Review of the State of Art: Ground Water Under the Direct Influence of Surface Water Programs

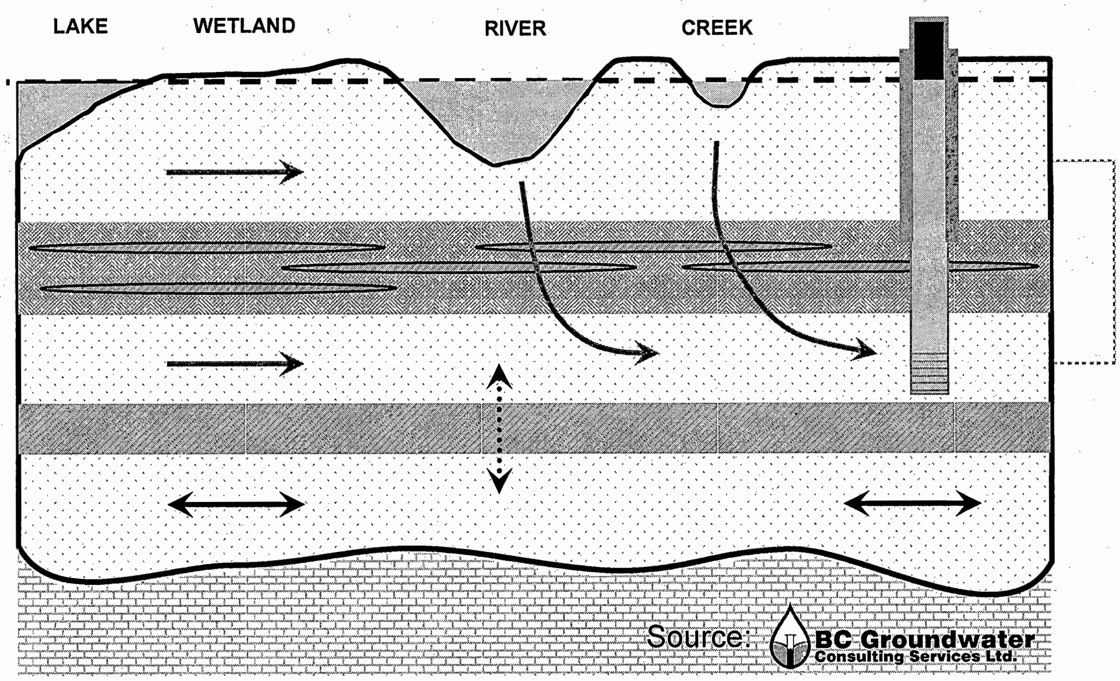

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Table of Contents

Executive Summary

The objective of this study was to (1) evaluate the state of the art for ground water under the direct influence (GWUDI) of surface water programs in the US and other countries, (2) evaluate the existing ground water under the influence (GUI) program in Texas with respect to hydrogeologic parameters and microbial indicators, including total and fecal coliform and microscopic particulate analyses (MPA), and (3) make recommendations to the Texas program based on a synthesis of best practices and elements from all reviewed programs.

The driving force behind these evaluations is the fact that particles entrained in water can make the disinfection process ineffective because pathogens can be shielded within microscopic debris (LeChevallier et al., 1981). Further, some particles themselves, such as Giardia and Cryptosporidium cysts, can be pathogenic even if not encased in debris. Hence, ground water sources that contain surface water linked debris (algae, nematodes, etc) that receive only disinfection have been implicated in many waterborne diseases.

Most states use the term ground water under the direct influence (GWUDI) of surface water, which is synonymous with the ground water under the influence (GUI) term as used in Texas. We were successful in obtaining information from 19 states in the US and 4 provinces in Canada. The GWUDI programs reviewed generally include three phases: (1) hydrogeologic screening and assessment, (2) water quality monitoring, and (3) MPA. The programs for Kentucky, Montana, and Saskatchewan were among the most advanced. The hydrogeologic assessment typically includes evaluation of the general hydrogeologic characteristics of the system, focusing on aspects that pertain to connectivity between surface water and ground water and including evaluation of historical water quality data, including bacteriological data and other parameters such as turbidity, conductivity, and temperature mostly available at monthly timescales. The water quality aspects of the program generally include much more detailed sampling of the relevant surface water and ground water systems at daily to weekly timescales and usually include bacteriological data (total and fecal coliform) and relevant water quality parameters such as turbidity, conductivity, temperature, and precipitation. The more detailed sampling should aim to capture periods of precipitation events in the data. The hydrogeologic assessment and water quality monitoring may provide sufficient information to classify a ground water source as a GUI. However, in the case of uncertainty, MPA analyses can be conducted to provide final assurance on the classification.

The current TCEQ GUI program has an initial screening step that includes a basic hydrogeologic assessment and evaluation of available water quality monitoring data. The ranking based on this screening analysis is used to prioritize wells for MPA analysis for final determination of GUI status. Once wells are classified as GUI, the PWS system has 18 months to come into compliance with State and EPA requirements for such systems through either approved treatment of the affected well's production stream or provision of an alternate supply for the PWS. One weakness in this approach is that Texas presently has ~ 45 wells prioritized for MPA testing (~25 PWS, City of Zavala PWS includes ~

20 wells). Presently the limited funding coupled with precipitation timing yields results for only 9-10 wells/year. Thus, high risk wells may remain unclassified for 4 – 5 years under this scheme. Additionally, MPA tests that are not collected soon after significant precipitation events may give a false negative result for the source. Thus another approach is called for to more quickly identify high risk wells.

Based on the evaluation of responders from 23 different programs from the US and Canada, it is clear that no standardized approach has been embraced. Rather, various approaches have been adopted for GUI program determinations. According to the Kentucky program, all wells in karst aquifers are automatically classified as GUI wells. This approach would be considered conservative and protective of human health. However, such level of protection may not be warranted in that it would unduly press many PWSs into expensive treatment or alternate supplies when their specific carbonate aquifer may provide suitable particle removal.

The five documented outbreaks of waterborne diseases in Texas within the last 30 years have occurred in PWSs in karst. These outbreaks include:

1) Georgetown (Williamson County)-1979. CDC and TDH epidemiology.
2) Georgetown (Williamson County) -1982. TDH investigation.
3) Braun Station (Bexar County)- 1984. CDC and TDH epidemiology
4) The Captains Club (Travis County) 1988, CDC and TDH epidemiology
5) Brushy Creek MUD (Williamson County) 1998-CDC and TDH epidemiology

In each of these cases, thousands of individuals were affected by ground water under the influence of surface water. Therefore, it is clear that karst sources warrant special interest. Such a level of protection, as noted in Kentucky, may not be warranted if a reliable GUI decision process is implemented. Outbreaks are often associated with heavy precipitation events (Rose et al., 2000).

Recommendations:

Our recommendations for modifying the existing GUI program include the following. We recommend a more detailed hydrogeologic assessment and reliance on bacteriological sampling and analyses of turbidity, conductivity, and temperature to determine whether a PWS groundwater source is a GUI or not. A PWS groundwater source can be classified as GUI if there are frequent positives of total and fecal coliform and turbidity fluctuations greater than 0.5 to 1.0 NTU during the year. In the case of infrequent positive total and fecal coliform results and turbidity fluctuations between 0.25 and 0.5 NTU during the year, MPA testing may be conducted because of uncertainties in the other parameters. The occurrence of frequent or infrequent total and fecal coliform results and no turbidity fluctuations should result in the system being risk managed by the Ground Water Rule (2006). If there are uncertainties in the test results, it is appropriate to err on the side of public health and safety and consider the well to be a GUI.

Once a system is classified as a GUI it is critical that a public advisory be sent immediately to the customers being served by the affected well. The TCEQ should collaborate quickly and diligently with the PWS to either find a suitable alternate source or install approved treatment that meets requirements required for the Surface water Treatment Rule.

1 Introduction

Ground water under the direct influence of surface water (GWUDI) has been defined according to EPA regulation (40 CFR 141.2) as "any water beneath the surface of the ground with: a) significant occurrence of insects or other macro-organisms, algae, organic debris, or large-diameter pathogens such as Giardia lamblia or Crytosporidium; or b) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions". Ground water defined as GWUDI may not have received adequate filtration to remove pathogenic organisms through the recharge process.

Many systems classified as GWUDI are found in alluvial aquifers adjacent to streams and rivers, karst systems, and fractured bedrock aquifers. Each state is responsible for classifying public water systems (PWS) groundwater sources as GWUDI, generally through evaluation of the hydrogeology of the system and hydraulic connections with nearby surface water bodies, through similarities between PWS groundwater source chemistry and surface water chemistry and through bacteriological analyses. Waterborne pathogens include bacteria, viruses, protozoa, and helminthes (Table 1).

As a result of the potential threat from surface water pathogens contaminating ground water, the U.S. Environmental Protection Agency (USEPA) amended the Safe Drinking Water Act (SDWA) in 1986, mandating all U.S. states to identify ground water under the direct influence (GWUDI) of surface waters. Amendments to SDWA in 1996 required EPA to develop rules to strengthen protection against microbial contaminants, especially *Cryptosporidium*. The Interim Enhanced Surface Water Treatment Rule (IESWTR) of 1998 was the first set of rules under the required amendment, which included Cryptosporidium, in the determination of GWUDI. This rule applies to public water systems that use surface water or ground water classified as GWUDI and serve at least 10,000 people. In addition, States are required to conduct sanitary surveys for all surface water and GWUDI systems, including those that serve fewer than 10,000 people. A sanitary survey should be conducted every three years for systems serving 4,100 people or less and every five years for systems serving more than 4,100 people for both filtered and unfiltered systems. The EPA regulation (40 CFR 142.16(b)(2)(B)) required the states with drinking water primacy to define a program on how to determine which ground water systems are under the direct influence of surface water by June 29, 1994 for community water systems and by June 29, 1999 for non-community water systems. Recently, EPA published the Ground Water Rule in the Federal Register on November 08, 2006. The purpose of the rule is to provide increased protection against microbial pathogens in public water systems that use ground water sources, with special emphasis on ground water systems that are susceptible to fecal contamination (www.epa.gov/safewater/disinfection/gwr/).

The direct influence must be determined for individual sources in accordance with criteria established by the State. The State's determination of direct influence may be based on site-specific measurements or water quality and/or documentation of well construction characteristics and geology with field evaluation. If ground water in a PWS well is classified as GWUDI, it has to be treated according to the Surface Water Treatment Rule (SWTR).

Ever since the USEPA mandate in 1986, only a few states have adopted EPA's guidelines and have designed a well-defined GWUDI determination program. About 18 states in past 18 years have adopted, or adopted with modifications, the USEPA protocols of 1991 for GWUDI determination. Most of the modifications come from the limitation of Microscopic Particulate Analysis (MPA) criteria for GWUDI classification [*Wilson et al.*, 1996; *Gollnitz et al.*, 1997; *Chin and Qi*, 2000]. The applicability and limitations of GWUDI determining protocols are well discussed by the following published research [*Wilson et al.*, 1996; *Gollnitz et al.*, 1997; *Nnadi and Sharek*, 1999; *Qi*, 1999; *Chin and Qi*, 2000; *Jacangelo and Seith*, 2001; *Kerschen et al.*, 2002; *Nnadi and Fulkerson*, 2002; *Abbaszadegan et al.*, 2003; *Atherholt et al.*, 2003; *Maxwell et al.*, 2003; *Gollnitz et al.*, 2004; *Borchardt et al.*, 2007; *Gunter et al.*, 2008].

1.1 Limitations of Microscopic Particulate Analyses

a) The MPA criteria only relate to (current) conditions at the time the water sample is collected and do not address the possibility of the water source being GWUDI at some other time and under different water-management conditions such as precipitation events,

b) The MPA criteria can only be applied to existing wells and provides no guidance to utilities on whether a planned well near an existing surface-water body, or a planned (man-made) water body near an existing well, would cause the pumped water to be classified as GWUDI.

c) The MPA criteria are not based on the principle of acceptable risk. The risk tables used to interpret MPA results only rate one site versus another, yielding a relative risk and not an absolute risk.

d) An MPA analysis does not measure the removal efficiency of *Giardia*, *Cryptosporidium*, or any other pathogens, and therefore it is not possible to identify GWUDI in accordance with the removal-efficiency criteria in SWTR and IESWTR.

2 The EPA's GWUDI Determination Guidelines

The EPA's GWUDI determination is based on evaluation performed via completing a 'Preliminary Assessment Form'. This includes a series of questions with points associated as a measure for evaluation. The Preliminary Assessment Form evaluates physical characteristics such as; ground water source and its depth, history of microbiological contamination, nearest distance to surface water body and its elevation, well construction, location of spring, and sanitary seal Appendix 1. If a well scores ≥ 40 points, it is at high risk of having water that is contaminated with *Giardia* or *Cryptosporidium* and a series of MPA should be performed. The identified deficiencies should be repaird prior to conducting MPA.

The MPA is used as a deterministic approach to classify GWUDI. It is performed on suspect drinking water wells. The MPA method consists of filtering 1,900–3,800 L (500–1,000 gallons) of pumped water and conducting a microscopic analysis of the filtered material. The composition of the filtered material is assigned a corresponding relative risk factor as points.

1. If a system obtains ≥ 20 points, it is at high risk of being GWUDI. In the case of high risk, the State requires filtration and disinfection of the well or spring within 18 months. If a Bureau of Land Management (BLM) water source is determined to be GWUDI, the water source should be: properly abandoned or all water taps clearly labeled "NON POTABLE" and the information about *Giardia* and *Cryptosporidium* posted.
2. If a system scores 10-19 points, it is at moderate risk and the State may require: annual MPA testing, dye tests, comparison of turbidity, pH, conductivity and temperature between the well or spring and the nearby surface water.
3. If a system obtains points ≤ 9, it is at low risk and the state may require chlorination of a well or spring, nonetheless. The detailed sampling and analysis protocols are outlined by the USEPA Consensus Method for Determining GWUDI using Microscopic Particulate Analysis [*Vasconcelos et al.*, 1992].

3 State of the Art Programs

This study identified 19 states in the USA and 4 provinces in Canada that use USEPA GWUDI determination protocols in some form or with modifications. Note- additional states' programs likely exist but were non responsive to the study survey. A description of these programs is as follows:

3.1 Arkansas

The State of Arkansas has developed an evaluation process to determine GWUDI which includes assessment of ground water quality, well construction and location, and hydrogeologic conditions. The first step in the evaluation process is to determine the geologic setting. If the well is in one the non-sensitive geologic areas, such as the Gulf Coastal Plain or Mississippi Embayment regions, the evaluation is generally limited to a review of historical water quality, sanitary surveys of the system and, if available, well construction reports. Depending on the review of this historical information, follow-up raw water monitoring may be conducted. If the well is located in one of the sensitive geologic settings (i.e. the Ozark, Arkansas Valley or Ouachita Mountain regions), an on-site investigation is conducted on each well and raw water quality data collected.

A GWUDI determination depends on the presence of one or both of the following conditions: 1) indicator organisms such as chlorophyll containing algae or other surface water organisms are present in large numbers, and/or 2) well construction, siting, and hydrogeologic conditions indicate a definite pathway for surface water influence and water quality data validates the pathway. A typical evaluation will include the completion of a preliminary weighting form ('short form', Appendix A2 a) to prioritize follow-up actions. This preliminary evaluation assigns standardized point values for the geologic setting, well construction and siting, preliminary raw water data such as raw water coliform analyses and / or nitrate levels, and other factors. A review of the preliminary weighting form is made by one or more individuals other than the primary evaluator to determine follow-up actions. Follow-up actions may include one or more of the following:

1. Determine whether ground water in a well is GWUDI. (Note: A GWUDI determination using the preliminary weighting form is only made in obvious cases such as an unprotected hand dug well.)
2. Determine the additional monitoring data is necessary. Additional monitoring generally includes:
   a) Analyzing raw water for total coliform / fecal coliform, turbidity and iron at a frequency of one per week for six to twelve weeks.
   b) Measuring precipitation, raw water temperature and air temperature daily for six to twelve weeks.
   c) Collecting one or more samples for microscopic particulate analysis.

3. Determine whether a more detailed evaluation ('long form', Appendix A2 b) should be used.

   a) The detailed evaluation uses a standardized point system similar to the preliminary weighting form. Based on the number of points assigned, the well is determined to be either GWUDI or not GWUDI. A weighting system was established giving primary importance to raw water quality followed in importance by well construction and finally hydrogeologic conditions. Any well that scores 100 or more points is declared to be ground water under the direct influence of surface water. The order of importance of typical rating factors is indicated in the table below. Factors in the upper left portion of the table are considered more important in the decision process than factors in the lower right portion of the table below;

Raw Water Quality	**Well Construction & Siting**	**Hydrogeologic Conditions**
MPA results	Casing and grout depth	Static water level correlated with surface water conditions
Fecal / E. Coli results	Well head below grade or subject to flooding	Water producing zones correlated with surface water conditions
Total coliform results	Presence and condition of protective slab around casing	Proximity of sinkholes, depressions or fractures
Turbidity/Temperature variations correlated with climatological conditions	Proximity to surface water source or other sources of contamination	Proximity of rock outcrops and formation dip and strike
Other bio-indicators	Well seal & well venting	Other

3.2 California and Florida, USA, and Nova Scotia, Canada

The states of California, Florida, and Nova Scotia (Canada) have adopted guidelines similar to EPA's guidelines. The "preliminary assessment" used in EPA's guidelines is divided into screening and hydrogeological assessment with additions and elaborations of EPA listed guidelines.

To determine GWUDI, these states have adopted a three step process, which includes 1) screening, 2) hydrogeological assessment: Determining a hydraulic connection between ground water and surface water, and 3) MPA analysis. Systematic descriptions of these choices are also described by a flow chart in Appendix 3.

The process of screening for GWUDI includes examining: 1) sensitive settings to ascertain that the source is not a spring, infiltration gallery, horizontal collection well, well in karst aquifer, well in unconfined aquifer, and well that is a part of an enhanced recharge/infiltration project, 2) proximity to surface water, 3) well construction, and 4) water quality data for total coliform and turbidity.

Next, the hydrogeological assessment is used to determine if there is a hydraulic connection between ground water and surface water. It involves reviewing one year of water quality data (such as temperature, conductivity, turbidity, and pH). The well is classified as GWUDI if it is in hydraulic connection with surface water or precipitation. If there is any uncertainty, it is still classified as potentially GWUDI. The potential for a hydraulic connection is assessed based on time of travel between the well and surface water. A combination of aquifer characteristics, well characteristics, hydraulic gradient, and water quality are used together with a final MPA test to determine if the source is GWUDI. The MPA tests are conducted according to EPA's Consensus Method [*Vasconcelos et al.*, 1992].

3.3 Washington

The state of Washington stresses on the definition of surface water and employs water quality monitoring as a diagnostic test to determine if ground water is in hydraulic connection with surface water. The MPA testing is conducted only after a determination of GWUDI via water quality monitoring.

The state identifies sources of potential GWUDI as 1) infiltration galleries and Ranney wells, 2) springs, 3) shallow wells (≤ 50 feet), and 4) wells located within 200 feet of surface water body (Appendix 4).

The assessment of hydraulic connection of ground water to surface water is determined by water quality monitoring. Water and air temperature, conductivity, pH, turbidity, stream flow, surface water levels, ground water levels, and pumping are measured weekly whereas total coliform is monitored on a monthly basis both for ground water and the potential surface water source. The outcome of water quality monitoring, results in two possible designations; 1) designation of a source as ground water, and 2) designation of a source as ground water in hydraulic connection with surface water. At last, the MPA tests are conducted according to EPA's Consensus Method [*Vasconcelos et al.*, 1992].

3.4 Arizona

The Department of Environmental Quality (DEQ) in the state of Arizona determines GWUDI through a series of steps, which includes an initial identification of suspect sources of GWUDI. The sources and well characteristics under review are; 1) a spring, infiltration gallery, ranney well, horizontal well; 2) if distance of a well that is less than 500 feet from surface water, 3) a shallow well with well screens ≤ 50 feet, 4) a hand-dug or auger-bored well without a casing, 5) turbidity, 6) presence of total coliform, fecal coliform, or *E. Coli* in untreated ground water, and 7) temperature variations of 15% to 20% from the mean ground water temperature over the course of a year or if changes in the temperature of the ground water correlate to similar changes in the temperature of surface water.

If a ground water well is suspected to be under the influence of any of the above mentioned sources or characteristics, the department can require a public water system to conduct MPA monitoring of the ground water source. The MPA tests are conducted according to EPA's Consensus Method [*Vasconcelos et al.*, 1992]. Also, a public water system can use an alternative method to determine GWUDI. However, this method requires approval of the Arizona Department of Health Services under 9 A.A.C. 14, Article 6.

The MPA results are evaluated based on a decision matrix for determining GWUDI status (Table 1, Appendix 5). The relative risk index is assigned to MPA results to determine GWUDI; for example, a) if the MPA risk rating of the initial sample indicates a high or moderate risk of direct surface water influence, the public water system must collect a second sample for MPA at the same location. If the MPA risk rating of the second sample indicates a high or moderate risk of direct surface water influence, the department will classify the site as GWUDI. If the risk rating of the second sample indicates a low risk of direct surface water influence, the public water system must collect a third sample for MPA at the same location. If a third sample is taken and the MPA risk rating of the third sample indicates a high or moderate risk of direct surface water influence, the department will declare the site as GWUDI. If the MPA risk rating of the third sample indicates a low risk of direct surface water influence, the department shall determine that the ground water is not under the direct influence of surface water. b) If the MPA risk rating of the initial sample indicates a low risk of direct surface water influence, the public water system shall collect a second sample for MPA at the same location on a date scheduled by the department. If the MPA risk rating of the second sample indicates a low risk of direct surface water influence, the department will determine the site as non-GWUDI. If the MPA risk rating of the second sample indicates a high or moderate risk of direct surface water influence, the public water system must collect a third sample for MPA at the same location on a date scheduled by the department. The third sample is evaluated as described earlier in this section.

3.5 Illinois

In the state of Illinois, GWUDI is determined based on a questionnaire required to be completed by the public water system. The questions are designed to understand: 1) the depth and length of the well casing, the host material of the well casing, 2) location of a well relative to surface water body, livestock, grazing areas or feedlots, if within 50 feet of the well; sewers of non-watertight construction, if within 50 feet of the well; sewage disposal pits, leach beds, or improperly abandoned wells, if within 400 feet of the well; septic tanks or subsurface septic tanks effluent disposal tile, if within 75 feet of the well, and 3) history of flooding, total coliform or fecal coliform contamination in last 3 years, significant water quality shifts (e.g. turbidity, temperature, pH, taste & odor), and disease outbreaks.

These questions once completed by a professional representing the agency, are evaluated by the Illinois Environmental Protection Agency to determine the source if GWUDI (Appendix 6). The state department doesn't indicate if any MPA testing is performed on potential GWUDI wells.

3.6 Kentucky

In the state of Kentucky, the Department of Environmental Quality (DEQ) requires that all raw water sources for all public water supplies be evaluated and classified as surface water, ground water or GWUDI. GWUDI is determined in a series of steps which include: 1) examination of local geology with respect to possibility of surface water influence, 2) long-term monitoring of the untreated water for variations in temperature, turbidity, conductivity, pH, and 3) MPA.

In the process of GWUDI determination, the source is reviewed first, which includes assessment of; 1) hydrogeology of the aquifer, 2) well depth, its construction and location relative to surface water body, 3) historical data of total or fecal coliform contamination (last 3 years), turbidity problems, and known or suspected disease outbreaks. If the result of source review does not indicate either GWUDI or non GWUDI, particulate analysis and review of other indicators should be conducted.

Several physical (e.g. temperature, turbidity), biological (such as the presence of Giardia lamblia, Cryptosporidium, algae, rotifers, diatoms, insects), and chemical (e.g. pH, conductivity, hardness) indicators are used for GWUDI determination (Appendix 7). These indicator parameters are measured/monitored daily over the course of a year to evaluate the influence of surface water. In addition, the source is be evaluated by MPA testing after the EPA Consensus Method [*Vasconcelos et al.*, 1992]. A systematic description of all these choices made for GUWDI determination is explained by a flow chart in Appendix 7. The results or interpretation of indicator parameters or MPA are not assigned any point but GWUDI determination is based on case by case basis. Presence of algae, rotifers, diatoms, insects, and other microorganisms (>7 μm), significant variation in physical and chemical characteristics in ground water and noted similarities to nearby surface water, are however, considered good indicators of surface water influence.

3.7 Montana

In the state of Montana, the GWUDI determination process is systematically classified into; 1) Preliminary Assessment (PA), 2) Hydrogeologic Assessment, 3) Water Quality Assessment, and 4) MPA.

At first, the Preliminary Assessment is conducted by completing a questionnaire which uses a point system to evaluate the water sources. The PA includes evaluation of: 1) location, depth, and height of ground water well relative to a spring, river, infiltration gallery, or horizontal well; 2) historical data of pathogenic organism and microbiological contamination of last 3 years; 3) well construction, casing, and sanitary seal; 4) hydrogeology of the aquifer and its overlying and underlying formations. A point score from each of the parameter is summed to determine GWUDI status. For example, a score of less than 40 classifies it as ground water and any score above that requires further assessment. Further assessment includes the WQA, HA, and MPA. A systematic decision making scheme to determine GWUDI is explained by a flow chart in Appendix 8.

The purpose of hydrogeologic assessment and water quality assessment is to determine if a hydraulic connection exists between the ground water source and surface water. A hydraulic connection is a pathway through which water can travel between surface water and an aquifer. If the WQA or HA results indicate a hydraulic connection, MPA testing is required to determine if surface water organisms are present. A hydraulic connection alone, however, is not considered sufficient to establish direct surface water influence. The hydrogeologic assessment and water quality assessment are considered optional and their evaluation can be bypassed to directly conduct MPA sampling, whose results are considered deterministic for finding surface water influence.

HA includes evaluation of; a) regional geology, b) regional and local ground water flow systems, c) surface water body (swb), d) PWS well construction, and e) PWS pumping well characteristics.

Water quality assessment is more rigorous than the hydrogeologic assessment. If the water quality assessment is negative (a hydraulic connection is not found), the source is declared ground water. This occurs even if the hydrogeologic assessment had "indicated" an apparent hydraulic connection. If the water quality assessment is positive (indicates a hydraulic connection), the source must undergo MPA testing or be classified as surface water. The results of the MPA will, in most cases, dictate the final classification of the source.

Water quality assessment involves weekly measurements up to a year of water quality parameters in ground water and nearby surface water. The parameters monitored are 1) temperature, 2) turbidity, 3) conductivity, 4) weather conditions, and 5) pH.

If the data from the ground water shows little or no correlation with data from the surface water (i.e. a "negative" result), then there is not a hydraulic connection and the source will be classified as ground water. If a correlation is found between the data (i.e. a "positive" result) or the results are ambiguous, MPA will be required.

Finally MPA is used to determine if surface water organisms are present in the ground water. The state recommends using the EPA's Consensus Method for GWUDI determination [*Vasconcelos et al.*, 1992].

3.8 New Jersey

The Department of Environmental Quality (DEQ) in the state of New Jersey requires the PWS operators to complete a questionnaire, based on which the department determines GWUDI status (Appendix 9). The questions are designed to evaluate: 1) well depth, construction, casing size and length, screen size and length;2) well capacity, aquifer type and its adjacent formations; 3) operational status; 4) location of well relative to an infiltration gallery, spring, cistern, catchment, or dug well; and 5) data history of last 60 months for microbial pollution (i.e., septic systems, cesspools, feedlots, storm water detention basins or point discharges of highway drainage).

Based on the answers to the above mention questions, the DEQ determines if the source is GWUDI. Should the source be GWUDI, it becomes subject to the monitoring provisions of the Surface Water Treatment Rule. The DEQ does not specify any requirement for detailed hydrogeological assessment, water quality monitoring, or MPA.

3.9 Oregon

The state of Oregon requires a state level review to identify all the systems with ground water sources within 500 feet of surface water sources and evaluation of the history of coliform bacteria in those ground water sources. These wells within 500 feet of surface water, but without coliform bacteria problems are reviewed for the grout seal. The wells that have neither source-related bacteria problems nor inadequate seals are not considered further. However, for systems where either source-related *coliforms* are suspected or the seal adequacy is questionable, further study involves a detailed hydrogeologic assessment and an evaluation of water quality parameters over a period of 12 months (Appendix 10).

Hydrogeologic assessment evaluates: 1) well characteristics; 2) aquifer characteristics and its association with neighboring formations; 3) vadose zone characteristics; 4) local and regional hydraulic gradient and its variations with time; and 5) ground water flow in relation to steady state capture zone and estimated travel time for water between potential surface water source and the well. If the hydrogeologic assessment indicates the potential for hydraulic connection, the system will be required to initiate a water quality assessment.

Water quality analyses require weekly data collection for a year to determine if ground water quality varies sympathetically with surface water, supporting or refuting the surface water connection. The parameters monitored include; weekly rainfall, temperature, pH, conductivity, dissolved oxygen, hardness, or other dissolved constituents. Turbidity is not used because previous data have shown that turbidity is not a good indicator.

If either the hydrogeologic or water quality assessments indicate that the aquifer is in hydraulic connection with surface water, EPA's Consensus Method using MPA is used for determining GWUDI. The presence or absence of "insects, algae or other larger diameter pathogens" from the MPA analysis alone is considered not to be used as criterion to determine GWUDI.

3.10 Tennessee

In 1991, the state of Tennessee required that the presence or absence of direct surface water influence must be determined for each individual ground water source used to supply public water systems (PWS). The state described at least three different ways to determine whether or not a ground water source is under the direct influence of surface water: 1) determination of hydraulic connection, 2) long term monitoring of water quality, and 3) Micro-particulate analysis (MPA). The state also point out that there are other physical, chemical, and biological indicators that could help determine GWUDI. These parameters listed by the state of Tennessee are the same as those listed by the state of Kentucky (Appendix 7 and 11).

The process of GWUDI determination includes a procedure of reviewing a well source, a spring source, and evaluation of sources via particulate analysis. Well sources that are that are subjected to this review process are categorized as; 1) systems that do not disinfect, 2) systems that disinfect water pumped from sand and gravel aquifers, 3) systems that disinfect water from wells in middle and eastern Tennessee, 4) systems with wells that produce water from aquifers at depths ≤ 50 feet. All these categories of wells are reviewed for the presence of coliform bacteria, turbidity, temperature that could correlate with those of the surface water. Only the wells that show correlation with surface water conditions are required to pursue additional sampling for MPA.

Springs are evaluated to determine if they are under the influence of surface water. Historical water quality data are reviewed for the presence of coliform and changes in conductivity, turbidity, temperature, and pH especially after a rainfall event. Any indication of influence from surface water requires additional MPA testing. The EPA's consensus method for determining GWUDI is used as the sampling and risk assessment protocol [*Vasconcelos et al.*, 1992].

3.11 Utah

In an initiative to protect the public from waterborne disease, the state of Utah has adopted multistep protocols to determine GWUDI. The steps include identification of the contamination sources, and processes of Screening, Intermediate Analysis, and Final Analysis (Appendix 12).

The sources of Giardia contamination are considered as surface water, livestock, on-site sewage systems, feedlots, injection wells, and sewage sludge pits. The systems which have experienced outbreaks of *Giardiasis, Cryptosporidiosis*, or other diseases caused by pathogenic organisms strictly associated with surface water are automatically classified as GWUDI sources. Bacterial and viral outbreaks are not exclusively associated with surface water; therefore, they do not automatically trigger the GWUDI determination, but at least trigger an Intermediate Level analysis.

Screening comprises 1) evaluating springs and infiltration galleries relative to the location of a ground water well, 2) evaluating hydrogeology to determine hydraulic connection between ground water well and a nearby surface water source, and 3) assessing the history of microbial contamination. Points are assigned based on factors such as, the distance of ground water well from surface water body, well depth, aquifer characteristics, presence of impermeable formation, fractures, history of microbial contamination, and number of disease outbreaks etc. Based on the points assigned, the ground water source is either defined as ground water, or prescribed for Intermediate Analysis, or prescribed for Final Analysis.

Intermediate Analysis consists of evaluating a sanitary survey and water quality monitoring. Sanitary surveys conducted within the previous two years should be valid and are used to detect surface water intrusion, identify potential *Giardia* sources in the vicinity of the well, and gathering information for water quality monitoring locations. Total coliform, conductivity, and specific ions are monitored almost on a weekly basis whereas; temperature, and turbidity are monitored on a daily basis, for a period of one year. Points are assigned based on similarity between ground water data with that from a nearby surface water source. A significant similarity determines the source as GWUDI whereas some similarities mandate Final Analysis. If the data do not indicate any correlation between the two sources, it is classified as ground water.

Final Analysis involves MPA testing, a form of most conclusive evidence for determining GWUDI. If MPA results conflict with hydrogeologic analysis or water quality parameter monitoring results, the MPA results are considered conclusive. However, MPA results cannot be used to overrule the 5 NTU ground water turbidity standards. The EPA's consensus method is used for determining GWUDI.

3.12 Connecticut

The state of Connecticut has tabulated a list of criteria for GWUDI determination for existing, new, or replacement wells, and wells which are not in the bedrock. If a well is; 1) ≤ 200 feet from a nearby upgradient surface water body, 2) or ≤ 50 feet from a surface water body when a well screen is separated by a confining layer, 3) has no history of waterborne disease outbreak due to *Giardia* or other pathogenic organism or *E. coli*, and 4) source water turbidity has not exceeded 1.49 NTU in previous three years, the source is classified as ground water, otherwise it is potentially under the direct influence of surface water (Appendix 13).

A GWUDI demonstration study must be performed on wells determined to be potentially under the direct influence of surface water. Such a demonstration study entails; 1) collection and analysis of weekly surface and ground water samples for conductivity, temperature, turbidity, pH, color, and rainfall, 2) weekly testing for total coliform and *E. coli* bacteria, and 3) quarterly testing for microscopic particulates (MPA). These tests are intended to show if: a) there is a relationship between surface and ground water physical parameters; b) bacteria are present in the untreated ground water; and c) biological indicators of surface water are present in the ground water.

The results from the GWUDI demonstration study are compiled in a report which should include analytical test report for the four quarterly MPA samples, determination of relative risk factors as presented in EPA's Guidance Manual, and graphs depicting weekly monitored physical parameters. The final determination of GWUDI status, based on demonstration study findings is, however, determined on a case-by-case basis.

3.13 Georgia

In the state of Georgia, the environmental protection division is in the process of conducting investigations to determine those public ground water sources that are under the direct surface water influence. These determinations are based on evaluations of information from system records, site inspections, and water quality analysis. Water quality analysis includes Microscopic Particulate Analysis (MPA) (Appendix 14).

In addition, water sources are tested for indicators such as plant debris, algae, protozoa, cyanobacteria, living diatoms, nematodes, rotifers, crustaceans, insects, insect parts, spores, pollen, and human pathogens such as *Amoeba*, *Giardia cysts*, and *Cryptosporidium*. A significant occurrence of indicators implies that a ground water source is under the direct influence of surface water (GWUDI).

3.14 New Mexico

In the state of New Mexico, GWUDI determination is seen as a measure to control waterborne pathogens, i.e. *Cryptosproridium* and *Giardia lamblia*. GWUDI status is determined by collecting samples for the MPA. The samples are collected from spring houses, infiltration galleries, shallow wells less than 100 feet in depth in known bedrock or karst areas, wells located within 200 feet of known surface waters, wells located in areas that are periodically flooded, wells without sanitary seals, and wells suspected of waterborne sickness or outbreak. Turbidity, pH, and temperature are also used in conjunction with the (MPA) to determine if a ground water source is under the influence of surface water. The MPA testing is conducted periodically (every (4-6 months) until the system is classified as surface water or two consecutive samples have been classified as "Non-detect", in which case the source is classified as ground water (Appendix 15).

3.15 Pennsylvania

The GWUDI determination protocols from the State of Pennsylvania are inferred from a study reported by the Center of Environmental Quality, Wilkes University. The GWUDI evaluation is conducted in three steps; 1) hydrogeologic setting, water quality monitoring, and MPA/MET analysis, 2) long-term daily monitoring, and 3) follow-up water quality and particulate analysis. The Microscopic Evaluation Technique (MET) involves identification, sizing, and population estimates of microorganisms and organic or inorganic debris found in water. The MPA/MET sample collecting protocol is described in Appendix 16. The hydrological assessment is conducted to determine the potential sources of contamination, possible routes of contamination, and overall security of the source. The daily monitoring for a period of six months is conducted for temperature, pH, turbidity, conductivity, static water level, pumping rate, and flow rate. The MPA/MET results for Giardia, Coccidia, algae, insect/larvae, rotifers/crustacea, and plant debris are categorized into relative risk factors, which in turn help decide the surface water influence. The tables used to classify microorganisms relative risk factors are described in Appendix 16.

3.16 Vermont

The State Secretary determines if the source is GWUDI based on water quality testing data and site visits. Ground water samples are collected for Microscopic Particulate Analysis when the source meets any one or more of the following criteria: 1) history of water-borne disease; 2) one or more violations of total coliform maximum contaminant level; 3) subject to annual flooding; 4) spring or infiltration gallery; 5) yield more than 500 gallons per minute; 6) less than 150 feet from a surface water body and: a) less than 50 feet of soil over the screen, end of casing, or bedrock surface; b) no confining layer; or c) a direct hydraulic connection; 6) bedrock well farther than 150 feet from the nearest surface water but has: a) less than 50 feet of watertight casing; and b) no confining layer. In addition, water quality testing is conducted for a period of six months which includes total coliform testing and E coli testing, as an indicator for MPA testing (Appendix 17).

3.17 West Virginia

The State of West Virginia is in the process of determining PWS wells that are under the direct influence of surface Water. The criteria for GWUDI determination used by the State are based on 1) physical parameters in wells and in surface water in the nearby streams and 2) monitoring bacteria (bacti test) to determine which ground water sources are affected by surface water sources (Appendix 18).

3.18 Wisconsin

The GWUDI determination protocols from the State of Wisconsin are inferred from a study reported by the Public Water Supply Section, Wisconsin (Appendix 19). The study was conducted to determine whether wells under consideration were GWUDI or not. The study methodology includes evaluation of; 1) raw water Total Coliform Test, 2) well construction, and 3) well location. The GWUDI determination is carried out in three phases. Phase 1 is one time sampling for macroorganisms (Giardia, insects, algae, crustaceans, etc.) and Total Coliform Bacteria, and monitoring of physical parameters such as temperature, turbidity, conductivity, and hardness. Phase 2 is similar to Phase 1, but increase in number of sampling events and sampling intervals. Phase 3 includes evaluation of well depth, casing depth, aquifer type, transmissivity, specific capacity, storativity, physical proximity to surface waters, and total pumpage (during the sampling and during normal operation), and calculation of zone of influence and time of travel.

The Total Coliform Test is used as an indicator for the occurrence of *Giardia cysts* and as a measure of direct influence from surface water. The monitoring of the physical parameters and hydrogeological investigation is to evaluate if there is a link between the ground water source and the nearby surface water. The GWUDI determination decision process is also explained in a flow chart (Appendix 19, Fig. 1).

3.19 Ontario, Canada

In Canada the state of Ontario defines GWUDI as ground water having incomplete/undependable subsurface filtration of surface water and infiltrating precipitation. Well water is considered GWUDI if it has: a) physical evidence of surface water contamination (eg. insect parts, high turbidity); and b) surface water organisms (e.g. Campylobacter, aerobic spores, Cryptosporidium, Giardia). In addition, communal wells are "flagged" as potential GWUDI if they: a) regularly contain Total Coliforms and/or periodically contain E. coli; or b) are located within approximately 50 days horizontal saturated travel time from surface water or are within 100 m (overburden wells) or 500 m (bedrock wells) of surface water (whichever is greater) and meet one or more of the following criteria: 1) wells drawing water from an unconfined aquifer; 2) wells with screens ≤ 15m from the surface; 3) wells which are part of an enhanced recharge/infiltration project; 4) similar variation of water quality parameters (such as temperature, conductivity, turbidity, total dissolved solids, pH, color, oxygen) between ground water and nearby surface water sources.

Wells are considered GWUDI unless a hydrogeological study proves otherwise. This hydrogeological study includes, but not necessarily limited to; a) characterization of hydrogeologic setting; b) description of local surface water features; c) assessment of the physical condition of on-site wells; and d) evaluation of source ground water quality.

Characterization of hydrogeologic setting involves determining travel time between the ground water well and nearby surface water and configuration of zone of influence of the well. This entails a detailed study for aquifer characteristics, evaluating aquifer and bedrock geology including description of structural feature (such as fractures, joints, bedding planes, faults, and shear zones), and local hydrogeology which involves defining hydrogeologic features (aquitards and confined, unconfined and semi-confined aquifers) including details of their depth, thickness, lateral continuity, porosity, vertical/horizontal hydraulic gradients, hydraulic conductivity, transmissivity, storativity/specific storage and the location/nature of aquifer recharge supplying the well. In addition historical/seasonal ground water level trends are evaluated along with pump test analyses. The hydrogeological study also includes interpretation of three dimensional flow patterns and assessing hydraulic connection between aquifers and between water producing zones in wells and nearby surface water under pumping and non-pumping conditions.

A detailed description of surface water features involves evaluating the role of local topography, understanding seasonal variations and associated water levels (based on field measurements or historical photo interpretation), impact of surface runoff drainage patterns on the supply well, effect of land use and evaluation of historical/seasonal trends of surface water quality.
Assessment of physical condition of on-site wells includes well construction history, description of well casing, screen interval, and yield.

Evaluation of source ground water quality (electrical conductivity, pH, turbidity, temperature, water levels, and rainfall) is used to determine whether any observed significant or rapid shifts in water quality reflect impacts from infiltrating surface water or are caused by geochemical reactions within the aquifer. This would include correlation of source water quality data with seasonal variations, observed historical trends, precipitation events and pump use. Each water supply well is classified as being either a) under the direct influence of surface water, or b) not under the direct influence of surface water. In case of uncertainty, it is still classified as under the influence (Appendix 20).

3.20 Saskatchewan, Canada

The state of Saskatchewan has adopted GWUDI determination guidelines that consist of three phases, beginning with a screening phase that helps identify obvious non-GWUDI sources that do not require a detailed investigation. Sources that fail the screening are considered potentially GWUDI and are subject to enhanced water quality monitoring. The sources that fail the monitoring evaluation are declared GWUDI or are tested for the presence of hydraulic connection. If there is no hydraulic connection then a source is non-GWUDI. If a hydraulic connection exists, samples are collected for MPA analysis to determine if there are particles present in the ground water source that are indicative of surface water. However, the final determination of whether a well is GWUDI or non-GWUDI is considered a matter of professional judgment based on all of the evidence collected (Appendix 21).

3.21 Yukon, Canada

In the state of Yukon, Canada, the GWUDI determination consists of similar protocols to those of the state of Saskatchewan. At first, potential GWUDI sources are identified through a screening process. If a source passes the screening test, it is called as non-GWUDI. If the source fails the screening test, it requires hydrogeological review and, depending on the confidence of the results, it may be classified as non-GWUDI or may require detailed hydrogeological investigation. The detailed hydrogeological investigation is a means to determine if there is a hydraulic connection. If there is no hydraulic connection, the source is classified as non-GWUDI. Alternative MPA samples are collected for final determination based on travel time analyses. MPA testing is, however, optional and GWUDI determination can be made via screening or hydrogeological investigation, independently (Appendix 22).

3.22 TCEQ Ground water under the Influence Program

In the state of Texas, TCEQ is in the process of re-evaluating its GUI (Iin Texas GUI is synonymous with GWUDI) determination program. The current decision support system is based on evaluating different attributes and assigning points which are summed up and used as a ranking scheme for possible MPA sampling. The attributes evaluated are:

1) Local attributes - this is assessment of distance to nearby surface water body and nearby GUI well.
2) Type of potential contamination source – this involves evaluating the possible source of contamination: lake, pond, septic field, river, creek, or stream.
3) Plumbing and operational procedures – it is assessment of sampling logistics such as available pumping rates and access point for sampling.
4) Well construction/lithology – this involves noting the depth of well screen, static water level, extent of annular cement and lithology around the well.
5) Contamination – analysis of historical data for Giardia/Cryptosporidium related disease outbreak, frequency of fecal coliform detection, occurrence of diatoms, algae, insects, rotifers, and plant debris.

Each of the above discussed attributes is assigned points between 0 and 20. The points from each attribute are added to fit a ranking scheme, which then helps determine need for MPA sampling. MPA sampling is out sourced under a contract to the USGS.

4 Recommendations for TCEQ GUI Program

TCEQ currently relies heavily on MPA testing for classifying a PWS groundwater source as GUI or not. Texas uses a preliminary assessment (GUI Determination Decision Scoring System, Fig. 1) to short list 'candidate wells' for MPA testing. Our recommendation begins with suggesting that MPA could be used as an optional testing method rather than its current usage as the ultimate testing approach. This recommendation is based on the following;

1) The MPA criteria only relate to (current) conditions at the time the water sample is collected and do not address the possibility of the water source being GWUDI at some other time (different precipitation) and under different water-management conditions.
2) The MPA criteria can only be applied to existing wells and provide no guidance to a water supplier on whether a planned well near an existing surface-water body, or a planned (man-made) water body near an existing well, will cause the pumped water to be classified as GWUDI.
3) The MPA criteria are not based on the principle of acceptable risk. The risk tables used to interpret MPA results only rate one site versus another, yielding a relative risk and not an absolute risk.
4) An MPA analysis does not measure the removal efficiency of *Giardia*, *Cryptosporidium*, or any other pathogens, and therefore it is not possible to identify GWUDI in accordance with the removal-efficiency criteria in SWTR and IESWTR.
5) MPA testing is not a cost or time effective exercise especially when the regulatory entity (State or Province) has to classify large numbers of PWS groundwater sources.
6) MPA testing requires sampling with specific timing relative to rainfall events; therefore, limiting its frequency especially in states like Texas, where long-term droughts occur.

It is very important that PWS well candidates receive GUI determinations in a timely manner to be protective of public health. Most of the waterborne disease outbreaks in Texas and many other states have been associated with PWS wells sourced in karst. The State of Kentucky has classified all PWS groundwater sources in karst/carbonate aquifers as GWUDI. This approach could be considered in Texas and would ensure that the program is protective of human health; however, it would unduly include and force costly treatment or alternate sources on many PWS wells that have sufficient particulate removal by the carbonate aquifer to be considered safe supplies without additional treatment.

From review of most of the State GUI/GWUDI programs, MPA testing is described as an ultimate analysis for classifying systems as GUI/GWUDI; however, these guidelines predate the current revised methods used by many of the states, which either completely skip MPA testing such as in Kentucky or reduce it to an optional requirement, such as in Arkansas. Since EPA's mandate in 1993, states have obtained experience in using EPA's protocols of more than a decade and many have come to realize that 'hydrogeological assessment' and 'water quality monitoring' in conjunction with professional judgment, can be used to determine whether a source is GUI/GWUDI and that MPA testing is not essential.

We recognize that the preliminary assessment (GUI Determination Decision Scoring System) conducted by TCEQ is integral to screening conducted by most states for potential GUI wells and we recommend that it be continued. The hydrogeological assessment should be enhanced and aspects of assessments such as those described in the Kentucky program should be considered for inclusion in the Texas program. For GUI determination of those candidate wells selected based on the screening, total coliform and fecal coliform, and turbidity monitoring on weekly or bi-weekly basis for a period of six months, should be initiated. In addition, readily measured parameters such as temperature and electrical conductivity, could also be monitored. Precipitation should be monitored locally if there is no nearby precipitation gage because heavy precipitation is an important factor in waterborne disease outbreaks (Rose et al., 2000). These weekly or biweekly data reports in conjunction with the professional judgment may be used to classify a PWS well as GUI or not. Note- It is reasonable to expect that the PWS operator could collect these data parameters and submit the data to TCEQ. Existing TCEQ resources going toward the MPA implementation could continue to be performed as supplemental documentation of risk ranking of this accelerated operator-based approach. As the data are received and reviewed, actions for TCEQ to consider are as follows:

1) if there are frequent positive results from total coliform and/or fecal coliform tests and turbidity fluctuations are greater than 0.5 to 1.0 NTU over the course of the review period, then the source may be classified as GUI
2) if the results show infrequent positive results from total coliform and fecal coliform tests and or moderate turbidity fluctuations between 0.25 to 0.5 NTU over the review period, then the source may be tested for MPA analysis (following a precipitation event if possible) and GUI determination would be dependent on results of MPA testing.
3) If there are frequent or infrequent positive results of total coliform and fecal coliform tests and little or no turbidity fluctuations, then the source is risk managed by the recently promulgated Ground Water Rule (2006).
4) If there is uncertainty even after all tests and analysis, it is appropriate to err on the side of public health and safety and consider the well to be GUI.

In the case of uncertainty and with the need to establish a hydraulic connection between a ground water source and suspected surface contamination sources, we recommend the use of tracer dye tests which will both evaluate a connection if any and determine the travel time for potential contaminants. Both or either outcome will provide valuable information for employing effective treatment, especially under variable rainfall conditions. Dye tracer tests are economical and simple to administer. They provide a simple and effective tool to establish hydraulic connection between to points in the field.

Turbidity is a very instructive indicator of surface water input to a ground water source ; however turbidity data require some careful consideration because;
1) turbidity may be caused by very small particles (< 1 µm) not originating in surface water or that the largest particles are being filtered out and only the very smallest particles migrate into the ground water sources (EPA Guidance Manual, 1991),
2) pump surges during variable pumping rates may temporarily cause turbidity to occur. Therefore, we recommend timing of turbidity monitoring to follow establishment of a steady state conditions of well production. Also consider utilizing other parameters, such as temperature and electrical conductivity, which are cost effective and reliable indicators of variations in ground water especially related to extreme rainfall events. All these methods should be used in conjunction with professional judgment to provide the best protection for public health.

4.1 Process after PWS Ground Water Source Classified as GUI Source

Once TCEQ classifies a PWS groundwater source as GUI, the PWS is notified that the source must meet enhanced treatment requirements within 18 months or abandon the well. If the PWS continues to use the source without enhanced treatment, they are issued a Notice of Violation each month until the issue is resolved.

It is recommended that once the PWS ground water source is classified as GUI, the following actions should be taken to better protect public health;

1) A public advisory should be sent immediately to the connections being served by the affected well. This is critical to prevent a potential waterborne disease outbreak

2) If an alternate supply is available the PWS should shut down the affected well immediately, until it meets enhanced treatment requirements.

3) If an alternate supply is not quickly available the PWS disinfection system should be upwardly adjusted to meet 4-log removal of viruses at a minimum. Sources that are determined to be at risk of containing *Giardia Lamblia,* are required to meet 3-log (99.9%) removal of *Giardia Lamblia* in accordance with ARM 17.38.208, 40 CFR § 141.70, and "Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources," EPA, 1991.

4) If a PWS ground water source is at risk of contamination from Giardia or other large pathogens (>7 µm), it should become subject to the SWTR requirements.

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Table - 1 Waterborne pathogens and their significance in water supplies[a]

Pathogen	Health significance[b]	Persistence in water supplies[c]	Resistance to chlorine[d]	Relative infectivity[e]	Important animal source
Bacteria					
Burkholderia pseudomallei	High	May multiply	Low	Low	No
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Escherichia coli – Pathogenic[f]	High	Moderate	Low	Low	Yes
E. coli – Enterohaemorrhagic	High	Moderate	Low	High	Yes
Legionella spp.	High	May multiply	Low	Moderate	No
Non-tuberculous mycobacteria	Low	May multiply	High	Low	No
Pseudomonas aeruginosa[g]	Moderate	May multiply	Moderate	Low	No
Salmonella typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	High	No
Vibrio cholerae	High	Short to long[h]	Low	Low	No
Yersinia enterocolitica	High	Long	Low	Low	Yes
Viruses					
Adenoviruses	High	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Astroviruses	High	Long	Moderate	High	No
Hepatitis A viruses	High	Long	Moderate	High	No
Hepatitis E viruses	High	Long	Moderate	High	Potentially
Noroviruses	High	Long	Moderate	High	Potentially
Sapoviruses	High	Long	Moderate	High	Potentially
Rotavirus	High	Long	Moderate	High	No
Protozoa					
Acanthamoeba spp.	High	May multiply	Low	High	No
Cryptosporidium parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply[i]	Low	Moderate	No
Toxoplasma gondii	High	Long	High	High	Yes
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

a This table contains pathogens for which there is some evidence of health significance related to their occurrence in drinking-water supplies. For these and other pathogens, there is more information available, which is presented in chapter 11.

b Health significance relates to the severity of impact, including association with outbreaks.

c Detection period for infective stage in water at 20 °C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month.

d When the infective stage is freely suspended in water treated at conventional doses and contact times and pH between 7 and 8. Low means that 99% inactivation at 20 °C generally in <1 minute, moderate 1–30 minutes and high >30 minutes.

e From experiments with human volunteers, from epidemiological evidence and animal studies. High means infective doses can be $1–10^2$ organisms or particles, moderate $10^2–10^4$ and low $>10^4$.

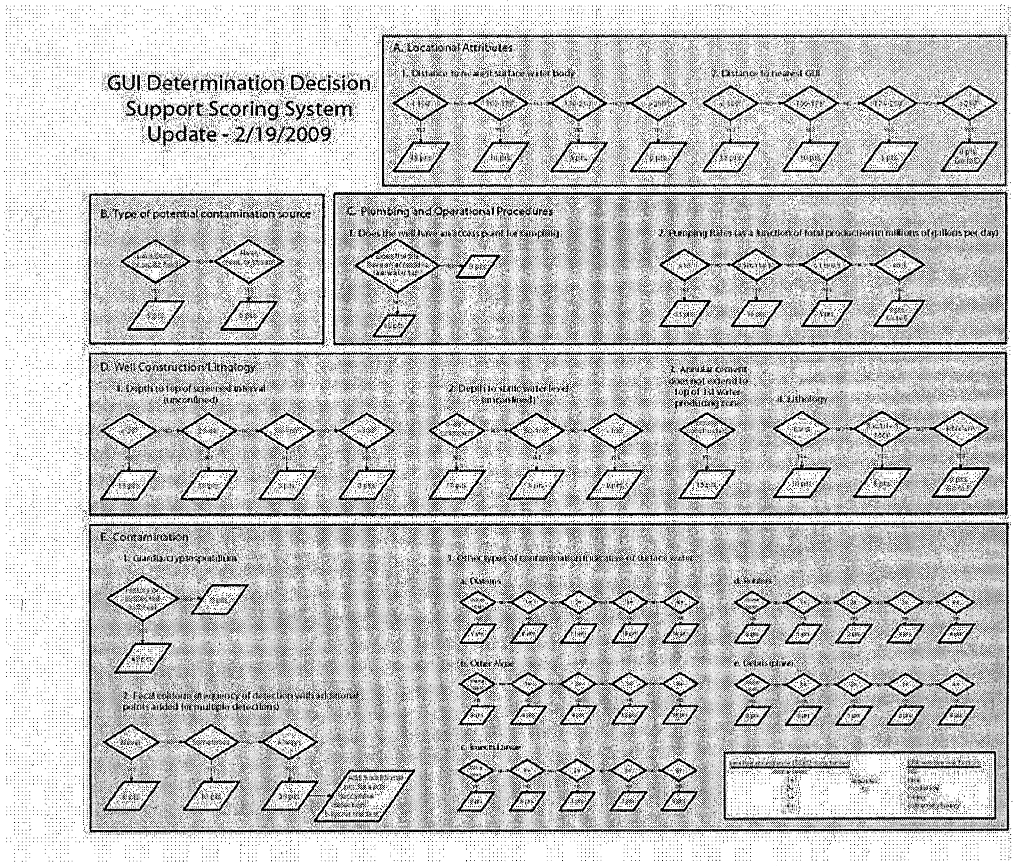
f Includes enteropathogenic, enterotoxigenic and enteroinvasive.

g Main route of infection is by skin contact, but can infect immunosuppressed or cancer patients orally.

h *Vibrio cholerae* may persist for long periods in association with copepods and other aquatic organisms.

i In warm water.

Figure 1. Flow chart describing screening guidelines for TCEQ to select candidate wells for MPA testing.



6 List of Appendices

Appendix 1: GWUDI determination guidelines by EPA

Appendix 2a and 2b: GWUDI determination guidelines from the State of Arkansas

Appendix 3: GWUDI determination guidelines from the States of California and Florida States, USA, and Nova Scotia, Canada

Appendix 4: GWUDI determination guidelines from the State of Washington

Appendix 5: GWUDI determination guidelines from the State of Arizona

Appendix 6: GWUDI determination guidelines from the State of Illinois

Appendix 7: GWUDI determination guidelines from the State of Kentucky

Appendix 8: GWUDI determination guidelines from the State of Montana

Appendix 9: GWUDI determination guidelines from the State of New Jersey

Appendix 10: GWUDI determination guidelines from the State of Oregon

Appendix 11: GWUDI determination guidelines from the State of Tennessee

Appendix 13: GWUDI determination guidelines from the State of Utah

Appendix 14: GWUDI determination guidelines from the State of Georgia

Appendix 15: GWUDI determination guidelines from the State of New Mexico

Appendix 16: GWUDI determination guidelines from the State of Pennsylvania

Appendix 17: GWUDI determination guidelines from the State of Vermont

Appendix 18: GWUDI determination guidelines from the State of West Virginia

Appendix 19: GWUDI determination guidelines from the State of Wisconsin

Appendix 20: GWUDI determination guidelines from the State of Ontario, Canada

Appendix 21: GWUDI determination guidelines from the State of Saskatchewan, Canada

Appendix 22: GWUDI determination guidelines from the State of Yukon, Canada