

**GUIDELINES FOR EVALUATING STREAMFLOW DEPLETION FROM  
GROUNDWATER WITHDRAWALS  
- DRAFT -**

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**15 pages with 1 table and 5 figures**

**Last revised: Dec 17, 2009**

## **1.0 INTRODUCTION**

This document details the Department of Environmental Protection (DEP)'s recommended methodology for evaluating the impact of a groundwater withdrawal on nearby streamflow, or "streamflow depletion". Conservative assumptions can be utilized to estimate depletion with minimal data. If more data are available, a better estimate of streamflow depletion can be determined. Note that the information provided in this document is intended as guidance only. Compliance with Connecticut's regulations and statutes are the responsibility of the water user.

In Connecticut, the shallow groundwater and adjacent surface water are typically closely connected: the surface water body is often the discharge point for groundwater. Groundwater is the primary contributor to the natural base flow of a stream, and is therefore critical to sustaining streamflow during dry periods of the year. Extracted groundwater is either coming directly through the streambed by induced infiltration, or is captured groundwater that would have discharged to the stream and contributed to streamflow. However, a number of factors influence where along the stream and when that reduction in streamflow will occur. These factors are specific to the particular well/aquifer/stream system, and are not readily quantifiable without detailed study of the system. The factors include well withdrawal volume, duration and seasonality, as well as aquifer materials, well depth, streambed sediment, distance of the well from the stream and disposition of the withdrawn water (i.e. if the water is consumed or added back into the local flow system at some point). These factors are collaborative, so just knowing that a well is 800 feet from the stream is not sufficient information to determine how that might mitigate streamflow depletion.

Conducting a detailed study of the aquifer/stream system for each groundwater withdrawal to determine its impact on streamflow is not always practical or necessary. Therefore, a tiered approach to evaluating streamflow depletion based on available data is recommended. If additional refinement is necessary, suggestions are made to guide the water user in collecting additional data. The methodology intentionally incorporates conservative assumptions (i.e. has a

tendency to overestimate, rather than underestimate, potential streamflow depletion). The initial evaluation tier simply makes the assumption that the groundwater withdrawal is operated at the maximum permitted rate all the time and that all of the withdrawal comes directly from the stream. If data is available on the water-user's actual average withdrawal volume and on basic aquifer properties, a tier 2 evaluation can refine the estimate of streamflow depletion. Tier 3 utilizes a simple, site-specific analytical approach to evaluate depletion. Tier 4 allows for alternate analytical methods using site-specific data if it can be justified. Finally, tier 5 utilizes extensive site-specific data to either develop a field-monitoring program or detailed computer modeling of the aquifer system to directly quantify streamflow depletion. Each successive tier requires more data than the one before, but the estimate of streamflow depletion improves with each step in the methodology.

Please call DEP's Bureau of Water Protection and Land Reuse, Planning and Standards Division, at 860-424-3720 if you have any questions.

## **2.0 DEFINITIONS**

**Annual Q99 Streamflow** – The calculated daily streamflow exceeded 99 percent of days in a year, on average.

**Area of Influence** – The land area that directly overlies and has the same horizontal extent as the part of the water table or other potentiometric surface that is perceptibly lowered by the withdrawal of water.

**Capture** – Water withdrawn from an aquifer is derived from a decrease in storage in the aquifer, a reduction in the discharge from the aquifer, an increase in recharge, or a combination of these changes. The decrease in discharge plus the increase in recharge is termed capture.

**Diversion** – Any activity which causes, allows or results in the withdrawal from or the alteration, modification or diminution of the instantaneous flow of the waters of the state. DEP issues permits or registrations for diversions in accordance with Section 22a-365 to 22a-378, inclusive, of the Connecticut General Statutes.

**Maximum-Month, Average-Day Withdrawal** – This is based on the actual volume of water that the utility has withdrawn over the period of record. The maximum month of usage is selected and the average withdrawal per day during that month is determined.

**MODFLOW** – A three-dimensional finite-difference groundwater model that was first published in 1983 by M.G. McDonald and A.W. Harbaugh of the U.S. Geological Survey. This computer groundwater model is in widespread use and continues to be supported and updated by the U.S. Geological Survey.

**MODPATH** – A particle-tracking post-processing package that was initially developed in 1989 by the USGS to compute three-dimensional flow paths using output from steady-state or transient groundwater flow simulations.

Point of Assessment (POA) – Point on the stream at which the decrease in streamflow due to a ground water withdrawal is to be evaluated. In general, it is the point on the stream that is the shortest distance to the withdrawal point (well). The POA may be changed under certain circumstances, as discussed under the tier 2, 4 or 5 analyses.

Return Flow – Water that has been withdrawn from the aquifer and returned to the surface or groundwater system through a wastewater treatment plant, septic systems, etc.

Seasonal Withdrawal – Groundwater or surface water extraction that only occurs during a limited portion of the year (e.g. agricultural or golf-course irrigation).

Stream – For purposes of this guidance, a stream is any flowing body of water, and is interchangeable with “river”.

Streamflow Depletion – A decrease or loss of surface water or streamflow due to groundwater withdrawal.

Streambed Conductance – A modeling parameter that consists of the vertical hydraulic conductivity of the streambed times the width of the channel divided by the thickness of the streambed.

### **3.0 GENERAL PROCEDURES FOR EVALUATING STREAMFLOW DEPLETION**

Below is a general outline of the methodology. It allows for progressively more data-intensive analyses if such data is available or a more refined estimate of streamflow depletion is necessary. Note that for wells in bedrock that produce more than 35 gpm, the porous media assumptions inherent in the following methodologies may be appropriate, and these methods may provide reasonable estimates of streamflow depletion. However, if hydrogeologic data are available that would improve such estimates, an alternative approach can be taken under tiers 4 or 5. More detailed discussion of each tier follows in subsequent sections of this guidance.

Tier 1: The simplest assumption is that groundwater is withdrawn at the maximum allowable rate all the time and that one hundred percent of the water is coming directly from the stream, at the closest point on the stream. This method may be appropriate if the withdrawal is very small compared to streamflow or the targeted standard, or if additional data on the groundwater withdrawal or the aquifer system are not available.

Tier 2: If actual-use data on the daily pumping rate is available, along with some basic data on aquifer properties and distance of the well from the stream, tier 2 methods can be applied to improve the streamflow depletion estimate. A point of assessment (POA) for streamflow calculations (which is not necessarily the closest point on the stream) can be determined in this tier and the maximum-month, average-day withdrawal can be used instead of the maximum withdrawal rate.

Tier 3: If some additional aquifer property data is available or can be estimated, a basic computer analysis (STRMDEPL08) may be run to estimate streamflow depletion in

the tier 3 methodology. In this methodology, DEP provides estimates for use in STRMDEPL08 for some aquifer parameters that are not readily available.

- Tier 4: Under certain site-specific conditions, the water user may (a) apply alternative STRMDEPL08 criteria, (b) justify use of a streamflow depletion rate less than fifty percent of the withdrawal rate, (c) use an alternative POA on the stream, or (d) propose alternative methods for assessing wells in bedrock or confined settings. In such cases, a proposal may be submitted to the DEP justifying what site-specific conditions or analyses would be appropriate for the assessment of streamflow depletion. The alternative analysis must be based on verified site-specific data and sound hydrogeologic assumptions.
- Tier 5: If further refinement of the streamflow depletion estimate is necessary, the water user has the option to (a) design a field-monitoring program that accurately determines streamflow depletion volume and identifies the point of greatest impact to the stream or (b) conduct detailed computer modeling analysis of the aquifer. Both of these options require considerable time and resources. A plan for conducting modeling or monitoring may be submitted to DEP for review before such a program is carried out to insure the results of this effort will be acceptable to DEP.

#### **4.0 SUMMARY OF INFORMATION NEEDED TO CONDUCT STREAMFLOW DEPLETION EVALUATION**

The following site-specific information will likely be needed to evaluate streamflow depletion:

1. Specific information contained in the diversion registration or permit for withdrawal of water from the well or well field.
2. Topographic maps at 1:24,000 (1"=2,000') or a more detailed scale. The maps should extend beyond the area of influence to the surrounding watershed divides.
3. Locations and geologic logs of all production wells, test borings and observation wells associated with the well field.
4. Aquifer test data associated with the well field pertinent to the calculation of transmissivity of the aquifer.
5. Record-of-use data for the well(s).
6. Any available previously conducted geologic and hydrogeologic studies and surveys.

#### **5.0 SOURCES OF EXISTING INFORMATION**

The water user typically has available much of the background information required to assess streamflow depletion from a groundwater withdrawal. Some types of data that may be available and potential sources of this information are as follows:

1. In-house data generated for well-site testing, yield or safe yield testing, a diversion permit, or Level A Aquifer Mapping for the well or well field is the primary source of information. The aquifer test results should provide an estimate of transmissivity for the aquifer system.
2. The most up-to-date topographic base maps at scales of 1:24,000 (1"=2,000"), are available online from DEP at [www.ct.gov/dep/gis](http://www.ct.gov/dep/gis). The DEP Store has 1:24,000 quadrangle maps for sale at 79 Elm Street, Hartford, CT 06106, tel.: 860-424-3555 or 860-424-3692.
3. DEP has produced state maps that delineate the surficial materials (Surficial Materials Map of Connecticut) and the thickness of these materials (Surficial Aquifer Potential Map of Connecticut); both maps are available online at [www.ct.gov/dep/gis](http://www.ct.gov/dep/gis).
4. Drainage basin maps at 1:24,000 and 1:250,000 are available online at [www.ct.gov/dep/gis](http://www.ct.gov/dep/gis).
5. The DEP Records Center maintains files of well completion reports for water wells drilled since 1955. Well completion reports are filed by town and include private residential, commercial, industrial, and public supply wells. These records may also be available at the local Health Department.
6. The U.S. Geological Survey provides GIS software (StreamStats) for Connecticut that will compute the drainage-basin area for a selected stream site and provide flow statistics. <http://water.usgs.gov/osw/streamstats/connecticut.html>

The USGS Connecticut Water Science Center may have pertinent studies for the areas supplied by stratified-drift wells at the USGS Connecticut Water Science Center 101 Pitkin St., East Hartford, CT 06108 or at their web site <http://ct.water.usgs.gov>. The U.S. Geological Survey also maintains a national web site focused on water resources (<http://water.usgs.gov/>) where there is considerable information related to surface water and groundwater hydrology.

## **6.0 DETAILED METHODOLOGY**

### **6.1 TIER 1: Initial Assessment – Maximum Allowable or Proposed Withdrawal Rate**

The simplest assumption and starting point for many evaluations of streamflow depletion from a groundwater withdrawal is to assume that groundwater is withdrawn at the maximum allowable withdrawal rate (MAWR) all the time and that one hundred percent of the water is coming directly from the stream. The MAWR may be the maximum registered, maximum permitted or maximum proposed ground water diversion rate. If there are multiple wells in a well field, the total maximum withdrawal rate for all wells cumulatively should be evaluated.

For such a tier 1 analysis, streamflow depletion is assumed to take place at the point on the stream that is the shortest distance to the well, or the shortest distance to the closest well if there are multiple wells in a well field.

## **6.2 TIER 2: Actual Use Assessment**

If a better estimate of streamflow depletion than the tier 1 assessment is necessary, some basic, site-specific factors can be taken into consideration in a tier 2 estimate, as follows:

- Many water users pump substantially less water on average than their MAWR, only pumping at maximum for short periods of time. Streamflow depletion from a ground water withdrawal is generally not instantaneous. Wells are located some distance from the stream, and groundwater flow rates are much slower than streamflow rates, so there is often a lag between pumping the well and its impact on the stream, and variation in pumping rates get dampened out over time. A reasonable estimate of streamflow depletion can therefore be made using the daily withdrawal rate averaged over the month. DEP recommends utilizing actual pumping rates based on the most recent five years of data available for which the well was in normal operation. The pumping record should be examined and the average daily withdrawal calculated for each month. (For seasonal withdrawals, this will be limited to the months of operation.) The five-year average for each month should then be calculated, and of these, the maximum-month, average-day withdrawal would be the value used to estimate streamflow depletion. Note that a new assessment may be needed if there is an increase in the maximum month, average-day use in the future.

As discussed below in section 6.2.2, Area of Influence Delineations, if there are multiple wells in a well field, the withdrawal rates should be totaled for any wells for which the Areas of Influence (AOI) overlap. The wells can be considered individually if the AOI do not overlap.

- Streamflow depletion is assumed to occur at the Point of Assessment (POA) on the stream. The POA can be determined using the method detailed below in section 6.2.1 of this guidance. The POA may be the same as that for the tier 1 analysis (i.e. the closest point on the stream to the well), or it may change depending upon the distance between the well and the stream, and the hydrogeologic characteristics of the aquifer.
- If individual septic systems are present within the watershed in areas served by public water supplied by either the well(s) under evaluation or by a supply located outside the basin, such systems return or add flow to groundwater, and can contribute to baseflow. Credit (to the withdrawal rate) for these return flows may be included at 65% of the calculated water use. Data on the absence of sewers within the watershed upstream of the POA (or in portions of that watershed), water service areas, source of supply and census data supporting the number of households and population must be presented to support the return flow calculation. Water use of no more than 75 gallons per day per person, up to a maximum of 300 gallons per day per household, can be considered.

## 6.2.1 Point of Assessment Determination

The point of assessment is the point on the stream where the impact of the groundwater withdrawal on streamflow is evaluated. The area of influence (AOI) is a tool to help identify where the POA should be located, and the methodology to calculate the AOI is provided in the section below.

If the AOI intersects the stream, then the POA should be the closest point on the stream to the well (See figure 1). If the AOI does not intersect the stream, measure the distance (x) between the edge of the AOI and the stream. Find the point on the stream that is closest to the well and add x to it in a downstream direction. This downstream point is the POA (See figure 2).

If there are multiple wells in a well field, an AOI should initially be calculated for each well. If the AOI for any wells overlap, the wells should then be considered cumulatively. The cumulative AOI for the overlapping wells must be recalculated using the cumulative total withdrawal for the overlapping wells. The POA will then be determined using the mid-point between the overlapping wells, as discussed further below (See figure 3).

## 6.2.2 Area of Influence Delineations

The estimated radius of the area of influence (AOI) (or cone of depression) is based on the drawdown relationship between pumping rate and aquifer transmissivity. It is used as discussed above to help determine the Point of Assessment on the stream. The following steps are involved in delineating the area of influence:

1. Determine the average aquifer transmissivity, in cubic feet per day per foot from aquifer test data and/or test boring information.
2. Figures 4 and 5 indicate the relationship between transmissivity, pumping rate, and AOI radius. After average aquifer transmissivity has been calculated, a vertical line may be constructed from that value of transmissivity on the horizontal or x-axis of Figures 1 or 2 to the proper pumping rate curve (some interpolation may be necessary between the given pumping rate curves). In the case of a single well, the maximum pumping rate of the well is used; in the case of a multiple wells with overlapping individual AOIs, the maximum total pumping rate for all of the overlapping wells should be used along with an average transmissivity for the aquifer. The AOI radius may be read from the vertical or y-axis. *The minimum area of influence radius for any well is 200 feet.*
3. In the case of a single well facility, a circle representing the area of influence area can be constructed using the radius, with the well as its center (see figure 1). In the case of multiple wells, a circle representing the cumulative AOI can be constructed using the radius, with the mid-point between the two furthest wells being considered its center (see figure 3).

### 6.3 TIER 3 Analytical Option (STRMDEPL08)

If, after taking into account the tier 2 factors, a better estimate of streamflow depletion is needed, an analytical groundwater model can be utilized. There are numerous equations that can be applied, but DEP recommends the use of a one-dimensional USGS model called STRMDEPL. The latest version is STRMDEPL08 (Reeves, 2008), and is available online (see references at the end of this document). To use STRMDEPL08, site-specific data on aquifer parameters are entered into the model to run the calculation. In tier 3, DEP has specified default parameter values for data that are not readily available.

Under tier 3, STRMDEPL08 is run using the Hunt 1999 Solution. The solution assumes that pumping rate is constant over each time step, there is no aquifer recharge and the stream is only partially penetrating the aquifer. The aquifer characteristics necessary for model operation include:

Parameter	Description	Standard Option Value
Distance	Distance from the well to the stream	Site-specific
Transmissivity (T)	Hydraulic conductivity (K) of aquifer material times thickness (d) of the aquifer $T = Kd$	Site-specific
Storage Coefficient	Based on geologic material of the aquifer	0.2
Streambed conductance	Hydraulic conductance of streambed material $2[\text{transmissivity}(T)/\text{stream leakage}(L)]$ $L = K \text{ aquifer} * \text{streambed thickness} / K \text{ streambed}$	5 ft/d
Pumping Rate	Maximum Month Average Day withdrawal rates	Site-specific
Pumping Duration	2x longest consecutive pumping period over last 5 years of record	Site-specific

Storage Coefficient and Streambed leakage are set values under the tier 3 approach. Storage Coefficient is the volume of water that can be removed from storage during pumping. In unconfined aquifers the storage coefficient is close to the specific yield of the surficial material, and a value of 0.2 is recommended. A value of 5 feet/day was set for streambed conductance to eliminate the need for an in-situ measurement to calculate the hydraulic conductance of the streambed material.

Distance, transmissivity and pumping rate are specific to each individual groundwater withdrawal and must be collected prior to utilizing STRMDEPL08. For existing facilities, pumping rate and distance will be known, and existing aquifer test and boring information should be sufficient to determine hydraulic conductivity and aquifer depth.

Once the information is collected, the model should be run for a period of twice the normal period of operation, up to eighteen (18) months. So, year-round withdrawals (12 months of operation) should be run for 18 months, and a well field that normally operates May to September (5 months) would be run for 10 months.



The output at the end of the model run represents the daily amount of water in cubic feet per second being removed from the nearby stream at the POA. The minimum stream depletion that will generally be acceptable for a tier 3 analysis is 50% of the pumping rate. If the calculated streamflow depletion is more than 50% of the pumping rate, further analysis of the assumptions inherent in the STRMDEPL08 model must be completed, and justification can be submitted under tier 4(a), below.

#### 6.4 Tier 4: Alternative Analytical Options

Under tier 4 there are four options that might help further refine the stream depletion estimate: Option (a) allows for the use of additional site-specific information to re-run STRMDEPL08; Option (b) allows for justification of a stream depletion of less than 50% of the withdrawal rate; Option (c) allows for the use of an alternative POA; and Option (d) provides for alternative proposals for wells in bedrock or confined settings. It is recommended that the water user submit a proposal and justification for DEP's review and approval before using one of these options.

**Option (a):** When utilizing Option (a) the parameter values must be based on verified site-specific data, and an evaluation of the validity of the inherent assumptions of the model for the hydrogeologic setting must be conducted. The STRMDEPL08 criteria that could be altered for a site-specific value are streambed conductance, aquifer storativity and pumping duration. Transmissivity, distance to the POA and pumping rate are already site-specific values under tier 3.

- **Streambed conductance:** Under tier 3a a default streambed conductance value of 5 feet/day is set. However, if in-situ measurement of streambed conductivity has been conducted at the site, an alternate streambed conductance value may be calculated and applied to the model.
- **Aquifer storativity:** The default aquifer storativity value used during tier 3a is 0.2, which is on the higher side for stratified drift aquifers. However, if site specific information is available that indicates the aquifer storativity is different a request/proposal may be submitted to the DEP for approval. The alternate storativity value can then be used to rerun STRMDEPL08.
- **Pumping duration:** The default duration of pumping calculated during tier 3a is 2 times the longest period of operation over the last 5 years of pumping records with a maximum duration of 18 months. However, if site-specific information is available that would decrease the pumping duration used in tier 3a then a proposal may be submitted to the DEP for approval. The alternative pumping duration can then be used to rerun STRMDEPL08 to evaluate compliance.

**Option (b):** Stream Depletion < 50% of withdrawal rate: In some cases, STRMDEPL08 may calculate a depletion of less than fifty percent of the withdrawal rate. In order to accept such a value, the assumptions inherent in STRMDEPL08 must be evaluated and shown to be

appropriate for the aquifer under consideration. For example, STRMDEPL08 assumes an infinite aquifer extent. If the aquifer system under consideration is areally limited, this assumption may not be valid, and a stream depletion of less than 50% of the withdrawal rate would not be accepted by the Department.

**Option (c):** This option allows for an alternative POA to be proposed. Under tier 3 the POA is either the point on the stream that is closest to the nearest stream or a specified point downstream of the closest point if the AOI does not overlap the stream. In addition, multiple compliance points may need to be utilized if the AOI intersect more than one stream. There are some settings where the assumptions used above to calculate the POA are not suitable and an alternant POA may be appropriate.

For example: If the AOI intersects more than one stream: It can be assumed that if there are two or more streams within the withdrawal's AOI, 100% of the diverted water is not coming from one stream but a portion of water will be coming from each stream. More than one compliance point will need to be used, and a case can be made for apportioning the withdrawal among the streams. Considerations can include distance, presence of confining units, and the relative size and position of the different streams. A proposal (with supporting evidence for the apportionment) may be submitted to DEP for approval that indicates what percentage of each stream is being affected by the withdrawal.

**Option (d):** In bedrock or confined drift settings, the assumptions inherent in the above methods may not be appropriate, both in calculating the volume of stream depletion and the POA. Alternative proposals for analytical analyses may be made to accommodate these conditions for DEP's review and approval. Such proposals must be based on site-specific data and sound hydrogeologic considerations.

The options under tier 4 are intended to allow for some flexibility by using site-specific information that is not accounted for by the default settings in tiers 2 or 3.

## 6.5 TIER 5: Streamflow Monitoring or Numerical Modeling Options

In some circumstances, it may be necessary to quantify streamflow depletion as accurately as possible. Direct measurement or detailed numerical groundwater modeling may be appropriate in such a case. Tier 5(a) discusses the monitoring option, and tier 5(b) discusses the numerical modeling option. In either option, a detailed proposal may be submitted for DEP's review and approval before the work is carried out.

**Option (a):** The water user may employ the option of monitoring groundwater and/or streamflow to directly measure streamflow depletion. The primary advantage of monitoring is that it is a more tangible approach and consequently, more defensible. While such an approach may also be more accurate, the disadvantages are that the inherent natural variability may cause complications and total costs may be high. The guideline for this monitoring option is not prescriptive, rather it allows the water user to develop and apply a customized approach.

There are basic considerations for any proposed plan. The streamflow calibration should be over a period of time that captures seasonal and annual variations. Streamflow measurements may not be sufficiently reliable for low flows (e.g. < 5cfs) or for the high flows of a river. The procedures for measuring streamflow rate should follow the standards that have been developed by the US Geological Survey. Monitoring should include an upstream point that provides the background flow for the area, and a point downstream of the POA to determine the impact on streamflow from pumping of the well(s). The streamflow hydrographs should be compared to predicted flows through StreamStats (USGS 2008a). The results should be evaluated and conclusions drawn that define relationships between streamflow volumes and volumes withdrawn from the well(s). These points or another piezometer(s) must be monitored over the long term to evaluate streamflow depletion. An example of the monitoring option is as follows:

1. Prepare a plan for data collection that outlines the specific procedures for developing a water monitoring plan and submit it to DEP for review.
2. Install a staff gauge in the stream or a piezometer directly adjacent to the stream at a point just upstream of any expected impact on the stream by the well.
3. Install a second staff gauge/piezometer in or along the stream where no further impact is expected from withdrawals by the well.
4. Install a third monitoring point (i.e. piezometer) between the stream and the well.
5. Monitor groundwater levels and streamflow over a period of three years.
6. Develop a stage-discharge relationship for the stream.
7. Compare the actual streamflow data to the predicted streamflow results based on Stream Stats provided by the USGS.
8. Develop a relationship between withdrawals at the pumping well and the difference between the upstream and downstream monitoring points to determine streamflow depletion.
9. If necessary, identify trigger levels at which mitigative measures would need to be implemented.
10. Prepare a report that summarizes the data collected and the conclusions for DEP review and approval.
11. Monitor the third monitoring point on a regular, on-going basis for reporting and trigger levels.
12. Continue to monitor all three points on an intermittent basis to verify that the stage/discharge relationship and response to pumping has not changed.

This example is intended to provide some considerations when a monitoring plan is being developed. The water user should employ standard procedures such as those outlined by Rantz and others (1982) for collecting and analyzing streamflow data.

**Option (b):** The water user has the option of constructing a groundwater model to evaluate streamflow depletion as a result of pumping. The requirements established in DEP's Level A Mapping Regulations (RCSA Section 22a-354b-1) are appropriate for this groundwater-modeling project. The groundwater model developed for Level A mapping may form the basis for this modeling option. A water-budget, mass balance should be part of the solution.

The primary goal of this three-dimensional modeling option is to evaluate the timing and magnitude of impact to streamflow from pumping under transient conditions. The numerical groundwater model, MODFLOW, allows for a more accurate evaluation of streamflow depletion than STRMDEPL08. It includes consideration of recharge and a more accurate recognition of the site-specific characteristics, particularly streambed conductance. Running the model under transient conditions allows for more accurate simulation of water use and variation in pumping on a seasonal or intermittent basis. Application of the software MODPATH will allow the water user to do particle tracking and identify the area of the stream that is affected.

There is also the option of using more advanced software and managing the water resource through optimization (USGS 2007). By understanding the lag time for a pumping well to impact the stream, the water user can manage his water system in a way that maximizes yield while minimizing streamflow depletion.

## 7.0 REFERENCES

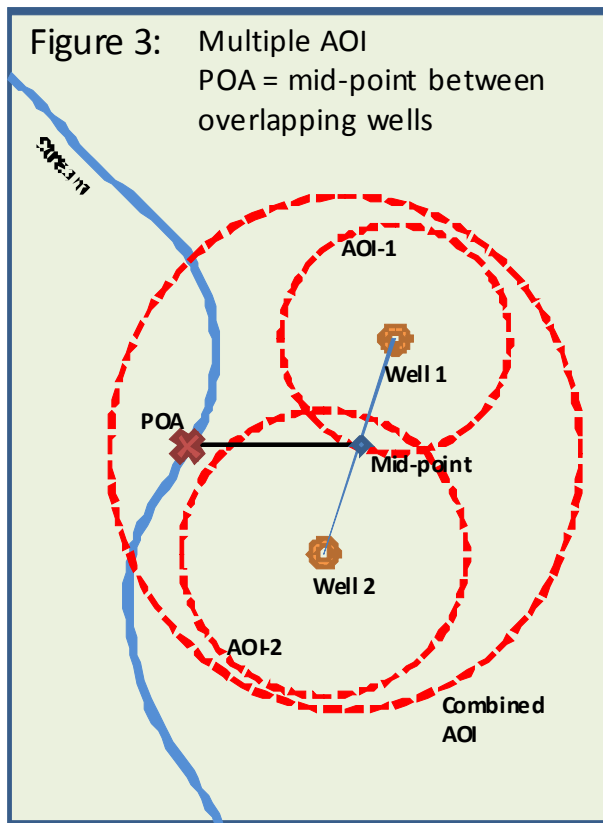
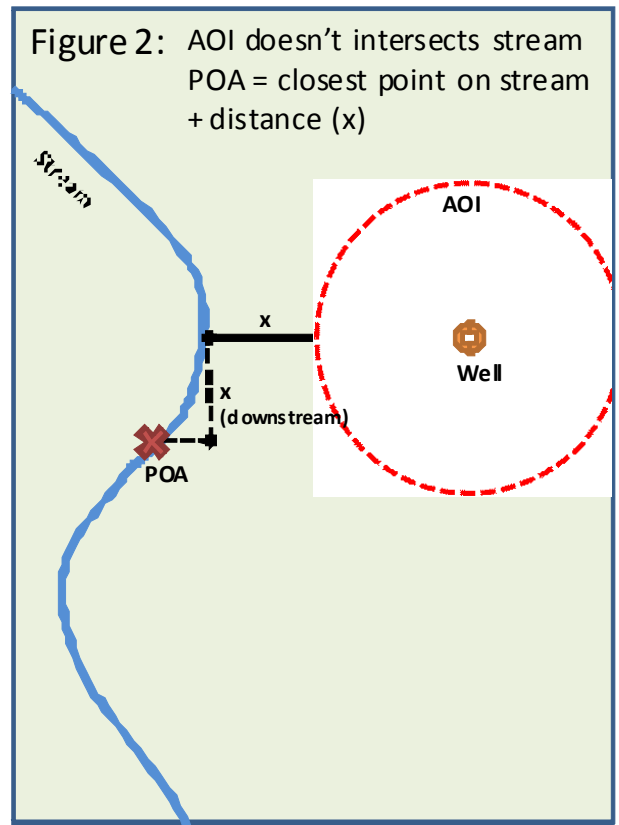
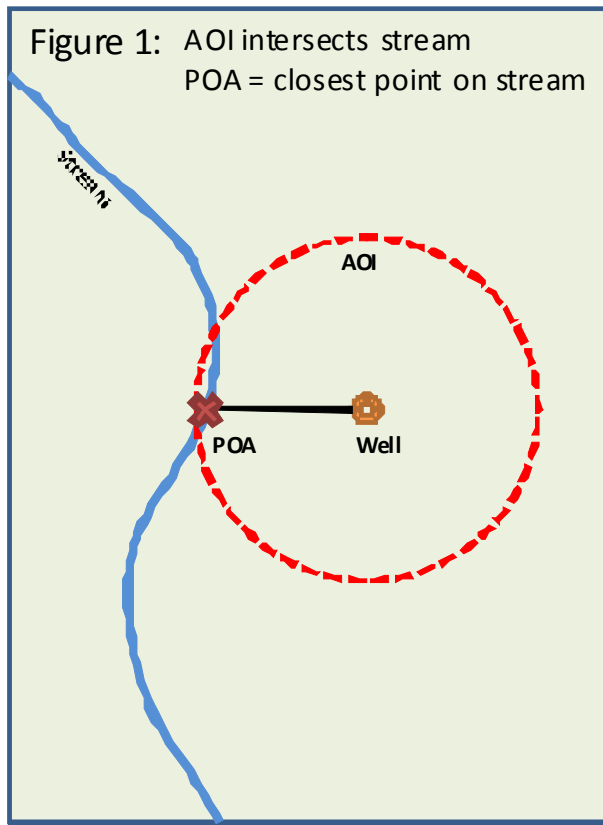
Rantz and others, 1982, *Measurement and computation of streamflow*, Vol.1. Measurement of stage and discharge, Vol. 2. Computation of discharge: U.S. Geological Survey, Water Supply Paper 2175. <http://pubs.usgs.gov/wsp/wsp2175/>

Reeves, H. W., 2008, *STRMDEPL08 — An extended version of STRMDEPL with additional analytical solutions to calculate streamflow depletion by nearby pumping wells*: U.S. Geological Survey Open-File Report 2008-1166. 22 p. <http://pubs.er.usgs.gov/usgspubs/ofr/ofr20081166>

USGS, 2007, *Ground-water management (GWM): Three-dimensional ground-water flow simulation with ground-water management capability using optimization*: <http://water.usgs.gov/nrp/gwsoftware/gwm/gwm.html>

USGS, 2008a, *StreamStats for Connecticut* <http://water.usgs.gov/osw/streamstats/connecticut.html>

USGS, 2008b, *STRMDEPL08 — An extended version of STRMDEPL with additional analytical solutions to calculate streamflow depletion by nearby pumping wells*: <http://mi.water.usgs.gov/software/groundwater/strmdepl08/index.html>



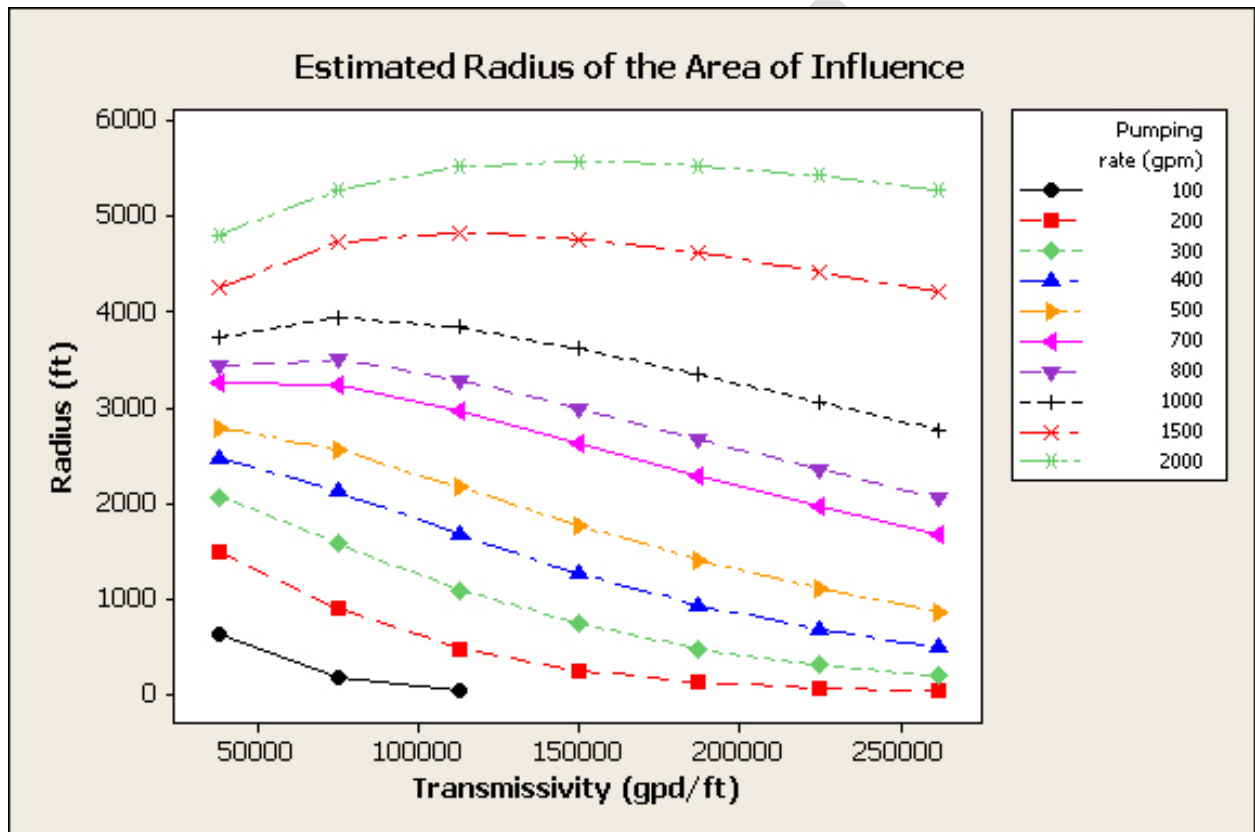


Figure 4. Estimated radius of influence for wells pumping 100 gpm and above.

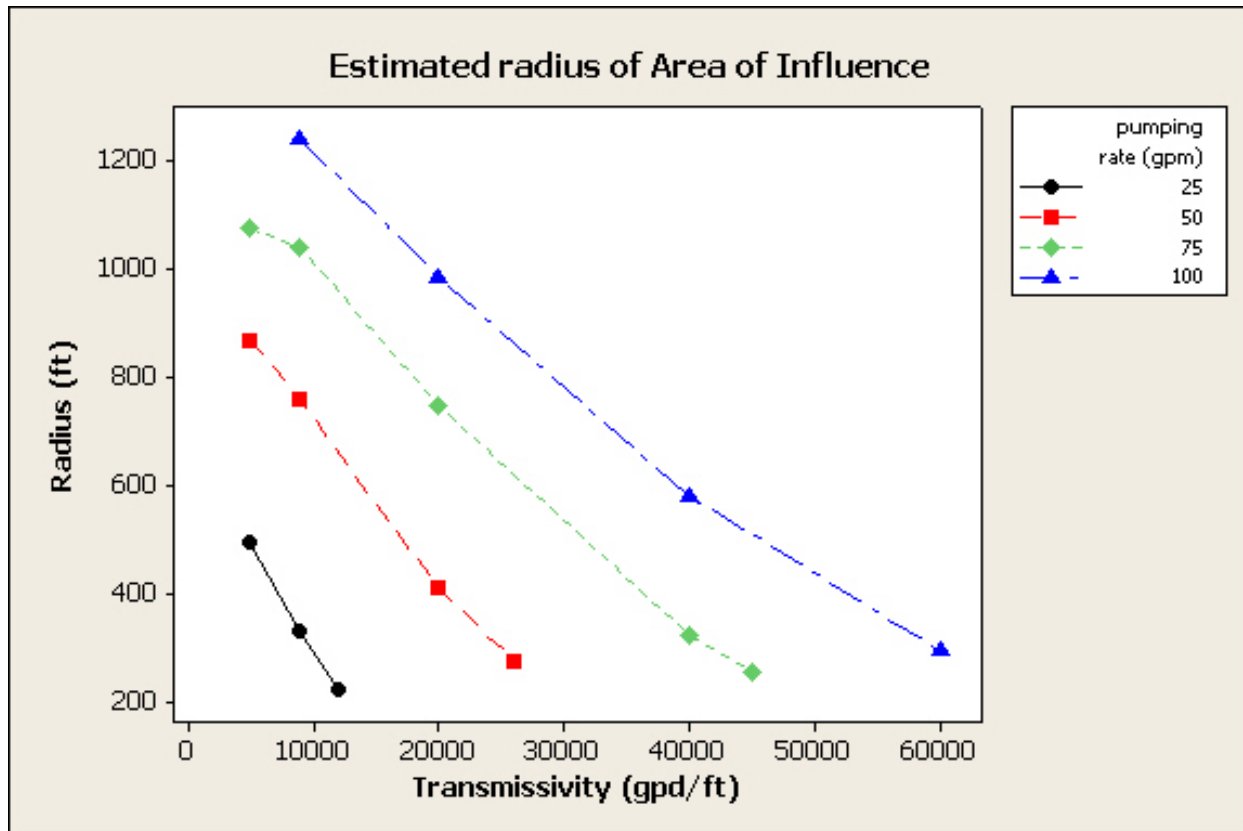


Figure 5. Estimated radius of influence for wells pumping 100 gpm and below.