48-hours. Weather station data available from within a reasonable distance of the test site can be utilized (preferably within the same WMA or watershed).

5. **Identification of Additional Nearby Pumping Wells -** Other pumping wells which could affect water levels in observation well(s) should be identified and located on a scaled site map. If possible, pumping should not be performed near the APT site for at least 24 hours prior to the APT. If there are nearby wells that could affect drawdown during the APT, note these and discuss in report what effect, if any, they might have on the APT data. Information to discuss can include the pumping schedule, pump capacity, and pumping duration prior to, during, and after the APT.

6. **Evaluation of External Environmental Concerns -** Identification of potential offsite environmental issues is recommended as a best practice to prevent the exacerbation of offsite environmental contamination. Contact the local health department and check EGLE's online Environmental Mapper, and the Michigan PFAS Action Response Team PFAS Geographic Information System (arcgis.com). If groundwater contamination sites are identified near the APT's ROI, then contact the appropriate EGLE district office for further information about the nature and extent of the groundwater contamination.

PART B. TEST DESIGN AND OPERATIONAL GUIDANCE

Multiple references provide guidance on test selection and design beyond this guidance document, including ASTM Standard 4043, Kruseman and de Ridder, and others. A complete set of references has been provided in Appendix A documenting available resources for test selection and research on APT theory and methodology. Any well installed in service of the APT should be installed in accordance with applicable rules described in R 325.1601, et seq., Groundwater Quality Control Rules, adopted under Part 127, Water Supply and Sewer Systems, of the Public Health Code, 1978 PA 368, as amended. Coordinates for each APT well are to be obtained using a global positioning system and reported as latitude and longitude in decimal degrees to five decimal places. Lateral distances between the pumping well and observation well(s) must be measured to the nearest 0.1 ft. Vertical elevation of a fixed reference point for each observation point must be established to the nearest 0.01 ft and reported. To ensure that a complete, meaningful set of drawdown data can be obtained once an aquifer test begins, it is important to also consider the following:

1. **Pumping Well -** An existing or new well may be identified as the APT pumping well. If a new well is constructed, an appropriate filler pack, screen, and annular seal should be used. Well connectivity with the aquifer should be confirmed prior to testing. Wells which are not screened over the full length of the aquifer will require a partial penetration data correction. A description of the well construction and lithology encountered should be documented in a well log and provided.

2. **Observation Wells and Piezometers -** Observation wells and piezometers should be constructed with an appropriate filter pack, screen, and annular seal. All wells or piezometers should be properly developed to ensure proper aquifer connection preceding the test. Existing wells or drop pipes installed in the pumped aquifer may be used as observation points; however, steps should be taken to prevent pumping of observation points during the test. A well log documenting screened interval and well construction details should be provided for all observation wells or piezometers used in the test. Highly variable geologic deposits identified in the CSM may require additional observation wells or piezometers.

   Single well pumping tests, in which no observation wells or piezometers are present, may be used in very limited situations (Pechstein, Armin; 2016, Kruseman and de Ridder 1970, Osborne 1993). A single well pumping test checklist is provided as Appendix B.

   Observation well configuration coincides regularly with aquifer configuration and is outlined below. Note that MCL 324.32706c (12)(a)(i) requires that an APT in service of an alternate analysis include at least one (1) monitor well in addition to the pumping well, screened in the same aquifer and roughly at the same depth interval as the pumping well.

   a. Unconfined aquifer APT have the pumped well screened within the same aquifer as surficial waterbodies, without significant continuous hydraulic barriers between the pumped interval and the overlying streams (see Figure 1). A recommended minimum of two (2) observation wells or piezometers should be used for the aquifer performance test, placed at approximately 30-50 feet and 300 feet from, and preferably oriented at a right angle to the pumping well. Lateral distances and angles may be adjusted as appropriate for area geology and hydrography.

b. Confined aquifer APT are characterized by a pumped well hydraulically separated to some degree from the overlying surficial waterbodies (see Figure 2). A minimum of one (1) observation well or piezometer should be screened within the pumped aquifer. Additional observation wells should be considered for geologic settings with a higher degree of heterogeneity or to obtain estimates of additional aquitard parameters required by the Hunt 2003 depletion model.

c. Leaky-confined aquifers will have a pumped interval partially separated from an overlying aquifer in which surficial water bodies are present, or where confining materials cannot be documented as being present between surficial water bodies and the pumped aquifer in the expected zone of influence of the pumping well (see Figure 3). If the applicable stream depletion model (or models) requires parameters for multiple aquifers, a minimum of two (2) observation wells or piezometers should be screened as a vertically nested pair within the pumped and surficial aquifers, with additional wells being required for geologic settings with a higher degree of heterogeneity or to obtain estimates of additional aquitard parameters required by the Ward and Lough 2011 depletion model.

Observation well placement may be affected by issues like aquifer boundaries, irregular aquifer geometry, and/or partial well penetration. Additional information regarding aquifer configuration and solution options is provided in Part C, Aquifer Performance Test Data Analysis.

3. **Reliable Power Source -** Having power continuously available to the pump, for the duration of the test, is crucial to the success of the test. If power is interrupted for longer than 10 minutes within the first two hours of the test, terminate the test, allowing for sufficient time for water level recovery, and start over. Any power interruptions need to be documented and a discussion describing the impact on test accuracy needs to be included in the report.

4. **Pump Selection -** It is important to have a reliable pump when conducting an APT. The pump and power supply should be capable of operating continuously at an appropriate and constant discharge rate for at least the expected duration of the APT unless a step-test is being performed. If recovery data will be analyzed and installation is logistically possible, a check valve should be installed at the base of the pump column pipe in the pumping well to prevent the back flow of water from the column pipe into the well when the pumping portion of the test is terminated. Back flow into the well can interfere with or mask the water level recovery of the aquifer which could make the aquifer analysis based on recovery data questionable (Osborne, 1993).

   Electrically powered pumps reportedly produce the most constant discharge and are often recommended for use during an APT. However, in irrigation areas, line loads can fluctuate greatly, causing variations in the pumping rate of electric motors and if the lift increases (water level declines), the pumping rate decreases. It is therefore important to monitor changes in the discharge rate.

Engine-powered (usually gasoline or diesel) pumps may result in water discharge varying greatly over a 24-hour period, requiring more frequent monitoring of the discharge rate during the test. For example, under extreme conditions a diesel-powered turbine pump may have more than a 10 percent change in discharge because of the daily variation in temperature. The change in air temperature and variations in barometric pressure may also affect the engine operation (Osborne, 1993).

5. **Length of the Test -** The amount of time the aquifer should be pumped depends on the type of aquifer, the location of suspected aquifer boundaries, and the degree of accuracy needed to establish the storativity or storage term and transmissivity. The test should continue until the data are adequate to define the shape of the type curve so that the parameters required are sufficiently defined. This may require continued pumping after the rate of water level change initially becomes small and approaches water level “stabilization” or near steady-state conditions. This is especially the case when the locations of boundaries or the effects of delayed drainage are to be defined. In leaky-confined aquifer systems extended pumping is particularly important to determine any delayed drainage effects since under these conditions a pseudo steady-state can develop rapidly that will change after additional pumping. Because the cone of depression expands more slowly in an unconfined aquifer than in a confined aquifer, it takes unconfined aquifers longer to reach “stabilization” or steady-state. Therefore, aquifer tests conducted in unconfined aquifers should be run longer than confined aquifer tests. At a minimum, the following guidelines on the length of the APT must be followed:

   a. Unconfined aquifer – when the pumping well is completed in an unconfined aquifer, the duration of the APT will be a minimum of 72 hours, as required by MCL 324.32706c (12)(a)(iv). If delayed yield is indicated, the test may need to be extended using professional judgement.

   b. Confined aquifer – when the pumping well is completed in a confined aquifer, the duration of the APT will be a minimum of 24 hours, as required by MCL 324.32706c (12)(a)(iv).

   c. Leaky-confined or unknown aquifer – when the pumping well is completed in a leaky-confined or unknown aquifer type, the duration of the APT will be 72 hours to estimate long-term leakage and delayed effects. If the aquifer is behaving like a confined aquifer, it may be appropriate to terminate the test early after the first 24 hours of pumping.

Drawdown data should be plotted during the aquifer test. Preliminary plotting will often display anomalies in the data, may indicate how much longer the test should continue, and may reveal the presence of suspected or previously unknown boundaries. Any change in the trend of the time-drawdown curve should have a record long enough to confirm the boundary (Kruseman and de Ridder, 1970, Osborne, 1993). Any boundary condition encountered during a confined test, or the last 24 hours of pumping for an unconfined or leaky-confined test, may require that the test be extended.

6. **Pumping Rate -** The APT pumping rate used must be at, or above, the pumping rate for which water withdrawal approval is being sought per MCL 324.32706c (12)(a)(iii). The pumping rate, whether in a constant or step APT, must be maintained throughout each phase of the APT as large variations are a major cause of erratic drawdown (Driscoll 1986). The pumping rate must be documented during each phase of the APT. A step-test may be required to evaluate APT pumping rates prior to the completion of a constant rate test completed to identify aquifer parameters. If a pumping rate cannot be used that will stress the aquifer, then the test should be designed to provide information to evaluate the potential for a hydraulic connection of the withdrawal interval to surface water.

   During the first hour of the test, failure to pump within 10 percent of the test pumping rate for any reason requires termination of the test, recovery of water levels to static, and a restart of the test. Later pump failures must be demonstrated to have no significant effect on the data, or a similar termination and restart will be necessary. Additional information regarding variable rate solutions is provided in Part C.

7. **Monitoring Discharge Rate -** Recording periodic measurements of the discharge rate is recommended to ensure system functionality. At a minimum, the discharge should be checked four times distributed throughout the day, typically in early morning, mid-morning, mid-afternoon, and early evening (Osborne, 1993), primarily to verify no water loss is occurring.

8. **Water Disposal -** Discharge water should be handled in such a way as to prevent recirculation of water during the test to prevent effects on drawdown/recovery data. The location and management strategy should be identified in documentation submitted alongside test data, see Part D for additional details. This may necessitate using an unrestricted temporary pipeline, large diameter hose (e.g., fire hose), lined ditch or canal, or existing irrigation system to convey the discharge water a sufficient distance from the test site. No regulator or control should be present within the discharge line which would result in pressure build up in the line and possibly alter the APT data collected. Driscoll (1986) and Kruseman and de Ridder (1970) describe various means and devices for the discharge of pumped water.

   If the aquifer is confined or if it can be otherwise demonstrated that discharged water will not recharge the aquifer being tested, a more convenient method of discharge can be used. Whatever method is selected to manage discharge, it is important that any discharge operations remain in compliance with all applicable local, state, and federal regulations. EGLE Water Use Program staff can direct you to the appropriate WRD surface water or groundwater discharge permitting staff for further information about applicable discharge regulations.

9. **Water Level Measurement and Access -** It must be possible to measure depth to the water level in the pumping well before, during, and after pumping. The quickest, and generally the most accurate, means of measuring the water levels is to use a pressure transducer-datalogger system. Manual water level measurements are recommended periodically throughout the APT to confirm the accuracy of the transducer data and to check for instrument drift, which may require data corrections.

10. **Water Measurements -** MCL 324.32706c (12)(a)(v) and (12)(a)(ii, iv, v) require baseline and recovery measurements be collected for a minimum of 24 hours at one (1) minute intervals. Water measurements should be collected prior to the APT (baseline), active testing, and recovery.

    - Baseline water elevations must be obtained from all wells and piezometers utilized in the aquifer test and provided in feet above mean sea level (ft. AMSL) with reference to NAVD of 1988, along with the TOC and ground surface elevation.
    - During the APT and recovery, water levels are recommended to be collected at the schedule in Table 1:

Table 1 - Water Level Measurement Minimum Schedule

ELAPSED TIME	MEASUREMENT FREQUENCY
0 – 5 minutes	Every 0.5 minute
5 – 10 minutes	Every 1 minute
10 – 20 minutes	Every 2 minutes
20 – 60 minutes	Every 5 minutes
60 – 180 minutes	Every 15 minutes
180 – 360 minutes	Every 30 minutes
360 – to completion	Every 60 minutes

The recommended schedule differs from the frequency required by MCL 324.32706c (12)(ii, iv, v) to provide suitable data density during test periods of large and small water level changes, to accommodate the logarithmic data evaluation typically undertaken with curve matching data analysis, and to conform with data collection recommendations made within multiple published standards and references [Kruseman and de Ridder (1970), Driscoll (1986), Osborne (1993), USGS 1971, and ASTM D4050-96, et cetera]. Adherence to the schedule in Table 1 will not be required to submit an APT for consideration; however, collecting insufficient early-time data to successfully analyze APT results may prevent test acceptance. All water level measurements should be made to the nearest 0.01 ft.

PART C. AQUIFER PERFORMANCE TEST DATA ANALYSIS

The analysis and interpretation of APT data will, at a minimum, include the following information:

1. **Water level** response data must be summarized in the form of plots and tables in consistent units, with units labeled in all submitted datasets.
2. **Data analysis** methods used to evaluate the aquifer test data should be identified and appropriately referenced in the site investigation report. At a minimum, the aquifer hydraulic properties of transmissivity and storage coefficient or specific yield will be determined by employing the methods of Cooper and Jacob (1946) or Theis (1935). More complex methods of analysis should be used where appropriate based on the site geology and hydrogeology and responses of the aquifer to pumping. A guide providing suggested APT analysis methods is provided in Appendix C.
3. **Data correction** for any "external factors and trends." Water level data, graphs, and interpretations must be corrected as appropriate or deemed significant for the effects of background water level trends which may include any of the following:
    a. Partially penetrating production well;
    b. Partially penetrating observation wells;
    c. Delayed yield from unconsolidated aquifers;
    d. Aquifer thickness, recharge, and/or impermeable boundaries;
    e. Barometric pressure changes;
    f. Changes in stage in nearby surface water bodies, if applicable;
    g. Recharge events (rainfall, snow melt) during the week preceding the test, during the test, or during the recovery period;
    h. Influence from nearby pumping wells;
    i. Variable pumping rates; or
    j. Any other hydrogeologic influences.

    All such data and calculations must be included in the APT report. These data should be presented in both tabular form and on data plots (as elevation versus time).

4. **Data analysis** can include a predicted stream flow depletion if the goal of the APT is a water use registration. The predicted proposed depletion should be included as justification for the depletion model selected.

PART D. REPORTING AND DATA PRESENTATION

Information submitted in support of a requested water withdrawal must include the following.

1. Units - All data collected must be presented in consistent and clearly stated units, preferably standard English units, as well as all datum and coordinate systems used during the APT.

2. Static Water Level Data - Pre-test water levels in the pumping well and observation well(s) or piezometer(s) should be included as electronic or paper datasets and plots (as elevation versus time) in the report.

3. Test Water Level Measurements - Water level measurements taken during the aquifer test should be presented in electronic format or as attached datasets in the report. The equipment/data logger type and model should be identified, along with calibration procedure and date. The format for the report should include the following information, at a minimum:

   a. Identification of the pumping well
   b. Identification of the observation wells
   c. Date and time the aquifer test began
   d. Date, clock time, and elapsed time
   e. Measuring point (TOC) elevation
   f. Distance from TOC to ground level or grade elevation
   g. Time since pumping started
   h. Measured depth to water
   i. Depth of the pump intake
   j. Calculated drawdown
   k. Comments noting any "unusual" events (such as stopping of the pump or changes in discharge rate, changing weather patterns, or passage of a train or heavy machinery etc.)
   l. Date and time the pumping phase ended and the recovery phase began
   m. Initial and final water levels for the recovery phase

4. **Raw Data -** All data necessary to conduct an independent review and analysis should be presented and submitted. Water level measurement, drawdown, and recovery data should be provided in electronic format as delimited ASCII files.

5. **Data Plots and Tables -** All raw data should be summarized. Tables should contain all information needed to clearly identify the data. All data corrections (e.g., pre-pumping trends for barometric pressure or water levels, man-made impacts, etc.) should be given separately. All plots used for corrections should be referenced on the appropriate table. At a minimum include:

a. Data plots of drawdown versus time, depending on the data analysis methods employed, should be presented for the pumping well and each observation well on double-logarithmic and semi-logarithmic graphs. Time data should be depicted along the horizontal axis, and drawdown should be depicted along the vertical axis. For semi-logarithmic plots, drawdown should be presented along the vertical arithmetic axis.

b. In APT with multiple observation wells/piezometers, data plots of drawdown versus distance from the pumping well should be presented; calculations of hydraulic properties based on these plots should be used to corroborate calculations made from time-drawdown data plots.

c. Data plots of residual drawdown versus time since pumping stopped should be presented for recovery data if used in the analysis.

d. Any barometric and rainfall data should be presented on data plots at the same scale as the water level data and should be accompanied by a discussion in the test report describing the effects of each parameter on test water levels. BE calculations used in APT analysis should be included in the report.

e. Separate data plots depicting both adjusted and unadjusted drawdown versus time and versus distance should be presented if data adjustment is needed for the appropriate wells. Any plots, graphs, or equations used to determine the magnitude of drawdown adjustment should also be presented.

f. Data plots of discharge rate versus time should be presented. Any anomalies should be discussed in relation to the accuracy of the test. All flow rate adjustments must be documented with a measurement of flow before and after adjustment, the time at which the adjustments were made, and a rationale for the adjustment.

g. A well summary table should be provided, which summarizes APT wells or piezometers and any information on nearby surrounding offsite wells, if available. The well summary should include at a minimum: an identifier, coordinates in decimal degrees to five decimal places, distance from pumping well, pumping schedule (if available or applicable), and screened interval.

6. **Well Log Records -** Geologic and well construction logs (e.g., Wellogic well records) must be submitted for all cross-section wells, pumping well, and observation wells/piezometers used during the test.

7. **Scaled Site Maps -** Scaled site maps showing the following information, at a minimum:
    a. Water level elevation controls (i.e., TOC);
    b. Grade elevation of all wells used;
    c. Staff gages and other water measuring points;
    d. Pumping test discharge piping and discharge point;
    e. The location of nearby surface water bodies and streams;
    f. Location of any suspected or identified boundaries;
    g. Site topography.
8. **Geologic Cross-Sections -** Geologic cross-sections should be completed with axes clearly labeled, vertical exaggeration identified, and the location of the sections labeled on a scaled site map. A minimum of two cross-sections intersecting at a 90° angle should be presented. Additional cross-sections may be needed to illustrate any pertinent changes in aquifer thickness, composition, or boundaries in the site area if not clearly illustrated with two sections.
9. **Coordinates -** Coordinates for all wells and other measuring points should be presented as latitude and longitude in decimal degrees reported to five decimal places.
10. **Vertical Datum -** All vertical measurements should be referenced to the NAVD of 1988.
11. **Pump -** Clearly identify the pump type and model.
12. **Analyses and Interpretation -** Data presentation should clearly identify the methods and rationale used in analysis of the APT data. All calculations should clearly identify the data used at input and the equations used with reference to appropriate tables. Any assumptions made as part of the analysis (including data corrections) should be noted and discussed in the report. At a minimum, the following should be included in the report:
    a. Computer programs used for analysis should be referenced and all assumptions and limitations should be noted in the report. EGLE uses Aqtesolv® Professional V4.5 or Aquifer Win32 V6 for APT data analysis. If a different computer program is used for analysis, then all electronic input and output data files used in the analysis must be submitted.
    b. If more than one observation well is used, the average and range of aquifer properties such as transmissivity and storage value must be clearly identified, and the rationale used for the calculations discussed.
    c. If an analysis method is chosen that allows for the calculation of additional hydraulic properties (such as anisotropy ratios, leakage, or storage in unpumped aquifers), these values should also be included in tabular format in the site investigation report.

d. Supporting data that explains the placement of the observation wells should include, at a minimum, the following:

    i. geologic cross-sections,

    ii. lithologic logs,

    iii. observation well construction logs,

    iv. scaled map(s) indicating the locations of observation wells with respect to the pumping well and any boundaries, and

    v. table including, at a minimum, each observation well's name, coordinates, total depth, screened interval, and distance from the pumping well.

e. Should a specific depletion model be proposed because of aquifer conditions identified via the APT or using parameters obtained by the APT, the data analyses can include an evaluation of the nature and expected impact of the hydraulic connection between the withdrawal interval and the watershed streams. The evaluation should be based on the CSM including cross sections and hydraulic gradient, selected APT configuration, and test results.

13. Reporting - A brief report should be prepared to summarize APT planning, methodology, and results documenting the fulfilment of each item listed above. A description of the well configuration, installation, construction, and history if applicable, should be included in the report. The type of pump and pumping rate used throughout the test should be indicated in the report. Any conversion of collected data prior to analysis should be described. The report should include a description of the CSM and provide evidence supporting the CSM theory. A discussion of the results should be included in which all assumptions and process decisions can be described and justified.

APPENDIX A: REFERENCES

Copies of select references listed below are available through request from the WUAU.

American Society for Testing and Materials (ASTM), 1996, Standard Guide for Selection of Aquifer Test Method in Determining Hydraulic Properties by Well Techniques: D 4043-96*[1].

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APPENDIX B: SINGLE WELL APT CHECKLIST

The factors in the checklist below are required to be satisfied for the use of a single-well APT. They are based on single well solution analysis assumption requirements outlined by Kruseman and de Ridder, 1970. Documentation of each satisfied factor, along with this completed checklist, must be submitted alongside the APT report. Kriseman and de Ridder purport single-well APT data may be analyzed using Papadopulos-Cooper (1967), Rushton & Singh (1983), modified Jacob's straight-line method, or Hurr-Worthington (1966) methods. Any additional assumptions listed for each individual method must be adhered to and evidence supporting the use of the method and assumptions satisfied must be submitted for the APT to be considered.

- ☐ The APT is not being completed in service of an alternate analysis under MCL 324.32706c.
- ☐ No recharge to the pumped aquifer is present in the testing area (the aquifer configuration is either confined or leaky confined as defined in Part B.1).
- ☐ Early time data can be demonstrated to be sufficiently influenced by well bore storage.
- ☐ Non-linear well losses can be neglected.
- ☐ The pumping well screen is fully penetrating or spans the entire pumped aquifer thickness.
- ☐ The APT has been completed for a minimum of 48 hours.

APPENDIX C – APT SOLUTION GUIDANCE

The solutions listed in Table 2 below are designed to provide a guide if needed for APT solution given isotropic conditions. It does not represent a comprehensive list of available or approved APT solutions. Deviation from the table below should occur as warranted based on site-specific APT conditions.

Table C- 1: Aquifer Geometry-Based APT Selection Guidance

AQUIFER CONFIGURATION	MINIMUM NUMBER OBSERVATION WELLS	SOLUTION SUGGESTIONS
UNCONFINED (See Figure 1)	Two	• Neuman, 1972 • Neuman, 1974 • Boulton, 1954 and 1963 • Theim-Dupuit
CONFINED (See Figure 2)	One	• Papadopulos and Cooper, 1967 • Theim 1906 • Theis 1935 • Cooper and Jacob, 1946
LEAKY CONFINED (See Figure 3)	Two as a nested pair	• Hantush and Jacob, 1955

Figure 1 – Unconfined APT Example Configuration, Profile View

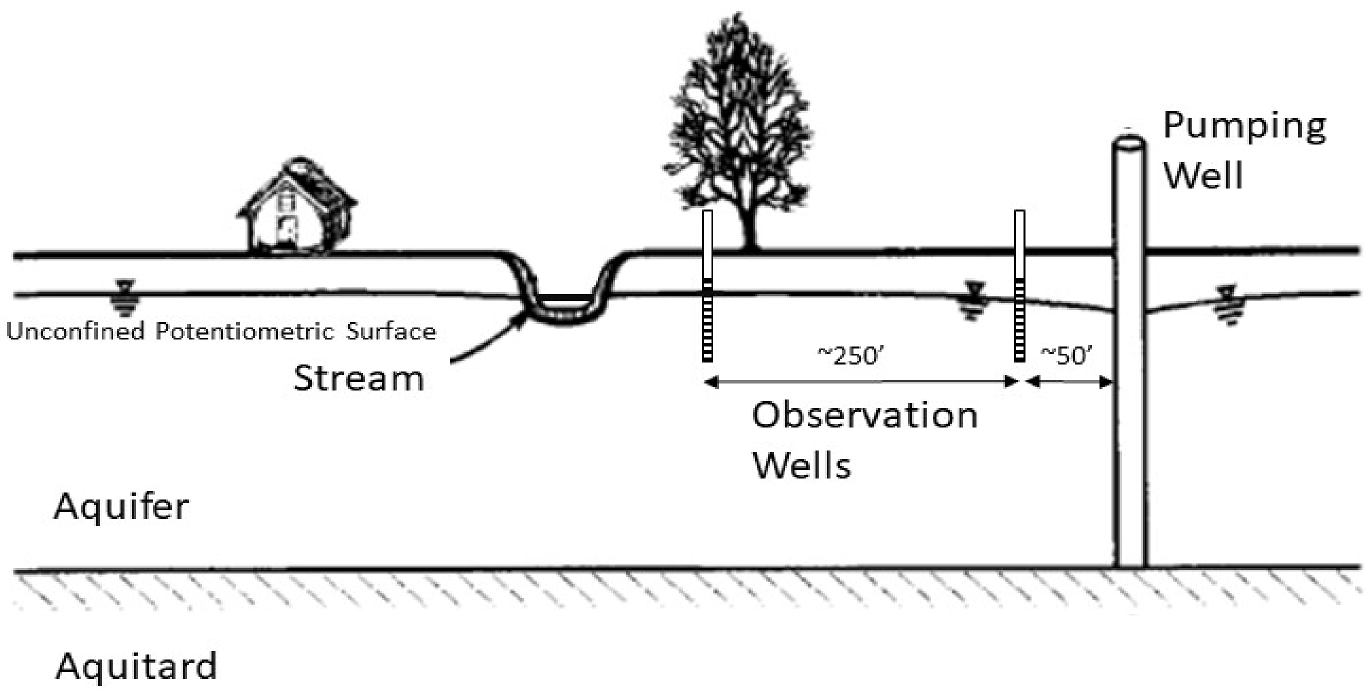

Figure modfied from Unsteady Stream Depletion from Ground Water Pumping, Figure 3, by Bruce Hunt, 1999.

Figure 2 –Confined APT Example Configuration, Profile View

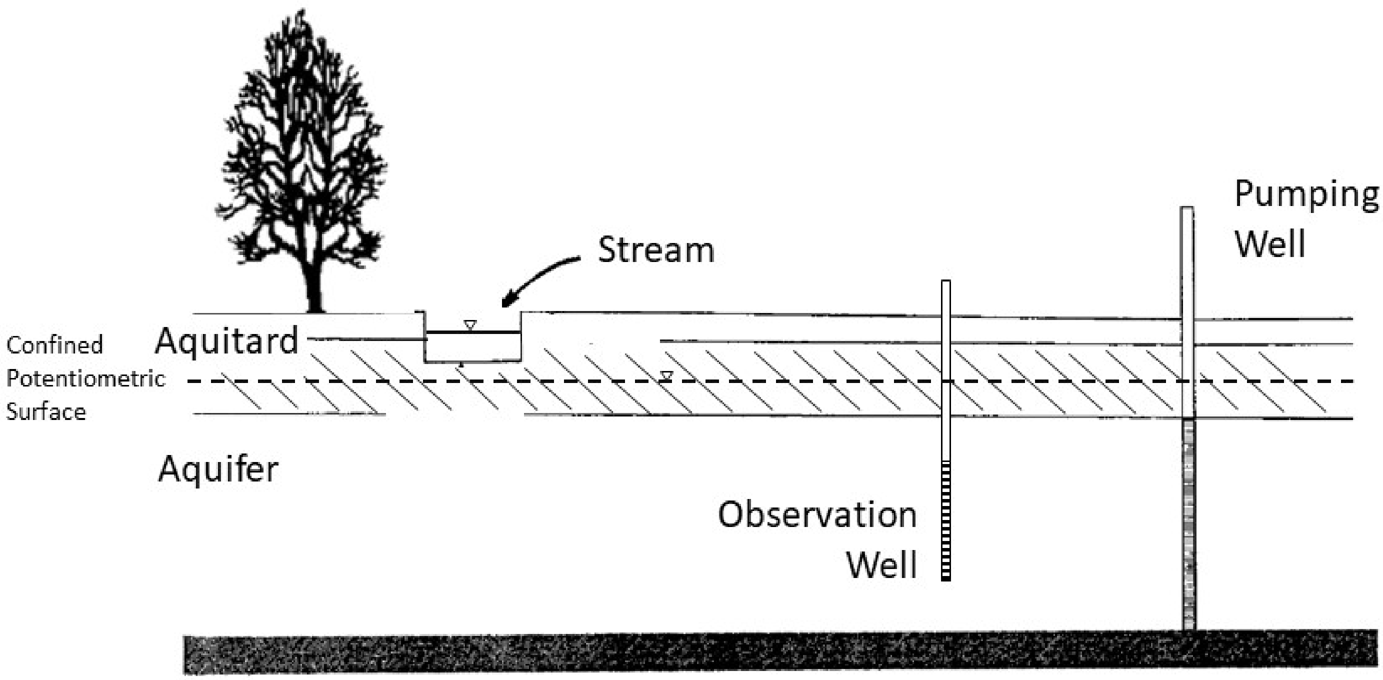

Figure modified from Unsteady Stream Deplection when Pumping from Semiconfined Aquifer, Figure 1, by Bruce Hunt, 2003

Figure 3 – Leaky-Confined APT Example Configuration, Profile View

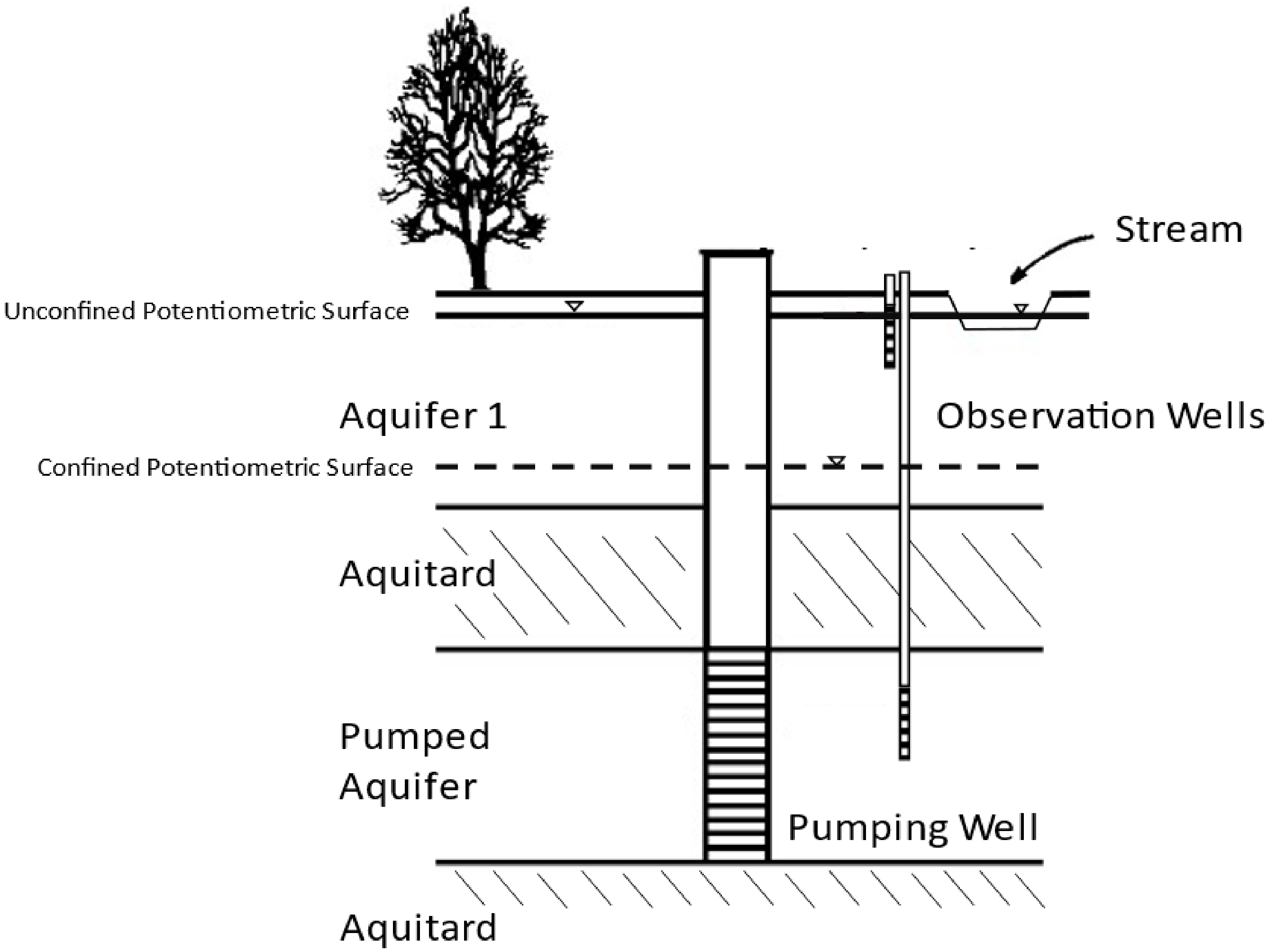

Figure modified from Stream Depletion from Pumping a Semi-Confined Aquifer in a Two-Layer Leaky Aquifer System, Figure 2, by Nicholas Dudley Ward and Hilary Lough, 2011