# *County-Wide Groundwater Assessment*

# *Jefferson County, West Virginia*

Prepared for

**Jefferson County Commission**
**124 E. Washington Street**
**Charles Town, West Virginia 25414**

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# Executive Summary

This groundwater water budget study has identified a theoretical surplus of available groundwater resources across Jefferson County. The availability of groundwater is controlled by the county's underlying hydrogeology, which is variable in character. Three areas deemed to have unique hydrogeologic properties were identified during this study. High yield wells have been documented from all three areas; however, the central area of the county identified as the "folded carbonates of the central valley" possesses the greatest number of higher yielding wells. This area, which covers nearly 60% of the county and includes the county's Industrial Park, would be expected to have the greatest potential for groundwater development. Regardless of a well's location within the county, the presence of secondary porosity features that include fractures, joints, bedding planes, and faults, are generally necessary to accommodate a high yield. A review of geospatially located well data along with mapped fracture traces (lineaments) and faults suggests a correlation between the presence of clusters of high yielding wells and nearby mapped lineaments and faults (Figure 7). Site-specific evaluation, including a review of available well data, mapped groundwater features and underlying geology, is recommended to better assess the potential for groundwater development at the site scale.

Conditions that enhance groundwater availability, such as secondary porosity features, can also have the potential to enhance the susceptibility of the groundwater aquifer to contamination, particularly in karst areas that contain dissolution channels and may have direct connection with surficial drainage patterns. Contaminants have been documented within groundwater across the county, some being more common within unique hydrogeologic settings. A summary of information pertaining to general bedrock geology, groundwater controls, well statistics, and common contaminants for each defined hydrogeologic unit has been provided in Table 10.

The identification of contaminant threats through source water area protection planning, both for existing water systems and for future water demand growth, along with ongoing monitoring of groundwater quality is important to promote long term groundwater protection. To provide further long term protection of the County's groundwater resources, additional assessment of planned high yield withdrawals should be conducted to evaluate well yield and if possible to determine potential for offsite impact from the planned well use. Recommended groundwater assessment standards are presented for review and consideration.

# 1.0 Background

The Jefferson County Commissioners sought to have a county-wide groundwater resources water budget study completed with the intent of identifying the extent of groundwater resources available for residential and commercial use within the county. Analytical Services, Inc. (ASI) prepared a proposal with a detailed scope of work designed to achieve the Commission's goal. Several technical groundwater studies have previously been conducted that have focused on groundwater supply and quality within Jefferson County. ASI's objective was to to use available data from these studies and, combined with the findings generated from this study, provide a report which is an informative and effective tool that can be used to promote the long term management and protection of the county's groundwater.

The project workscope addressed required tasks within the county's request for proposal and further included the development of a county-wide well database. ASI's experience with the development of geo-referenced well databases within other county-wide studies was valuable towards maximizing the use of available data towards better understanding groundwater resources within Jefferson County. To promote a cost savings to the county, certain portions of this project were completed with assistance from the county GIS Department, including the assembly of the well database and the construction of GIS graphics. The County's existing GIS information provided an excellent set of tools toward completing this study in an efficient manner. An overview map of the county is provided as Figure 1.

This study included a review of available published literature, delineation of hydrogeologic units, identification and analysis of groundwater features, review of groundwater quality and a review of regulations that affect utilization of groundwater. To further promote the protection of the county's groundwater resources, ASI has prepared and included a draft set of groundwater assessment standards for the client's consideration within this report Appendix E.

# 2.0 Jefferson County Geology and Groundwater

Geologic processes over eons of time have determined the nature of the rocks that underlie today's landscape in Jefferson County. The rocks and their geologic structures have, in turn, determined the courses of rivers and streams, and locations of springs we see at the surface. The rocks are also key to understanding groundwater recharge, flow and availability in different areas of the county. A geologic map of the county is provided as Figure 2.

## 2.1 Geologic Setting

Jefferson County straddles two major physiographic provinces, Blue Ridge and Valley and Ridge. These are defined on the basis of distinctive geologic character and topographic landforms.

The portion of Jefferson County east of the Shenandoah River is situated within the Blue Ridge province, on the western flank of a regional fold called the Blue Ridge anticlinorium. The Blue Ridge of Jefferson County contains metamorphosed igneous and sedimentary rocks ranging in age from Neoproterozoic (about 600 million years old) to Early Paleozoic (about 550 million years old). These include metamorphosed mudstone, siltstone, sandstone, conglomerate and basalt (phyllite, metasiltstone and quartzite, metaconglomerate and metabasalt or greenstone, respectively). These rocks formed during extensional tectonics as an ocean basin opened on the margin of North America, in a location similar to the present Atlantic Ocean. The rocks were subsequently folded and faulted, along with rocks to the west, during continental collision tectonics in the Late Paleozoic Alleghanian orogeny.

The western and central portions of Jefferson County are part of what is commonly referred to as the Great Valley section of the Valley and Ridge physiographic province. This is a belt of Paleozoic-age (about 570 to 300 million years old) clastic and carbonate sedimentary rocks that extends for many hundreds of miles through eastern North America. At the latitude of Jefferson County, the Great Valley is underlain predominantly by carbonate sedimentary rocks (limestone and dolostone), situated within a regional geologic fold called the Massanutten synclinorium. Clastic sedimentary rocks (shale, siltstone and sandstone) are present at the surface in some areas of western Jefferson County. The carbonate rocks were deposited in shallow paleo-ocean waters adjacent to North America; clastic sediments were shed westward from tectonic highlands created during continental collision. The rocks of the Great Valley have also been deformed by folding and faulting. (Evans, 2011)

Comprehensive regional geologic mapping (1:100,000-scale) and discussion pertaining to Jefferson County are presented in Southworth and others (2007) and references therein. Detailed (1:24,000-scale) geologic mapping covering the county has been published by Dean and others, 1987 (Keedysville, Martinsburg and Shepherdstown quadrangles); Dean and others, 1990 (Berryville, Charles Town, Harpers Ferry, Middleway and Round Hill quadrangles); and Dean and others, 1994 (Inwood and Stephenson quadrangles).

## 2.2 Geologic and Geomorphic Features that Affect Groundwater

The rocks that underlie the county do not contain significant space between individual mineral grains (primary porosity), through which groundwater may flow. Instead, groundwater flows through openings created by geologic structural and geomorphic processes, that have affected the rocks over geologic time (Kozar and others, 2007). These secondary porosity features include:

***Bedding Planes*** *(planar surfaces that separate successive layers of stratified rocks):*
Bedding planes originate as horizontal surfaces between layers of unconsolidated sediment. In Jefferson County these have been folded and are inclined (dip) at various angles across the county, but most commonly dip in a southeasterly or northwesterly direction.

***Joints*** *(partings or fractures in the rocks):*
Joints form in solid rock as a response to tectonic stress; commonly joints occur in "sets" that have a consistent geometric orientation in a given area relative to the orientation of geologic folds. The county contains numerous folds and joints that formed in association with the regional Massanutten and Blue Ridge structures.

***Faults*** *(fractures in which there has been displacement of rock bodies on either side relative to one another):*
Faults occur throughout the county, with a variety of orientations. Many are *thrust faults*, which commonly dip to the southeast, and where the top plate has moved to the

northwest. *Cross faults* cut across other structures at a high angle; within Jefferson County these commonly trend west or northwest, and have steep or nearly vertical dips. Several thrust faults and a smaller number of cross faults have been mapped in the western part of the county, as shown in Figure 3. The eastern part of the county contains one prominent thrust fault, the Keedysville Detachment Fault, which separates the Antietam Formation of the Blue Ridge province from the Tomstown Formation of the Great Valley.

***Karst*** *(underground caves, solution cavities and channels):*
Karst features are common in carbonate rocks of the Great Valley. Formed by dissolution of calcium carbonate rock by slightly acidic rainwater, these features are apt to form along preexisting structural features in limestone that serve as conduits for groundwater. Karst can lead to accelerated rates of groundwater flow, and to increased sensitivity to groundwater contamination due to rapid influx of surface water.

***Incision by major rivers****:*
The Potomac and Shenandoah Rivers in the northern part of the county have cut channels that are several hundred feet below the average topographic surface of the Great Valley to the south (See Figure 4). This has resulted in local lowering of the water table in some areas within about a half mile of those rivers, relative to water table depths in the central and southern parts of the county. This potentially affects the static (unpumped) water levels - herein defined as the distance from water to top of well casing - in local wells.

# 3.0 Hydrogeologic Units

Analysis of available geologic mapping and hydrogeologic research data were performed to identify and delineate three (3) hydrogeologic units in Jefferson County. Each unit was deemed to have unique hydrogeologic characteristics that affect groundwater availability. The hydrogeologic units are depicted on Figure 5 and further described below. Information from a well database assembled for this report (see Section 5.0) were also used to describe well characteristics within each of the delineated units.

## 3.1 Western Fault-Dominated "Western Unit"

Definition: the western portion of the county, to include a series of mapped faults portrayed on regional geologic maps (Southworth and others, 2007).

***Topography***
The western Fault-dominated unit is characterized by gently rolling topography with approximately 50 feet of relief between hill tops and valley bottoms. Incision by Opequon Creek and its tributaries has resulted locally in relief of 120 feet or more.

***Stratigraphy***
Martinsburg Formation (Upper and Middle Ordovician): shale, calcareous shale and siltstone; thin to medium beds of sandstone and metagraywacke in the upper part; argillaceous limestone at base.

St Paul Group; Chambersburg limestone (Middle Ordovician): thick bedded micritic limestone; bioclastic limestone with chert nodules; argillaceous nodular limestone.

Beekmantown Group--Rockdale Run Formation, Pinesburg Station Dolomite (Middle and Lower Ordovician): thick bedded dolostone with chert nodules; thin to medium bedded fossiliferous limestone and dolostone.

***Structure***

This part of the county is situated near the core of the regional Massanutten Syncline. In map pattern and outcrop, bedrock units display a series of open to tight folds along northeast-trending axes; numerous faults, including southeast-dipping reverse (thrust) faults and steeply-dipping ENE-trending cross faults are present. Dolomite units are heavily jointed, with characteristic butcher block weathering; paleokarst collapse breccias and sink holes are present locally, dominantly within limestone bedrock.

***Hydrogeology***

Groundwater flow is significantly influenced by structural controls: thrust faults, cross-strike faults, joints, and by lower permeability units such as the Martinsburg Formation. Karst solution cavities and caves are locally significant in controlling groundwater movement. Karst features are commonly developed along structural features such as bedding planes, joints and faults.

***Water well characteristics***

The well database compiled for this report contains 263 wells located in the Western Unit. The mean and median yields of these wells are 19 gallons per minute (gpm) and 10 gpm, respectively. The significant difference between the mean and median values here reflects the wide range of reported yield values. Over half of the wells in this unit have yields of less than 10 gpm. This unit has the lowest maximum reported well yield (200 gpm) of the three units.

Both bedrock depth and water table appears to be shallowest in the Western Unit. The wells in this unit have the shallowest average static depth-to-water (DTW) of the three units (46 feet) and the shallowest average casing length (52 feet), which may be regarded as an approximation of the depth of competent bedrock in the area of the well. In addition, only 11% of the wells in the faulted shale unit had static water levels deeper than 80 feet (in contrast to 22% and 53% in the Central Valley Folded Carbonates and the Eastern Metamorphic Units, respectively).

## 3.2 Central Valley - Folded Carbonates "Central Unit"

Definition: the central portion of the county, west of the Keedysville fault (Southworth and others, 2007) and east of the Western Unit.

***Topography***

This central portion of Jefferson County is characterized by gently rolling topography with approximately 50 feet of relief between ridge crests and valley bottoms. In the northern portion, incision by the Potomac and Shenandoah Rivers and their tributaries has resulted in topographic relief of 150 feet or more.

***Stratigraphy***

Beekmantown Group (Stonhenge Limestone; Lower Ordovician): thick bedded fossiliferous limestone with black chert nodules.

Conococheague Limestone (Lower Ordovician and Upper Cambrian): interbedded laminated limestone, dolostone and sandstone.

Elbrook Limestone (Upper and Middle Cambrian): interbedded limestone, dolostone, calcareous shale and shaly dolostone.

Waynesboro Formation (Lower Cambrian): interbedded shale, sandstone, dolomitic limestone and dolostone.

Tomstown Formation (Lower Cambrian): limestone, dolostone and marble.

***Structure***

This unit is situated on the eastern limb of the Massanutten Syncline. There are numerous northeast-trending bedrock folds displayed in map pattern and in outcrop. Folds are open to tight and asymmetric, with steeply dipping or overturned southeast limbs and gently-dipping northwest limbs. A small number of northwest-trending cross faults have been mapped.

Two prominent joint sets are widespread in the carbonate rocks, both at high angles to bedding. *Longitudinal joints* are commonly parallel to fold axes (commonly trend northeast - southwest); *cross joints* are commonly perpendicular to fold axes.

***Hydrogeology***

Groundwater flow is significantly influenced by joints, bedding planes, and cross faults where present. Karst solution cavities are locally significant in controlling groundwater movement. Karst features are most commonly developed within limestone bedrock, along structural features such as bedding planes, joints and faults.

***Water well characteristics***

The Central Unit, with georeferenced 559 wells, has the highest mean well yield (32 gpm) of the three units, as well as the highest maximum reported yield (2,000 gpm). The median well yield is at least twice that of the other two units. Approximately 3% (17 of 559) of the wells in this unit have well yields higher than 100 gpm, a much higher percentage than the other units. The mean depth-to-bedrock (as inferred from casing length) and mean static depth-to-water are both deeper than the Western Unit, but shallower than the Eastern Unit.

## 3.3 Eastern Metamorphic "Eastern Unit"

Definition: the portion of Jefferson County southeast of the Keedysville fault (Southworth and others, 2007).

***Topography***

This part of the county is situated on the west flank of the Blue Ridge mountains. Topographic relief between the county line, at the crest of the ridge, and the Potomac River at Harpers Ferry, is about 1000 feet. The topography is generally steep.

***Stratigraphy***
Chilhowee Group, Antietam Formation (Lower Cambrian): ferruginous sandstone.

Chilhowee Group, Harpers Formation (Lower Cambrian): phyllite and metasiltstone.

Weaverton Formation (Lower Cambrian): quartzite, conglomerate and metasiltstone.

Loudoun Formation (Lower Cambrian): tuffaceous phyllite and conglomerate.

Catoctin Formation (Neoproterozoic): greenstone metabasalt.

***Structure***
This hydrogeologic unit is situated on the overturned northwest limb of the regional Blue Ridge anticlinal fold. The rocks have been subjected to low-grade metamorphic recrystallization resulting in a pervasive northeast-trending schistosity that dips southeast at moderate angles. Blue Ridge rocks are in contact with younger rocks to the west at the Keedysville fault.

***Hydrogeology***
The pervasive metamorphic schistosity in metasiltstone and phyllite bedrock has overprinted primary bedding planes, and does not generally serve as a good conduit for groundwater. Sandstone, conglomerate and quartzite locally retain primary bedding structures, and contain joint sets that are conducive to groundwater flow.

***Water Well Characteristics***
The Eastern Unit has the lowest mean and median well yields of the three units. Additionally, the means of total well depth, static depth-to-water, and casing length were all significantly deeper than the other two units, although the median casing length is actually slightly shallower than the Central Unit. Over half of the wells in the Eastern Unit had water levels deeper than 80 feet from the surface. Over 60% of the wells in the Eastern Unit had yields less than ten gpm. Over 17% of the wells were deeper than 500 feet.

# 4.0 Groundwater Resource Features

## 4.1 Fracture Trace Analysis

Within a bedrock aquifer system, groundwater flow is largely controlled by secondary porosity features such as zones of fracture concentration, jointing and fault planes. Extensive work has been completed in Jefferson County by others to map prominent fracture traces, often referred to as lineaments, which are surficial expressions of fracture concentrations within the underlying bedrock (McCoy and others, 2005). Preferential weathering along such zones can result in very linear surface features. ASI geologists performed stereoscopic analysis of aerial photography and mapped prominent fracture traces in the eastern portion of the county. This mapping was used to supplement existing mapped features already included in the county's GIS system to produce a county-wide map illustrating prominent fracture traces (Figure 3).

Stereo pairs of aerial photography (1:24,000 scale) covering the eastern portion of the county were obtained from Air Photographics in Martinsburg, West Virginia. The photos were analyzed with a mirror stereo-scope using both the regular and 6x magnifying oculars. McCoy and others (2005), which primarily focused on the area of the county underlain by the carbonate and shale geology, documented two prominent trends in mapped fracture traces: strike-parallel fractures and cross-strike fractures. The strike-parallel fracture were found to be most abundant; however, the cross-strike fractures were noted to perhaps be more important from a hydrogeologic standpoint as they document fracture zones that cut across bedding. This fracturing may enhance secondary porosity allowing groundwater flow through rocks with generally low primary porosity. McCoy and others (2005) also depicts bedrock geology mapping, including mapped faults. This geologic mapping references work most recently prepared by Southworth and others (2002). Both thrust faults and cross-strike faults are identified on the mapping. Figure 3 depicts mapped fracture traces which are considered to be prominent features along with mapped geologic faults as depicted on Jefferson County's GIS mapping.

The strike of the bedrock geology within the county is oriented in a slightly east of north orientation. Upon review of Figure 3, a pattern of recurring cross-strike trace features can be identified extending across the central (carbonate) portion of the county.

## 4.2 Correlation of Groundwater Features with High Yield Wells

To evaluate the occurrence of high yielding wells in proximity to mapped groundwater resource features, a map that included wells from the assembled database possessing only yields of 20 gpm and higher was produced as Figure 6. Color codes for yield were given to identify well yields ranging from 26-50 gpm, 51-75 gpm, and ≥76 gpm. Clusters of higher yielding wells that appeared to have good correlation with nearby mapped groundwater resource features (i.e. fracture trace lineaments and faults) were identified. Figure 6 depicts examples of three such clusters. One of the clusters consists of several high yielding wells that lie in close proximity to several cross-strike lineaments that, when viewed from a regional perspective, extend in a linear fashion in a general east-west orientation across the county. As discussed in Section 4.1, these cross-strike features generally extend across the carbonate geology (central portion of the county). Interestingly, additional recurring groups of cross-strike lineaments are mapped extending across the central portion of the county in a general east west orientation; however, little to no well database information exists within those areas. Such areas would be expected to have favorable potential for groundwater development.

Two other examples of high yield well clusters have also been depicted on Figure 6, both of which had a smaller areal extent than the previous discussed cross-strike feature. One cluster example along the western portion of the county is situated near geologic faulting, while another is located in the north central area of the county near mapped fracture traces.

These three clusters of high yield wells provide good examples of how a geo-referenced database can be used to aid in identifying areas that may have favorable groundwater development potential. It is important to note that while the database was assembled with 1,124 well completion reports, the spatial distribution of those wells is limited. Therefore large areas within the county, which could have favorable potential for groundwater development, again have little to no representative well data. Certainly, lower yielding wells are located in proximity to high yield well clusters (Figure 6), illustrating the need for site specific investigation toward identifying high yield wells near apparent groundwater resource features.

# 5.0 County-wide Groundwater Well Database

## 5.1 Database Development

The goal of developing a groundwater well database was to utilize existing well information in a geo-referenced format to enable assessment of well data spatially across the county. A challenge associated with development of the database was obtaining and identifying well records that provided both useful well construction data and adequate physical location data to enable assignment of georeferenced locations for each of the wells. In an effort to aid in reducing costs to the county, the Jefferson County GIS Department tasked their personnel to assist with the database assembly. ASI developed an outline of desired well construction information to the GIS Department and met with Department staff regularly to track progress and to give direction, if needed. The primary source of well completion information was the Jefferson County Health Department, which had kept records in electronic format for an extended period of time. The Applicable standards of the methods used to develop the database have been provided in Appendix A.

## 5.2 Well Statistics

Data from the newly assembled groundwater well database were statistically analyzed to obtain descriptive statistics of well yield, well depth, casing depth, and water level data from the available well records. Well records with available data were used from the database for each parameter analyzed. A total of 1,106 wells were evaluated for depth, 1,122 wells were evaluated for yield, 1,019 wells evaluated for static water level, and 1,100 wells evaluated for casing length. A summary of descriptive statistics of the database is provided below in Table 1.

**Table 1**

**Descriptive Statistics of County Well Database**

| | Depth (ft) | Yield (gpm) | Static DTW (ft)* | Casing length (ft) |
|---|---|---|---|---|
| *Mean* | 300 | 24 | 69 | 72 |
| *Standard Deviation* | 146 | 72 | 42 | 50 |
| *Median* | 276 | 12 | 64 | 61 |
| *Maximum* | 900 | 2000 | 300 | 504 |
| *Minimum* | 29 | 0 | 2 | 3 |

| | | | | |
|---|---|---|---|---|
| *Count*** | 1106 | 1122 | 1019 | 1037 |

*Notes: *(ft) = feet below top of casing; gpm = gallons per minute; ** number of database well records with available data.*

The applicable standards of the methods of the statistical analysis of the yield, casing length, depth, and static water level data have been provided in Appendix A.

Geologic mapping was obtained from the Jefferson County GIS Department and used to perform a statistical analysis of the parameters for yield and depth from geo-referenced well data within each mapped geologic unit. It is important to note that some geologic units were represented by more well records than others with the most records occurring in the OCc (Conococheague) Formation (265) and the least occurring in the Om (Martinsburg) formation (6). The number, or well count, should be carefully considered when comparing these data. A summary of the well statistic findings for geologic units has been provided below in Table 3.

**Table 2**
**Well Yield and Depth Statistics by Geologic Formations**

| **Bedrock** | **Count** (*yield*) | **Mean Yield** (gpm) | **Median Yield** (gpm) | **Count** (*depth*) | **Mean Depth** (feet) | **Median Depth** (feet) |
|---|---|---|---|---|---|---|
| *Ca* | 20 | 13.70 | 10.00 | 20 | 337.10 | 325.00 |
| *Ce* | 231 | 26.10 | 20.00 | 228 | 237.68 | 225.00 |
| *Ch* | 232 | 14.85 | 8.50 | 228 | 344.92 | 308.00 |
| *Ct* | 64 | 20.34 | 18.00 | 63 | 294.16 | 245.00 |
| *Cw* | 47 | 22.83 | 20.00 | 47 | 294.62 | 240.00 |
| *Cwl* | 34 | 8.88 | 6.00 | 34 | 421.59 | 392.50 |
| *OCc* | 265 | 40.78 | 15.00 | 259 | 302.82 | 285.00 |
| *Om* | 6 | 20.67 | 8.00 | 6 | 233.17 | 227.50 |
| *Omu* | 49 | 17.84 | 10.00 | 49 | 322.00 | 305.00 |
| *Opr* | 99 | 21.32 | 14.00 | 98 | 285.99 | 222.50 |
| *Os* | 61 | 10.75 | 6.00 | 60 | 264.45 | 270.00 |
| *Zc* | 16 | 7.13 | 5.00 | 16 | 412.81 | 352.50 |

Additional analysis was performed on each of the three defined hydrogeologic units within this study. Well yield, well depth, static water level, and casing depth were analyzed. A summary of the statistical results is provided below in Table 4. Supporting statistical data has been included as Appendix A.

A comparison of the statistical data generated from the individual hydrogeologic units further supports the unique characteristics within each of the delineated units. Assessing yield, wells in the Central Unit possesses a mean yield of 32 gpm which far exceeds the mean values for either the Western Unit (19 gpm) or the Eastern Unit (14 gpm). The Central Unit also possesses the shallowest mean total depth (278 ft) which is likely due to encountering adequate water supplies from more shallow depths without the need for deeper well construction.

Assessing total well depth, the Eastern Unit has the greatest mean well depth (355 feet), the lowest mean yield (14 gpm), and the greatest mean static depth-to-water (94 ft). These parameters may be influenced by higher elevations within the Eastern Unit. Similar to the

Eastern Unit, the Western Unit also possesses a lower mean yield (19 gpm) than the Central Unit, but interestingly has the shallowest mean casing depth (57 ft) and the shallowest mean depth-to-water (46 ft).

**Table 3**

**Descriptive Statistics Well Data by Hydrogeologic Unit**

| | Depth (ft) | Yield (gpm) | Static DTW (ft)* | Casing length (ft) |
|---|---|---|---|---|
| ***Western Fault-Dominated "Western Unit"*** | | | | |
| *Mean* | 281 | 19 | 46 | 57 |
| *Median* | 260 | 10 | 40.41 | 42 |
| *Maximum* | 800 | 200 | 224 | 286 |
| *Minimum* | 29 | 0 | 1.96 | 6 |
| ***Central Valley Folded Carbonates "Central Unit"*** | | | | |
| | Depth (ft) | Yield (gpm) | Static DTW (ft)* | Casing length (ft) |
| *Mean* | 278 | 32 | 66 | 74 |
| *Median* | 245 | 20 | 64 | 63 |
| *Maximum* | 900 | 2000 | 300 | 283 |
| *Minimum* | 42 | 0 | 4.8 | 16 |
| ***Eastern Metamorphic "Eastern Unit"*** | | | | |
| | Depth (ft) | Yield (gpm) | Static DTW (ft)* | Casing length (ft) |
| *Mean* | 355 | 14 | 94 | 83 |
| *Median* | 319 | 8 | 85 | 62 |
| *Maximum* | 800 | 300 | 300 | 504 |
| *Minimum* | 107 | 0 | 7 | 3 |

*Note: Static DTW = Depth to unpumped water level below top of well casing.*

# 6.0 County-wide Water Budget Analysis

## 6.1 Estimate of Groundwater Resources

ASI prepared a groundwater budget that assesses effective groundwater recharge from precipitation which would be expected to be available to the underlying groundwater aquifers. The theoretical volume of groundwater available for consumption in the county is assumed for this report to be equal to the volume of effective recharge minus the annual volume required to sustain critical base flow in county streams. Lateral subsurface inflows and outflows of groundwater are ignored, as well as potential recharge from "losing" stream segments. It is important to note that this analysis is theoretical and is based on certain assumptions.

The theoretical annual recharge volume of an area may be estimated by multiplying the annual effective recharge (as depth) by the areal extent over which it occurs. Extensive hydrological research in and around Jefferson County has yielded several estimates of effective recharge for the various rock types found in the county.

### *6.1.1 Recharge Zones*

A large portion of precipitation drains into topographic lows, frequently occupied by streams, rivers, or wetlands. These areas, including all or part of stream floodplains and riparian wetlands, are considered to be areas of groundwater discharge and do not contribute water for aquifer recharge. The total proportion of discharge area within a watershed can vary between precipitation events depending on climatic conditions, especially antecedent soil moisture (Callaghan and others, 1998). Freeze and Cheery (1981) estimated that five to thirty per cent of a watershed area typically acts as zones of groundwater discharge. These discharge zones are excluded from the calculation of the county's total area to obtain an estimate of the area of the county that receives recharge.

For this study, all 100-year flood plains within the county, perennial stream channels, and recorded wetland areas are assumed to be areas of groundwater discharge. The estimated zones of discharge in the county are shown in Figure 8. Using GIS methods, the combined aerial extents of the FEMA 100-year flood plain and the county's existing delineations of perennial stream channels and wetlands were subtracted from the total acreage of each of the Hydrogeologic Units, identified in Section 5.0 above, to obtain the acreage of each groundwater recharge zone. The total acreages and identified recharge acreage of each zone are listed below.

**Table 4.**
**Areas of Recharge Zones**

| Hydrogeologic Unit | Total Acreage | Recharge Acreage | Percentage of Total |
|---|---|---|---|
| **"Western Unit"** | 40,820.40 | 36,733.85 | 90% |
| **"Central Unit"** | 78,470.19 | 70,683.77 | 90% |
| **"Eastern Unit"** | 16,029.86 | 12,330.61 | 77% |
| Total | 135,320.50 | 119,748.23 | 85.66% (Average) |

### *6.1.2 Effective Recharge Rate*

To obtain an estimate of effective recharge that would be appropriate for each of the identified hydrogeologic units, ASI reviewed recharge estimates reported in published and unpublished research papers. The primary source of these estimates were obtained from the United States Geological Survey (USGS) publications from research that used a variety of graphical and statistical methods with data collected within, or in the vicinity of, the county area. Estimates from other government and academic publications were also reviewed. The estimates of recharge deemed most appropriate were obtained from research conducted either within the hydrogeologic units or in the same geologic formations located nearby. Table 5 below summarizes recharges rates found within the literature. Additional information on the literature search for the recharge rates assigned to each hydrogeologic unit has been provided in Appendix B.

**Table 5.**
**Recharge Rate Estimates Reported in the Literature**

| Publication | Reported Rates (in/yr) | Geologic Region |
|---|---|---|
| Kozar and others (1990) (“Geohydrology”) | 7.1, 11.0 | South-Central (Folded Carbonate Central Unit) |
| Kozar and others (1990) | 10.0 (probable) | Fault-Dominated Western |
| Kozar and Weary (2009) | 11.02 in carbonate rocks; 5.9 in Martinsburg | Opequon Creek near Berryville, VA (faulted carbonate and shale) |
| Yager and others (2008) | 9.05 (metamorphic); 9.72 (carbonate) 5.47 (clastic) | By linear regressions for different rock units in Shen. Valley |
| Yager and others (2008) | 7.4 | Shen. River at Milleville, WV |
| Kozar and Mathes (2001) (“Aq. Characteristics”) | 9.8 | Opequon Creek near Martinsburg, WV |
| Nelms and others (1997) | Range: 0.7 – 20.55 Median: 8.38 | Valley and Ridge (North) |
| Nelms and others (1997) | Range: 6.31 – 33.07 Median: 11.07 | Blue Ridge (North) |
| Kozar and others (2007) (“Hydrogeologic Setting, Leetown”) | 5.69; 8.3 | Drought year est. for Opequon Creek and Hopewell Run |
| Vinciguerra (2008) | 2.52 in/yr (Rock Gap); 6.57 in/yr (Breakneck Run); 13.31 in/yr (Sir John’s Run) | Morgan County |

The recharge values for years of normal precipitation assigned to the hydrogeologic units are 9.9 in/yr, 9.3 in/yr, and 9.1 in/yr for the Western, Central, and Eastern Units, respectively. Recharge rates during drought years are assumed to be 60% of recharge rates during normal years; therefore, the recharge rate for drought years assigned to each unit is 5.9 in/yr, 5.6 in/yr, and 5.5 in/yr for the Western, Central, and Eastern Units, respectively.

Applying these recharge rates for normal and drought years to the respective areas of the three hydrogeologic units yields, the estimated annual recharge volumes are summarized in Table 6 below. The applicable standards for the recharge calculations are provided in Appendix B.

**Table 6.**
**Assigned Recharge Rates**

| | **Western Unit** | | **Central Unit** | | **Eastern Unit** | | **County Total** | |
|---|---|---|---|---|---|---|---|---|
| | **Normal** | **Drought** | **Normal** | **Drought** | **Normal** | **Drought** | **Normal** | **Drought** |
| **Recharge Rate (in/yr)** | 9.9 | 5.9 | 9.3 | 5.6 | 9.1 | 5.5 | _ | _ |
| **Recharge Volume (mgy)** | 9,875 | 5,885 | 17,850 | 10,749 | 3,047 | 1,842 | 30,772 | 18,475 |

*Note: in/yr = inches per year; mgy = millions of gallons per year.*

## 6.2 Estimate of Groundwater Usage

Methods for estimating annual groundwater consumption in Jefferson County were modeled after the approach taken by Atkins (2004) in the USGS publication "*Water-Use Estimates for West Virginia, 2004*". This approach breaks down water use into multiple categories so that each type, or classification, of water usage can be analyzed and estimated separately. The water usage rates of all categories are then summed to estimate the overall water consumption across the county.

The six water-use categories which were used to estimate groundwater usage included: public, domestic, industrial, irrigation, commercial, and mining. Atkins included seven categories in his 2004 statewide West Virginia study; however, to our knowledge his seventh category (thermoelectric power) does not apply to Jefferson County.

Both groundwater and surface water resources are utilized within Jefferson County. Estimates from the 2004 USGS report indicate a daily groundwater usage of 4.014 million gallons per day (Mgal/day) and a surface water usage of 10.958 Mgal/day. This following estimate of water usage pertains only to groundwater withdrawal. Table 7 below provides the estimated values of groundwater usage determined during this study for Jefferson County. The values have been provided in million gallons per day (Mgal/day) and million gallons per year (Mgal/yr). For comparison purposes daily and yearly usage values determined by the USGS Report (Atkins 2004) have also been provided. Calculations for all groundwater usage estimates have been provided in Appendix C.

| **Table 7. Jefferson County Groundwater Use Estimates** | | | | |
|---|---|---|---|---|
| ***2011 Data*** | | | ***2004 Report*** | |
| **Usage Category** | **Mgal/day** | **Mgal/yr** | **Mgal/day** | **Mgal/yr** |
| Public Supply | 1.24 | 452.6 | 1.043 | 380.70 |
| Domestic | 1.86 | 678.9 | 1.512 | 551.88 |
| Industrial | 2.27 | 827.03 | 1.265 | 461.73 |
| Irrigation | 0.18 | 65.2 | 0.00636 | 2.3214 |
| Commercial | 0.1 | 36.1 | 0.088 | 32.12 |
| Mining | 0.1 | 36.5 | 0.1 | 36.5 |
| **Total** | ***5.75**** | **2,096.33** | 4.0144 | 1,465.25 |

*Note: * = Daily values are rounded and should be considered more approximate than estimated yearly values.*

### *6.2.1 Public Supply*

The public supply category includes water that is withdrawn by public or private suppliers and provided to users for a number of purposes including domestic, industrial, commercial, and other uses. Public supply data were obtained from the Data Management Unit of the Engineering Division of the Jefferson County Office of Environmental Health. The information provided by the Office of Environmental Health included a list of all public water supply systems (PWSs) in the county with source information (groundwater or surface water), population served, number of service connections, service connection types, and monthly operational reports (MORs) for select systems, documenting the total daily pumpage for reported months. ASI used the MORs as a guide to determine the best approach to calculate water usage in the public supply category.

As the historical extent of data (MORs) obtained for the public water supplies was limited, sufficient data were not available to simply sum up historical usage numbers. In Jefferson County there are 22 public supply systems, 18 of which are groundwater-sourced. ASI adopted the following regression model, as used in Atkins (2004), along with available Jefferson County public water supply data, to estimate a total groundwater withdrawal for public water supply of **1.24 Mgal/day** or **452.6 Mgal/yr**.

$$G_m = 13{,}987C_r - 7{,}816C_c$$

Where:

$G_m$ is the total water usage, in gallons per month,
$C_r$ is the number of residential connections, and
$C_c$ is the number of commercial connections.

#### *6.2.2 Domestic*

The domestic category includes water that is used for normal household purposes by residences withdrawing groundwater from private wells. This estimate was based on United States Census data and records of the public water supply population provided by the Data Management Unit of the Jefferson County Environmental Engineering Division. The total public supply population (30,295) was subtracted from the total county population (53,498) as reported in the 2010 United States Census to determine the domestic supply population (23,203). A previously published water-use coefficient of 80 gal/day/person (Atkins, 2004) was then applied to the remaining "domestic" population to obtain an estimate of **1.86 Mgal/day,** or **678.9 Mgal/yr** of groundwater withdrawal for domestic supply.

#### *6.2.3 Industrial*

The industrial category includes groundwater that is withdrawn by self-supplied businesses for industrial uses including fabrication, processing, washing, cooling and aquiculture. ASI obtained water usage data for industrial users from Mr. Brian Carr of the West Virginia Department of Environmental Protection, Division of Water and Waste Management. Using the sum of these reports, ASI prepared an estimate of the total groundwater withdrawal for industrial use. A total of 827,024,998 gallons (827.025 Mg/y) of annual water usage was reported, which equates to approximately 2.27 Mg/d for industrial purposes in Jefferson County; however, the accuracy of estimates in this category is limited by the information available. Industrial uses of less than 750,000 gallons per month are excluded from State of West Virginia reporting requirements; therefore, it is likely that some large quantity users who withdraw less than 750,000 gallons per month have gone unaccounted for in this water usage estimate. As documented in the footnotes of the summation calculations, two large users of water are aquaculture facilities. These facilities use a large volume of water but actual consumptive use is believed to be much less. Discussions with other users suggest that their water usage originates from a combination of surface water and groundwater. In an attempt to account for smaller (undocumented) volumes of industrial water usage, all reported uses have been considered consumptive in this groundwater usage analysis. The sum of reported industrial usage totaled **827.02 Mgal/yr.**

#### *6.2.4 Irrigation*

The Irrigation category includes all groundwater used for irrigation of crops and farmland, and golf course turf grass. On October 6, 2011, ASI spoke with a representative from the WVU Agriculture Extension Service – Jefferson County Office, who grew up farming in Jefferson County and currently lives on a working farm within the county. She stated that she knows of only one farmer in the county who has a center pivot irrigation system and that he no longer uses it. She informed ASI that very little crop irrigation occurs in Jefferson County as the costs associated with setting up and implementing an irrigation system are often too high to economically outweigh the benefits of using natural rainfall for nourishment and hydration of cropland. For the purposes of this water budget study, ASI has assumed that the only significant groundwater use application in the irrigation category is for golf course irrigation. Three golf courses were identified within the county. Water use information for two of the three golf courses was provided by Mr. Brian Carr with the West Virginia Department of Environmental Protection, Division of Water and Waste Management. Water use for the third golf course was estimated using a previously published coefficient of 5.37 gallons per day per hole (Atkins, 2004). ASI has estimated a total of **0.18 Mgal/day** of groundwater use in Jefferson County in the irrigation category which equates to an annual usage estimate of **65.2 Mgal/yr.**

#### *6.2.5 Commercial*

Commercial groundwater use includes all groundwater that is withdrawn for use at commercial facilities including restaurants, gas stations and hotels. Water use at institutions such as schools and churches is also included within this category. Many of the establishments that would fall under the commercial category in this study are likely also accounted for under the public supply category which complicates the ability to determine an estimate of commercial use without duplication. The value for commercial water supply was taken directly from the 2004 USGS report and adjusted proportional to population growth since 2004. In 2004 Atkins reported an estimate of 88,000 gallons per day of groundwater usage in Jefferson County in the commercial category. ASI adjusted this number proportional to the reported population growth from 2004 to 2010 (12.25% population increase) to obtain an estimate of **0.099 Mgal/day,** or **36.1 Mgal/year**, for commercial water use in Jefferson County.

#### *6.2.6 Mining*

The mining category includes all groundwater that is used at quarries and mines for any application associated with mining activities and mining facilities. Only one quarry, Millville Quarry, operated by Aggregate Industries, was identified in Jefferson County. Millville quarry is located on the western bank of the Shenandoah River. During a phone interview with Millville Quarry staff in August of 2011 the waters of the Shenandoah River were reported to occasionally breach a levee on the edge of the quarry pit resulting in the need for surface water to be removed from the pit. An estimate of groundwater usage for the pit was not obtained as water removed from the pit was reported to likely be due to surface water infiltration. Since mining activity in the county is not believed to have changed since 2004, and since no additional data for water volume use was identified, ASI utilized the previously determined value of 0.1 Mgal/day from Atkins (2004) for groundwater withdrawal associated with mining in Jefferson County. This daily value equates to an annual usage of **36.5 Mgal/year** for mining water use in Jefferson County.

## 6.3 Calculated Estimate of Groundwater Availability

An estimate of groundwater availability has been made considering groundwater recharge, groundwater usage, and the component of groundwater recharge that would be necessary to maintain sufficient baseflow to streams. The highest risk of adequate water supply occurs during drought conditions; therefore, a recharge volume has been estimated within this report assuming severe drought conditions (defined as 60 % of normal annual precipitation). The total volume of annual groundwater recharge in drought conditions within Jefferson County has been estimated to be 18,475,000,000 gallons as determined in Section 6.1 above.

The component of effective recharge that would be expected to be necessary for the maintenance of baseflow to streams in Jefferson County has been estimated with the use of available hydrograph data from a similar geologic setting in a neighboring County. The Maryland Department of the Environment (MDE) has developed effective recharge data for various watersheds via hydrograph separation analyses. These effective recharge data are representative of both drought conditions (a drought occurring at a frequency of 1 in every 10 years) and also of 7Q10 conditions. 7Q10 is the lowest flow expected to occur on a particular stream for seven consecutive days once every ten years. Water balance criteria adopted by the MDE use the drought condition recharge value to determine available recharge, then reduce the resulting drought recharge volume by the 7Q10 volume to account for maintenance of stream base flow (Hammond, 2007). This calculation method is adopted for the availability estimates in this study.

While specific effective recharge values for a 10-year drought and 7Q10 data were not readily available for the study area, data from a similar hydrogeologic setting within a neighboring county are useful towards estimating the volume of water that may be required to maintain baseflow to streams. The watershed for Antietam Creek includes Washington County, Maryland, which adjoins Jefferson County to the north. This watershed lies within the Valley and Ridge Province and is largely underlain by carbonate geology. The drought condition recharge value estimated by the MDE for Antietam Creek is 7.0 inches per year, which approximates the estimates determined for the three hydrogeologic units defined during this study within Jefferson County. The 7Q10 effective recharge value for the Antietam Creek watershed is 2.8 inches which equates to 40% of the drought recharge value.

The 7Q10 value (2.8 inches year) mentioned above represents 50% of the effective recharge rate (5.6 inches per year) selected for the Jefferson County “Central Unit’ during this study. A reduction of the theoretically available recharge volume by 50% would be expected to provide sufficient groundwater for the maintenance of baseflow to streams.

| | |
|---|---|
| Theoretical Effective Recharge Volume: | 18,475,000,000 gallons |
| Volume Necessary to Support Base Flow: (-50% Recharge) | 9,237,500,000 gallons |

<u>Estimate of Groundwater Available</u>

18,475,000,000 gal – 9,237,500,000 gal = **9,237,500,000 gallons**

<u>Percentage of Estimated Groundwater Available Currently Used</u>

1,465,250,000 gal groundwater used **/** 9,237,500,000 gals available = **15.86 percent**

Based on the assumptions herein, the percentage of theoretically available groundwater currently being utilized within Jefferson County is approximately 16 percent. While this estimation suggests an excess supply of available groundwater within the county, it is important to understand that hydrogeologic conditions across the county are variable. Site specific assessment should be made to understand the compatibility of a planned used with the existing hydrogeologic conditions.

# 7.0 Review of Groundwater Quality

The bedrock geology underlying Jefferson County is variable in character as represented by the three defined hydrogeologic units. Because the chemical signature of groundwater depends so much on the existence, abundance, and solubility of naturally occurring minerals, the geologic setting greatly affects groundwater chemistry. Generally water becomes more mineralized and bacteria content decreases with increasing depth below land surface (Hobba, 1981).

Groundwater underlying Jefferson County has been studied extensively with numerous investigations being conducted by the United States Geological Survey (USGS) since the 1960s. These investigations have primarily focused on the karst bedrock aquifer existing within the carbonate lithology across the county. Attention to the karst aquifer has likely been due to the large yields of available water and the susceptibility of the aquifer to contamination. Also carbonate rocks underlie approximately 86% of the county (Kozar, Hobba and Macy in 1991). The following summary on water quality include a discussion of each of the three identified hydrogeologic units referenced in Section 2.0 of this study.

## 7.1 Central Valley-Folded Carbonates "Central Unit"

Numerous Investigations of the karst region of Jefferson County have been conducted by USGS beginning with an initial study in 1961 (Paul P. Bieber) that described the hydrogeologic setting of Jefferson and neighboring Berkley Counties. Two additional studies were conducted by William A. Hobba (1976 and 1981) on the same counties with an emphasis on Ordovician age limestones and dolomites of the Great Valley. Hobba's work focused on assessing quality of the karst aquifer system and determining whether agriculture use was impacting water quality. Later work performed by Kozar, Hobba and Macy in 1991 involved assessment of water quality to determine if conditions had changed since the 1981 study. Findings from these studies indicate that water quality from the area of the county underlain by carbonates is often characterized by high levels of hardness, high nitrate concentration, and, in some cases, the presence of both fecal coliform and fecal streptococcal bacteria (Kozar, 2002).

Bieber (1961) documented overall good quality water from the carbonate aquifers, noting the exception that many wells produced hard to very hard water. Hobba's county-wide investigation of Jefferson County also documented high concentrations of nitrates (Hobba, 1981). Of 192 well water samples, 27 were found to have nitrate concentrations exceeding the 10 mg/L maximum contaminant level (MCL) drinking water standard. A second county-wide study included dye tracer testing to evaluate flow rates and directions within the karst bedrock aquifer. Sixty two (62) water samples collected from wells and springs were analyzed with 26% containing nitrates in excess of the MCL. Fecal coliform bacteria were found in 53% of the samples and fecal streptococcal bacteria were detected in 70% of the samples (Kozar and others, 1991).

The Central Unit is underlain by folded carbonate rocks with minor occurrences of shale bedrock. The carbonates consist of limestone and dolostone, which are made up of minerals that are relatively soluble when in contact with the natural acidity of infiltrating precipitation and groundwater. Groundwater from a bedrock aquifer contains dissolved ions representative of the composition of the bedrock. These ions slowly dissolve as the water comes into and maintains contact with mineral surfaces in the pore spaces of bedrock. The total mass of these dissolved ions in a water sample is referred to as total dissolved solids (TDS), which is closely related to hardness. TDS and hardness differ in that hardness is made up of mostly calcium and magnesium ions, while TDS is made up of all dissolved solids in solution. Calcium and Magnesium are two of the most abundant elements in the groundwater of Jefferson County and are important because they contribute to lime-scaling and soap consumption. The solubility of the carbonate bedrock results in higher concentrations of calcium and magnesium ions (higher hardness) compared to other bedrock aquifer settings.

Because of its relatively high solubility, the carbonate bedrock in Jefferson County has undergone varying degrees of karstification. Dissolution channels formed within the bedrock of karst terrain can provide conditions for preferential flow pathways, enabling rapid spread of groundwater contamination. Such conditions can have the potential to quickly transport contaminants from surface or near surface conditions to the underlying bedrock aquifer. In most geologic settings, thick soil overburden acts as nature's water purification system, filtering recharge water as it percolates downward to the water table; but in karst areas this natural filter can sometimes be bypassed by preferential rapid flow paths and drainage features such as sinkholes. Consequently, the carbonate aquifer underlying the Central Unit area is susceptible to groundwater contamination from non-point sources. This susceptibility can be enhanced by surface drainage patterns characteristic of karst aquifer systems.

Much of the carbonate terrain in Jefferson County is used as farmland, with common fertilizer and manure applications to provide nutrients to the landscape, and with large areas of pastureland occupied by livestock. Nitrate, coliform, and streptococcal bacteria are among the most common contaminants that have been detected in the county's carbonate aquifers; all are constituents of biological waste. Based on the ratio of coliform to streptococcal bacteria, Kozar and others (1991) concluded that the vast majority of this contamination in Jefferson County is derived from animal waste.

## 7.2 Western Fault-Dominated "Western Unit"

The western portion of Jefferson County is underlain by carbonates along with shales and sandstones of the Martinsburg formation. The groundwater from this unit has hardness values similar in range with those observed within the folded carbonates of the Central Unit aquifers. Naturally occurring ions of concern in areas underlain by the Martinsburg shale that can affect water quality are iron, manganese, sulfate, and possibly hydrogen sulfide as well as calcium and magnesium to a lesser degree, (Hobba, 1981). Water quality problems encountered in groundwater withdrawn from shale bedrock can typically be alleviated by the implementation of a common water softening system, with the exception of high sulfate concentrations, which may require additional treatment methods.

As supported by casing length data within the newly assembled groundwater database, the depth to bedrock associated with the Western Unit is typically less than observed in the Central Unit terrain resulting in relatively thin overburden (soil and saprolite) to act as a natural filter mechanism. The occurrence of numerous faults and karst drainage features also presents opportunities for the formation of preferential flow paths which could enhance the spread of groundwater contamination.

## 7.3 Eastern Metamorphic "Eastern Unit"

The eastern portion of Jefferson County is underlain by metasedimentary rocks of the Chilhowee group (Harpers, Weverton-Loudoun, and Antietam formations), with a minor occurrence of Catoctin greenstone in the southeast corner of the county. The rocks that comprise this unit are much less soluble than those found in the Central and Western Units and the groundwater gradient is steeper: both factors contribute to lower hardness and lower average pH (higher acidity) than in the other two units. Iron, manganese, and radionuclide issues can arise in wells completed in any formation within the Eastern Unit, with high manganese concentrations being typical of wells completed in the Harpers Shale.

Nitrate and bacterial contamination in the Eastern Unit is most likely indicative of borehole contamination from the wellhead or potentially from malfunctioning septic systems in shallow bedrock conditions. There is much less impact from non-point contaminant sources such as animal wastes, fertilizers and pesticides within the Eastern Unit than in the other two areas described above. This is due to the lower density of such activities and the lack of karst drainage conditions and associated preferential flow pathways.

Dunn Engineers (2008) reported radium exceedances in a number of public water supply wells along the western flank of the Blue Ridge within the Eastern Unit. The West Virginia Bureau for Public Health MCL for Gross Alpha Particle Activity is 15 pCi/l, and the MCL for Radium 228 (combined with Radium 226) is 5 pCi/l. Most reported exceedances in the Eastern Unit of Jefferson County do not fall significantly above the MCLs. As with any drinking water contamination, specifications for radionuclide treatment should be determined on a case-by-case basis.

## 7.4 Common Contaminants and Treatment Methods

The following table summarizes common contaminants identified in Jefferson County and includes a listing of typical treatment technologies used to improve water quality.

**Table 8.**
**Common Groundwater Contaminants in Jefferson County**

| Contaminant | Potential Effect | Common Treatment Methods | More Susceptible Areas* |
|---|---|---|---|
| **Iron & Manganese** | Forms hard reddish brown to black stains on appliances, stains laundry, objectionable taste | polyphosphate treatment<br>ion exchange<br>greensand<br>chlorination (oxidation) plus filtration | Eastern Unit |
| **Sulfate** | Bitter taste, can have laxative effect, corrosive to plumbing | reverse osmosis<br>ion exchange | Western Unit |
| **Nitrate** | Occasional odor, methemoglobiniemia in infants | Microfiltration<br>reverse osmosis | Central Unit, Western Unit |
| **Bacterial Contamination** | Bacteria, viruses and parasites can cause cholera, typhoid fever, dysentery and hepatitis, among other diseases. | uv radiation<br>ozonation<br>Chemical Disinfection-chlorination | Central Unit, Western Unit |
| **Hardness Ca and Mg Ions** | Forms precipitate scale in plumbing and appliances, also consumes soap. | ion exchange<br>Lime-soda treatment | Central Unit, Western Unit |
| **Radionuclides** | Health risk at elevated levels | precipitation/floculation<br>filtration<br>ion exchange | Eastern Unit |

*Notes: *The contaminants listed above can occur throughout the county, but are identified more often in certain areas due to either unique hydrogeology or predominant land uses.*

## 7.5 Groundwater Protection

The bedrock aquifer within any area of the county can be vulnerable to groundwater contamination from both point and non-point contamination sources. The type of land use can also affect the potential for contaminant impact. Leaking underground petroleum storage tanks, residential septic systems, and landfills represent a few examples of contaminant point sources. Common non-point sources result from agricultural activities, including animal waste and broadcast applications of fertilizer and pesticide. The introduction and migration rate of contaminants to groundwater within the bedrock aquifer can be enhanced by geologic conditions such as karst topography, but can also occur in any geologic setting. Shallow or improperly grouted wells can provide conduits or preferential pathways for contaminant migration to groundwater. Exposed or shallow bedrock can also provide ready access for contaminants into secondary porosity features, enabling contaminant migration downward to groundwater.

The identification of contaminant threats through source water area protection planning, both for existing water systems and for future water demand growth, along with ongoing monitoring of groundwater quality, is important for long-term groundwater protection. Such plans typically identify potential contaminant threats and specify best management practices to reduce the potential for contaminant exposure to the defined water source area. Groundwater quality monitoring results can be used to identify contaminants and, where present, establish any trends in contaminant concentrations or migration patterns. Likewise, groundwater protection should be incorporated into long term planning to identify and put protection measures in place for source water areas that are valuable for the development of future groundwater supplies.

# 8.0 Factors that May Affect Utilization of Groundwater

## 8.1 Regulatory Considerations

West Virginia's Public Water Supply Regulations contain specific state requirements and adopt federal regulations under CFR 141. Also, all states must comply with the U.S. Environmental Protection Agency (EPA) Groundwater Rule which requires states to monitor public wells for bacteriological contamination. A public well is defined in West Virginia as one that serves 25 people for at least 60 days per year or has 15 connections.

In Jefferson County, three state agencies maintain regulatory oversight of water wells of various purposes:

1. Office of Environmental Health Services, Environmental Engineering Division (OEHS) – The OEHS enforces compliance of Title 64 Series 19 "Water Well Regulations" as well as Series 45 "Water Well Design Standards." This office oversees public water supply wells, exploratory /observation/test wells for community supply purposes, oversees the source water protection program, and certifies well drillers. West Virginia adopts the federal drinking water standards.

2. Jefferson County Environmental Health Department – The county health department permits private water wells, industrial & commercial use wells, and exploratory/test wells for development of community water supply.

3. West Virginia Department of Environmental Protection, Office of Water Supply (DEP) – DEP oversees the installation and use of groundwater monitoring wells, recovery wells for remediation of contaminated sites, and industrial supply wells.

The 1990 amendments to the federal Safe Drinking Water Act required states to develop a Source Water Assessment and Protection Program (SWAP) with the objective of evaluating and minimizing threats to public drinking water supplies from contamination. West Virginia passed the Water Resources Protection Act (WRPA) in 2004 and its amendment, the Water Resources

Protection and Management Act (WRPMA), in 2008. These acts established the right of the state to regulate its waters and to require the Department of Environmental Protection (DEP) to prepare a water resources plan. Wellhead protection is included in West Virginia's Source Water Assessment and Protection Program. Part of the regulation and planning by the DEP is to "quantify" both the water resources and the water usage within the state.

One of the provisions of the WRPMA is that each facility withdrawing over 750,000 gallons per month must register with the DEP as a large quantity user. Large quantity users must provide estimates of water withdrawals to the state, but there is no permitting program. The DEP is not currently authorized to establish limits on the amount of groundwater that a facility can withdraw (English and Arthur, 2010).

The WRPMA encourages the quantitative or semi-quantitative inventory of groundwater in the state by requiring "a plan for the development of the infrastructure necessary to identify the groundwater resources" of West Virginia. The language does not call for a physical assessment, but a "plan" to develop only the means and methods to obtain such as assessment.

The WRPMA requires DEP to identify "critical planning areas" where increasing demand for water could potentially cause water shortages. According to a recent planning study (English and Arthur, 2010), karst areas in the eastern portion of the state (for example, Jefferson County) were noted as likely to be critical areas. These critical planning areas have not yet been established and potential policy changes under consideration for those areas were not discussed in the report.

## 8.2 Water Law

With the exception of public water supply wells, no formal permit requirements have been identified for groundwater withdrawals from the State of West Virginia. As documented in Section 8.1 above, reporting requirements have been established for large quantity users (750,000 gallons per month) but no limits on withdrawal volume appear to have been established. A summary of groundwater law prepared by the National Agricultural Law Center (Water Law Nutshell. Dean David H. Getches, Water Law, 3rd. ed. 1997*)* suggests that some states, including, West Virginia have adopted a form of the doctrine of reasonable use or the American Rule, which typically requires the water to be put to a reasonable use on the overlying tract of land and does not permit water to be taken to another tract.

The Water Resources Protection and Management Act (WRPMA) (West Virginia Code Chapter 22, Article 26) includes the following findings:

*(1) "The West Virginia Legislature finds that it is the public policy of the State of West Virginia to protect and conserve the water resources for the state and to provide for the public welfare. The state's water resources are vital natural resources of the state that are essential to maintain, preserve, and promote quality of life and economic vitality of the state"*

*(2) "The West Virginia Legislature further finds that it is the public policy of the state that the water resources of the state be available for the benefit of the citizens of West Virginia,*

*consistent with and preserving all other existing rights and remedies recognized in common law or by statute, while also preserving the resources within its sovereign powers for the common good".*

The following definition of beneficial use is also provided within WVC 22-26-2 (b).

*(b)"Beneficial use" means uses that include, but are not limited to, public or private water supplies, agriculture, tourism, commercial, industrial, coal, oil and gas and other mineral extraction, preservation of fish and wildlife habitat, maintenance of waste assimilation, recreation, navigation and preservation of cultural values."*

While language and definitions within the WRPMA suggest that the beneficial use of water can potentially cover a wide variety of uses, it is recommended that any planned groundwater withdrawal be consulted with applicable local, state and federal agencies. A copy of WRPMA WV Code Chapter 22, Article 26 has been provided in Appendix D.

### 8.3 Environmental Considerations

During the development of a groundwater supply, consideration should be given to the likely source area of the groundwater that will be utilized, particularly in areas underlain by karst terrain. A quantitative assessment of the baseline groundwater quality may be critical in evaluating subsequent monitoring data and could provide necessary information for the design of any treatment strategies, if deemed necessary.

Long term use of a groundwater well system can be promoted by employing wellhead protection measures, and by pumping at a carefully planned rate and schedule that efficiently provides needed water while minimally impacting water levels in the surrounding bedrock aquifer.

The recent use of hydraulic fracturing technology associated with extraction of natural gas, represents a potential risk to groundwater quality in many West Virginia localities. In contrast with most of West Virginia, the Marcellus shale does not underlie Jefferson County; therefore, groundwater issues related to natural gas extraction may be less prominent for the Jefferson County Commission as it would be for other West Virginia counties.

# 9.0 Findings and Conclusions

This groundwater water budget study has identified a theoretical surplus of available groundwater resources across Jefferson County. During the water budget analysis three areas deemed to have unique hydrogeologic properties were identified across the county. High yield wells have been documented in all three areas; however, the central area of the county identified as the "folded carbonates of the central valley" possesses the greatest number of higher yielding wells and this area (which covers nearly 60% of the county) would be expected to have the greatest potential for groundwater development. Regardless of a well's location within the county, the presence and connection of secondary porosity features that include fractures, joints, bedding planes, and faults, are generally necessary to accommodate a high yield. A review of geospatially located well data along with mapped fracture traces (lineaments) suggests a correlation between the presence of clusters of high yielding wells and nearby mapped lineaments and/or faults (Figure 6.) Site-specific evaluation, including a review of available well data, mapped lineaments and underlying geology, is recommended to better assess the potential for groundwater development at the site scale.

The Hydrogeology within Jefferson County is variable due to unique conditions of underlying lithology and landscape position across the county area. To enable a better assessment of groundwater availability across the county, three distinct areas, or hydrogeologic units, were delineated. These units are identified as: the Western Fault-Dominated "Western Unit", the Central Valley-Folded Carbonates "Central Unit", and the Eastern Metamorphic "Eastern Unit". The well database developed during this study was used to query well individual well data from each of the defined hydrogeologic units. Statistical analysis of the well data was performed to evaluate parameters of well yield, well depth, casing depth, and static water level. While all of these parameters are considered valuable toward understanding the underlying hydrogeology, well yield may be best indicator of groundwater availability. The highest calculated median well yield from the three units was 20 gpm determined from the Central Unit. Median yields of 10 gpm and 8 gpm were determined from the Western Unit and the Unit, respectively. Certainly, higher yielding wells occur across the county within all three of the defined areas. Well log data indicate maximum well yields of 2000 gpm, 200 gpm, and 300 gpm from the Central, Western, and Eastern units, respectively.

Groundwater availability is primarily determined by conditions present within the underlying bedrock aquifer including the presence and connection of secondary porosity features. The occurrence and connectivity of such secondary porosity features appear to be most prevalent in the "Central Unit". Secondary porosity, which can potentially support high yield wells, exists to a lesser extent in all the other two identified hydrogeologic units.

The Industrial Park (Burr Business Park) is located near Kearneysville within the defined "Central" Unit. The Industrial Park is underlain by carbonate bedrock with the Conococheague limestone formation underlying the eastern portion and the Stonehenge limestone of the Beekmantown Group underlying the western portion of the site. The Conococheague formation possesses groundwater wells with the highest mean well yield (40.78 gpm) of any geologic formation across the county. The bedrock is folded beneath the site as several overturned fold axes are mapped in the general site area. Both strike-parallel and cross-strike fracture trace lineaments have also been mapped in the general area suggesting that secondary porosity features likely exist. Review of the groundwater well database indicates the presence of some existing high yielding wells in proximity to the site area. Based on the findings of this study, the location of the Industrial Park would be expected to have good potential for groundwater development; however, performing additional "site-scale" investigation would be recommended to identify and locate optimal drilling targets.

Clusters of high yield wells have been identified in select locations in proximity to prominent lineaments depicted in fracture trace mapping of the county (Figure 6). One such cluster is located in an area where multiple lineaments were mapped in a general east-west orientation. When looking at lineament mapping at the county-scale, a recognizable pattern of recurring east-west trending lineaments is apparent. These east-west trending lineaments are roughly oriented perpendicular to strike of the underlying bedrock and lie within the central portion of the county. While sufficient well data do not exist to evaluate high-yield well correlation on all prominent lineaments mapped, the data available suggest that review of prominent lineaments should be considered when evaluating areas for the development of large volumes of groundwater.

Conditions that enhance groundwater availability can also have the potential to enhance the susceptibility of the groundwater aquifer to contamination, particularly in karst areas that contain dissolution channels and may have direct connection with surficial drainage patterns (e.g., sinkholes). The carbonate bedrock's dissolution can also cause elevated hardness concentrations in groundwater. Characteristic of the lower median well yields, the bedrock aquifer within portions of the Western Unit (more "shaley" areas) and within the Eastern Unit are typically less vulnerable to surficial contaminants and contaminant migration in the subsurface; however, other quality concerns such as iron, manganese, sulfate concentrations, and occasional radon can be present within the bedrock aquifers of these areas.

The following table summarizes the unique characteristics of each defined hydrogeologic unit with respect to general lithology, features influencing groundwater, well data, and common contaminants.

**Table 9**
**Informational Summary for Hydrogeologic Units**

| Unit | Hydrogeology | Well Data* | Common Contaminants |
|---|---|---|---|
| **Western Unit (Fault-Dominated)** | Dominant Lithology: Limestone, dolostone, and shale<br><br>Ground Water Influences: Faulting, joints, lower permeabililty shales, and karst conditions where present | Yield 19 gpm<br>Well Depth 281 feet<br>Well Casing 57 feet<br>Depth to Water 46 feet | Sulfate, Nitrate, Bacterial, and Hardness |
| **Central Unit (Folded Carbonates)** | Dominant Lithology: Limestone and dolostone<br><br>Ground Water Influences: Joints, bedding planes, cross faults and karst conditions where present | Yield 32 gpm<br>Well Depth 278 feet<br>Well Casing 74 feet<br>Depth to Water 66 feet | Nitrate, Bacteria, Hardness |
| **Eastern Unit (Metamorphics)** | Dominant Lithology: Metamorphic rock; phyllite, metasiltstone, | Yield 14 gpm<br>Well Depth 355 feet | Iron, Manganese, Radionuclides |

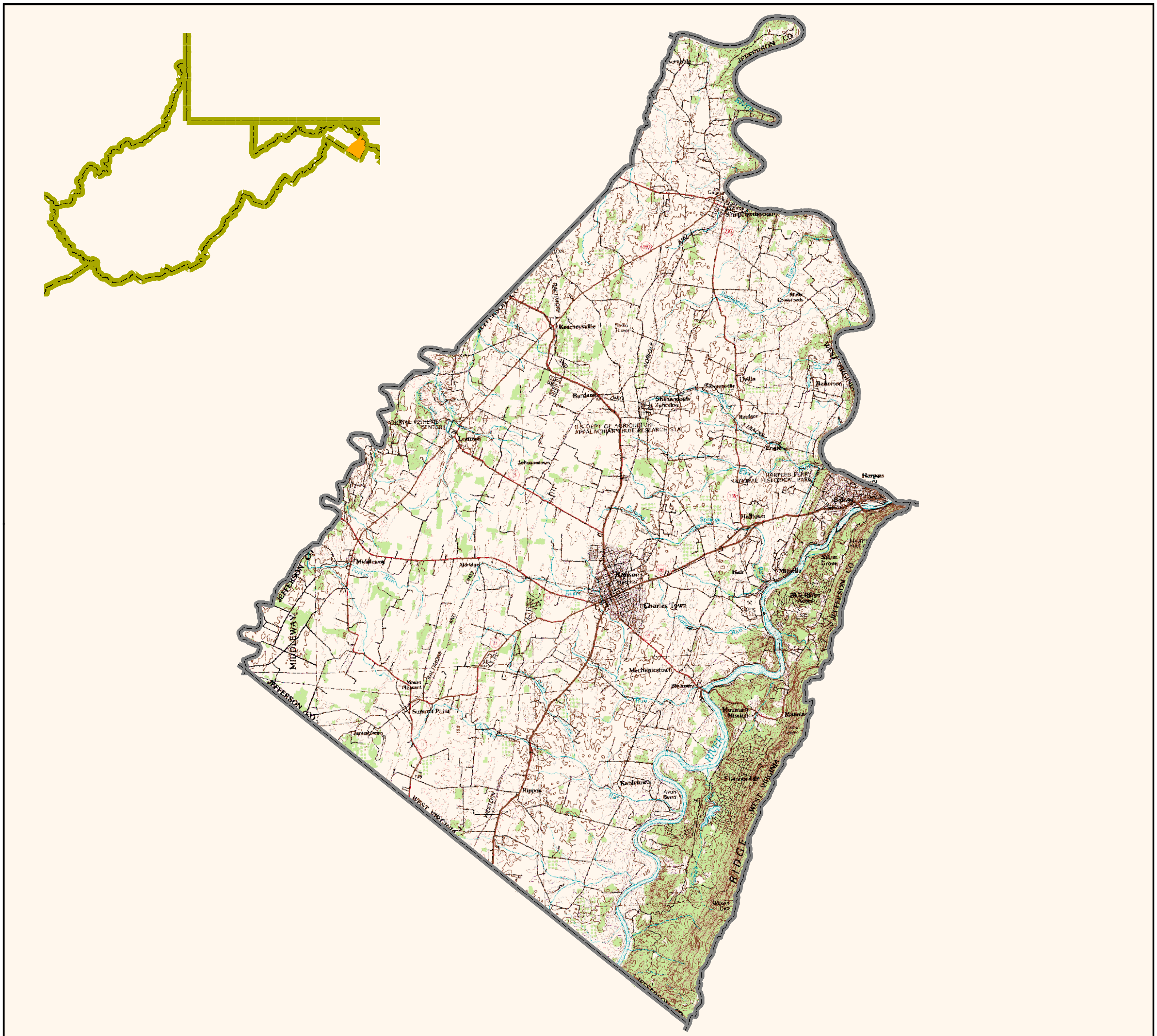
| | | | |
|---|---|---|---|
| | metaconglomerate<br><br>Ground Water Influences:<br>Joint sets and primary bedding structures within metaconglomerates and quartzites. Metasiltstone and phyllite lack primary bedding structures and may be more impermeable. | Well Casing 83 feet<br><br>Depth to Water 94 feet | |

**Mean data value obtained from groundwater well database, see Table 3*

While surplus county-wide groundwater resources are believed to exist for further utilization, the occurrence of groundwater is controlled by underlying hydrogeology which is variable in character. Three areas deemed to have unique hydrogeologic properties were identified in this study. High yield wells have been documented in all three areas; however, the central area of the county, identified as the "folded carbonates of the central valley," possesses the greatest number of higher yielding wells. This area (which covers nearly 60% of the county) would be expected to have the greatest potential for groundwater development.

To promote the sustainability and long term protection of the county's groundwater resources, assessment of planned high yield withdrawals should be conducted to evaluate well yield and, if possible, to determine potential for offsite impact from the planned well use. Existing West Virginia Bureau of Public Health regulations address permitting and pump testing of public water supply wells. While plans for groundwater management are reported to be under development by the State of West Virginia, no specific guidelines were identified during this study to readily assess groundwater withdrawal for uses other than public water supply. While not intended to supersede existing State regulations, recommended draft groundwater assessment standards have been developed and presented in Appendix E. These draft standards are intended to provide a framework for the county's review and consideration. It is important that the groundwater assessment standards match the needs of the county and ultimately promote sustainability and protection of the county's groundwater. To achieve this, the development of a groundwater committee, formed of community stakeholders, is recommended so that the task of reviewing and refining necessary portions of the standards is performed in a manner that best fits the needs of the Jefferson County community. Groundwater protection should be incorporated into long term planning to identify and establish measures in place to protect source water areas valuable to the county's economic future.

# FIGURES



# Jefferson County Site Location Map Figure 1

**Legend**

**CountyBoundary**

**State Boundary**

**Jefferson County**

0 1.25 2.5 5 Miles

**Base Map Source: Jefferson County DRG http://pubs.usgs.gov/of/2005/1407/**

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# Jefferson County Bedrock Geology Map
# Figure 2

## Legend

- **Om Martinsburg Formation** – shale with minor interbedded sandstone and siltstone
- **Omu Middle Ordovician Limestones** – limestone with interbedded limestone and calcareous shale
- **Opr Pineburg Station Dolomite and Rockdale Run Formation** – limestone and dolostone
- **Os Stonehenge Limestone** – fossiliferous limestone with minor black chert and dolomite
- **OЄc Conococheague Limestone** – interbedded limestone, dolostone and sandstone
- **Єe Elbrook Formation** – interbedded limestone, dolostone and shale
- **Єw Waynesboro Formation** – dolomite and dolomitic limestone with interbedded shale, mudstone and sandstone
- **Єt Tomstown Formation** – dolomite and dolomitic marble
- **Єa Antietam Formation** – metasandstone
- **Єh Harpers Formation** – phyllitic metasiltstone
- **Єwl Weverton and Loudoun Formations** – metasandstone, conglomerate and phyllite
- **Zc Catoctin Formation** – metabasalt

0 1.25 2.5 5 **Miles**

**Base Map Source: http://pubs.usgs.gov/of/2005/1407/**

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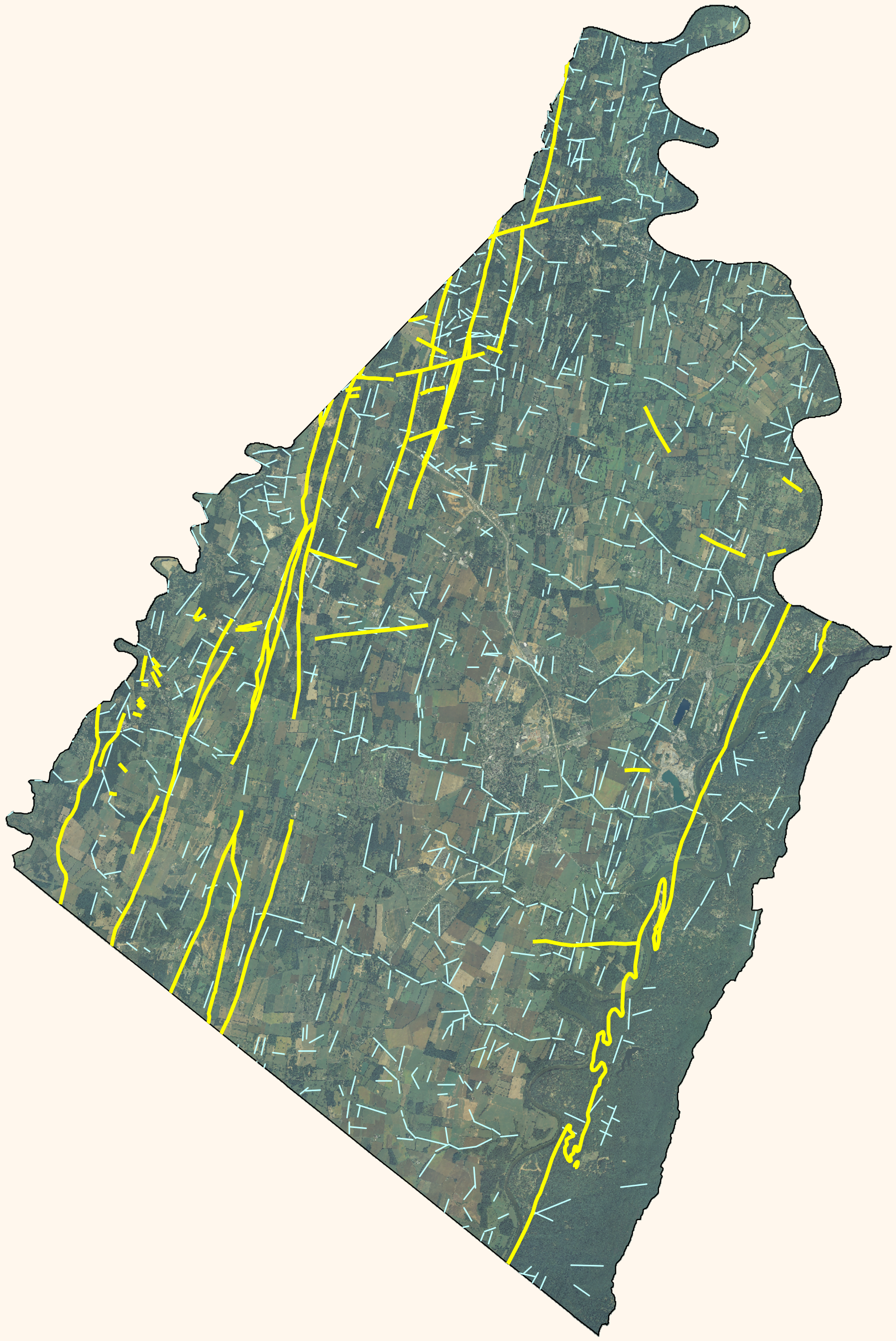

# Faults and Fracture Traces Map
# Figure 3

**Legend**

- Faults
- Fracture Traces
- County Boundary

COUNTY OF JEFFERSON 1801 WEST VIRGINIA

N

0 1.25 2.5 5 Miles

**Base Map Source: USDA-FSA Aerial Photography Field Office**

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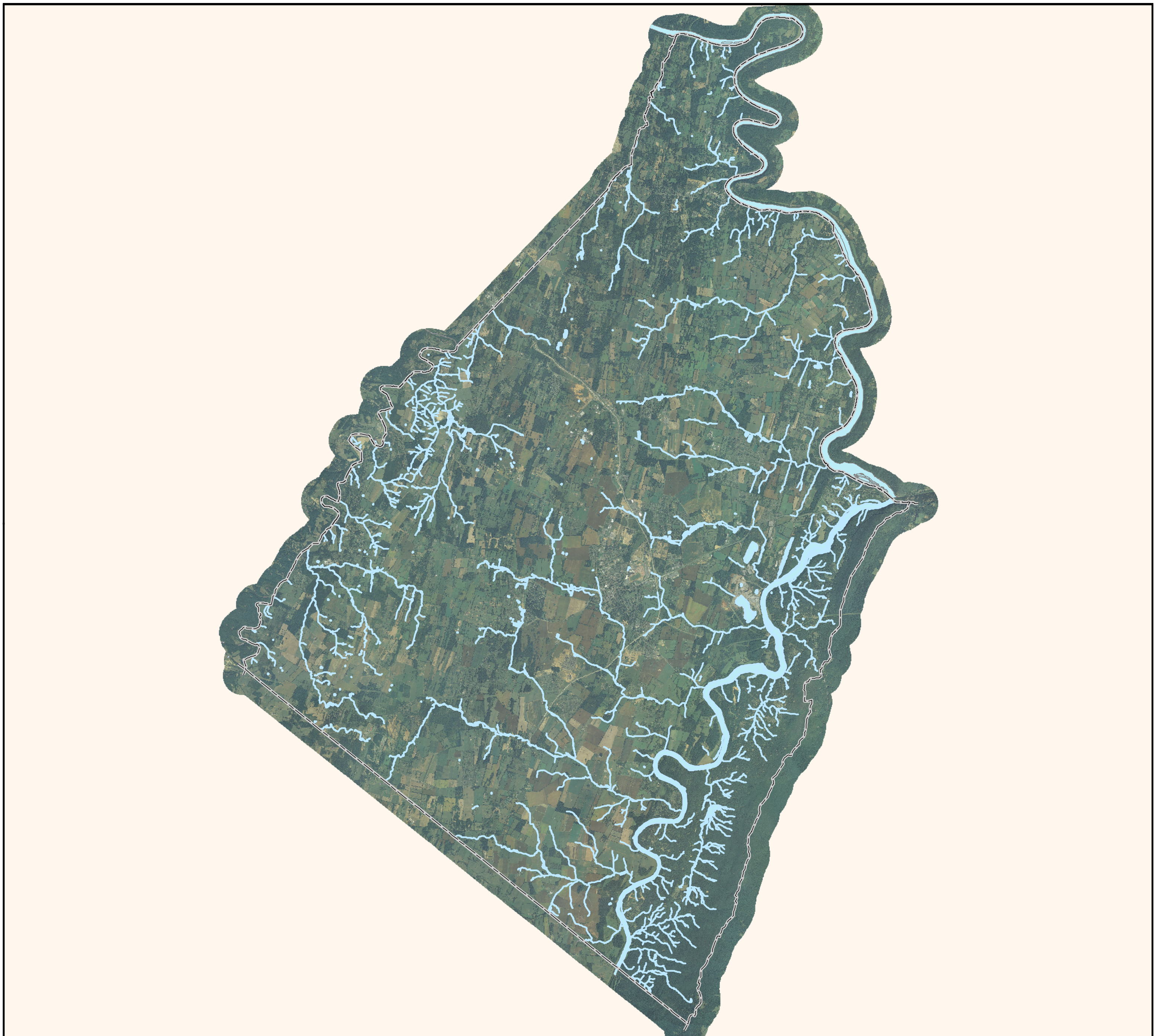

# Surface Water Features
# Figure 4

## Legend

CountyBoundary

Streams

Rivers/Lakes

0 1.25 2.5 5 Miles

Base Map Source: USDA-FSA Aerial Photography Field Office

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# Hydrogeologic Units
# Figure 5

**Legend**

- Metamorphic Eastern
- Folded Carbonate Central
- Faulted Western
- Roads


N

0 1.25 2.5 5 Miles

Base Map Source: USDA-FSA Aerial Photography Field Office

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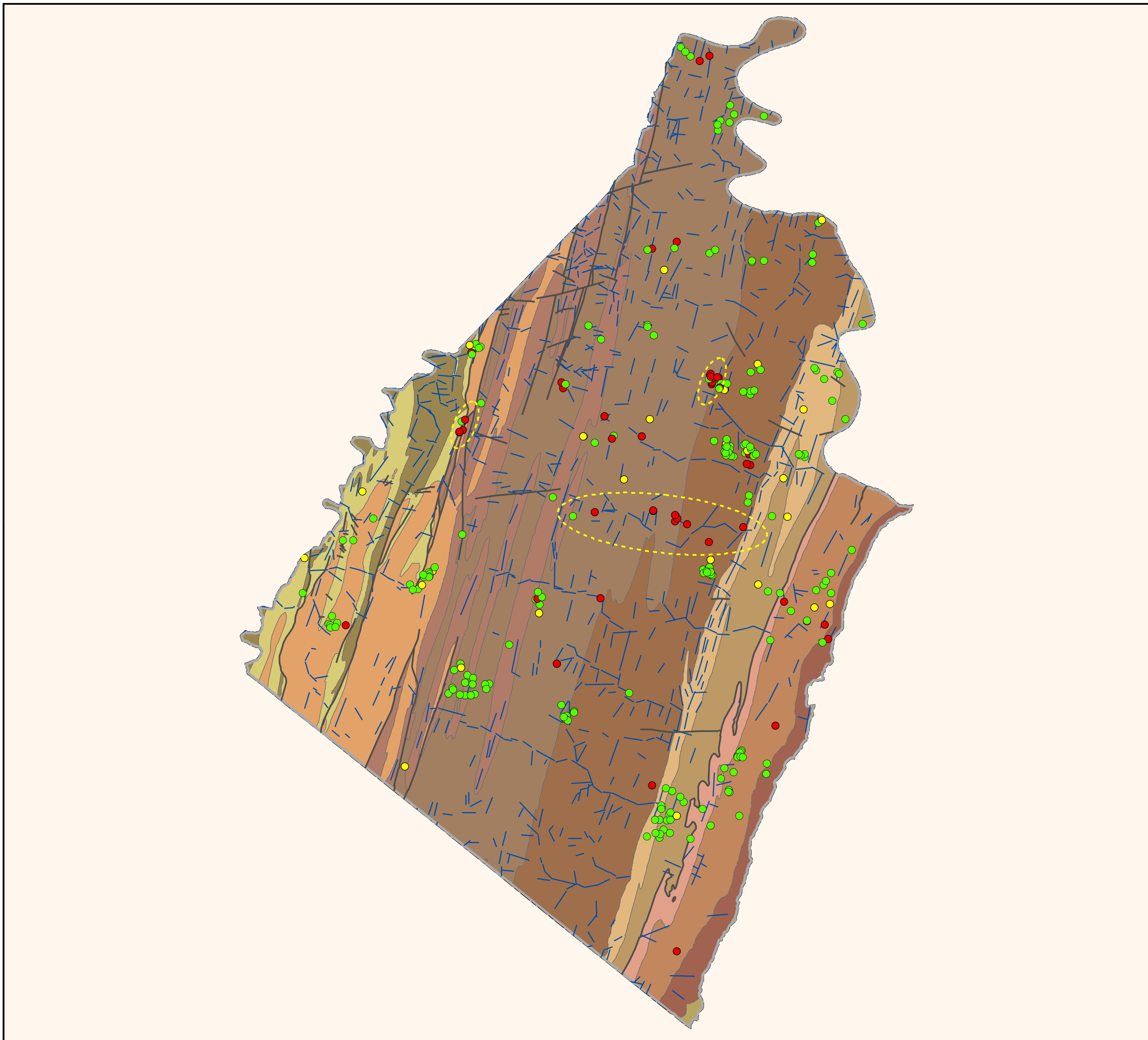

# High Yield Wells and Geologic Features Figure 6

**Legend**

**Bedrock**
- Om
- Omu
- Opr
- Os
- OЄc
- Єe
- Єw
- Єt
- Єa
- Єh
- Єwl
- Zc

**Yield gpm**
- 26-50
- 51-75
- 76+
- Faults
- Fracture Traces
- County Boundary
- Examples of High Yield Clusters

0 1.25 2.5 5 Miles

N

**Base Map Source: http://pubs.usgs.gov/of/2005/1407/**


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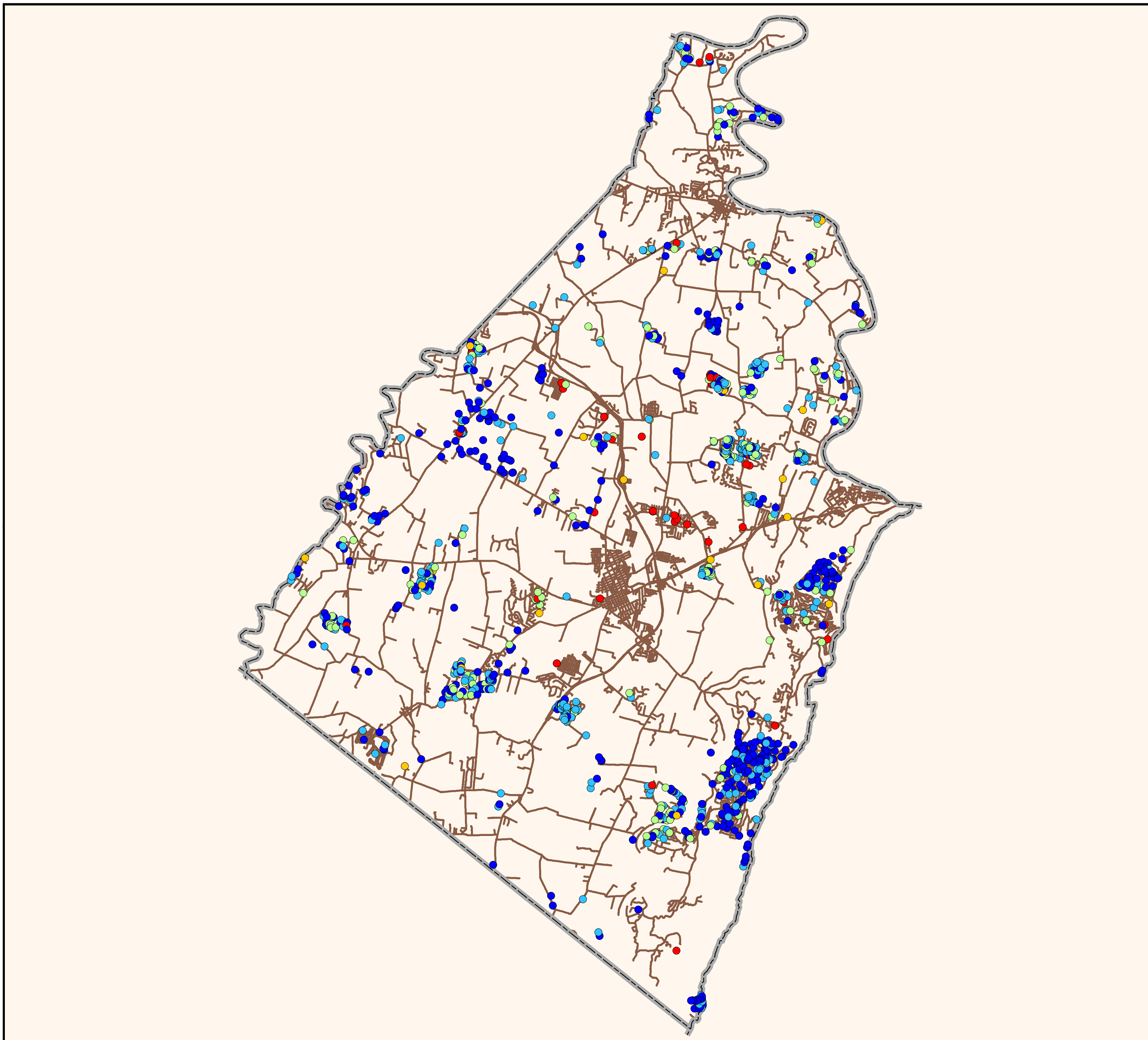

# Well Locations and Reported Yields Figure 7

**Legend**

**Yield gpm**

- 0-10
- 11-25
- 26-50
- 51-75
- 76+

County Boundary

Roads

N

0 1.25 2.5 5 Miles

Base Map Source: Jefferson County GIS/Addressing Office

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# Recharge and Discharge Zone Mapping Figure 8

## Legend

CountyBoundary

Discharge Zone

Recharge Zone

N

0 1.25 2.5 5 Miles

Base Map Source: USDA-FSA Aerial Photography Field Office

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# APPENDICES

# APPENDIX A.

## Summary of Statistical Analysis of Well Data

## Appendix A-1. Methods of Well Database Development

Available well record information from the County Health Department had been previously entered into a Microsoft Access database format. On the initial review, there were 15,553 entries of wells and/or septic systems within their database; however, there were no addresses listed for any of the entries. Entry location had been designated by the following six fields: Location, Section, Lot, District, Tax Map, and Parcel. There were a series of inconsistencies noted in the syntax of various location fields (i.e., hyphens present or absent, parcel and subparcel being combined, backslashes present, etc.). A series of queries were done and new location fields created to aid in achieving a geospatial location assignment for each well. The 15,553 entries were initially reduced to 1,652 and the newly created dbase file was added to ArcMap. The process resulted in a match of 1,276 parcels between the database information and the map parcel layer. In an attempt to conduct a quality analysis of the database, a 5% random sampling of the 1,276 entries (75) hard copies of the well completion forms were reviewed for accuracy of data entry, and accuracy of section, lot, location, and legal description. Five (5) of the 75 physical records could not be found. There were some inconsistencies found in mismatched parcels or those listed as routes. It was decided to move forward only with records that had a direct match between the section, lot, and location to the legal address. The total number of records that matched was 955.

The new database was assembled after review of physical well completion reports. Information within the new table was cross checked with physical records and corrections were made within the database if inaccurate information was found. If there was no information found for a particular field a hyphen (-) was inserted to show that no information was found as text. A zero (0) was inserted in the number fields to show that no information was found. Only the yield (pump test rate) field was initially found to have values of zero entered. While, this process may increase the number of wells with zero reported yields beyond the actual number of wells that did have zero yields, it is entirely possible that a driller may have not identified any yield value for a dry well. Based on the inability to identify exactly how many wells were dry, or had a yield of zero, all zero values of pump rate "yield" within the database were considered dry wells.

The 955 entries were then matched with parcels resulting in 921 entries being joined with parcel data. Some of the address points were deemed to have a poor match with the parcel map data. In those instances the address of the parcel owner was used in conjunction with the address point to refine the well point location. For some of the mapped parcels two points were found to exist. These "dual" points were likely the result of inaccuracies with the address points and parcel polygons. To identify a point that was deemed to be correct, aerial photos were reviewed to see which point was located on, or near, a building within the parcel. During this process some site locations were in doubt resulting in a total of 911 entries which were ultimately matched with address points.

Additional well data was obtained from the USGS 2005 Open File Report that included 181 wells along with useful well attribute information. The physical well locations had been previously been determined by others and a shapefile was downloaded from USGS. After including these wells into the database it was determined that two of them were duplicates resulting in a total number of 1,090 entries, or wells. Additional wells records were obtained from public well systems within the county via the State of West Virginia Bureau of Health. Location coordinates were also provided with this data. These public well records resulted in an additional 34 wells that were added to the database for a total of 1,124 well entries. Figure 7 depicts the locations of the wells within the database on a county basemap.

Well records were assigned geo-referenced locations based on GIS address points and parcel data shapefiles. In addition some points were obtained from prior research reports and from the West Virginia Bureau of Health. While the process used to assign locations for the wells within the database may not represent the exact well locations, the results are deemed to be adequate for assessment of well data on a county-wide scale. It should be noted that while well records were identified across Jefferson County, many of them were found to be situated near to roads and subdivisions. Wide areas of the county are not represented by well data.

## Appendix A-2. Methods of Statistical Analysis of Well Database

The bin number is the upper value of an arbitrary range that was selected to identify what percentages of the total wells fell within that range. For example, 44.65% of the wells had reported yields that fell between zero and ten gpm. While 1.87% of the wells had reported yields greater than 100 gpm.

The results of frequency analyses for all the wells in the county database are presented as histograms below in Table A-1. Descriptive statistics and results of frequency analyses of well data by Hydrogeologic Unit are presented on the following page.

**Table A-1**
**Frequency Analysis of County Well Data**

**Yields**

| *Bin* | *Frequency* | |
|---|---|---|
| 10 | 501 | 44.65% |
| 25 | 348 | 31.02% |
| 50 | 195 | 17.38% |
| 100 | 57 | 5.08% |
| More | 21 | 1.87% |
| | 1122 | |

**Casing Length**

| *Bin* | *Frequency* | |
|---|---|---|
| 40 | 260 | 25.07% |
| 60 | 252 | 24.30% |
| 100 | 300 | 28.93% |
| 150 | 165 | 15.91% |
| More | 60 | 5.79% |
| | 1037 | |

**Depth**

| *Bin* | *Frequency* | |
|---|---|---|
| 100 | 49 | 4.43% |
| 200 | 228 | 20.61% |
| 300 | 365 | 33.00% |
| 400 | 237 | 21.43% |
| 500 | 114 | 10.31% |
| More | 113 | 10.22% |
| | 1106 | |

**Static**

| *Bin* | *Frequency* | |
|---|---|---|
| 10 | 24 | 2.36% |
| 20 | 72 | 7.07% |
| 30 | 64 | 6.28% |
| 40 | 83 | 8.15% |
| 60 | 241 | 23.65% |
| 80 | 246 | 24.14% |
| More | 289 | 28.36% |
| | 1019 | |

**Appendix A-2 Well Data Statistics by Hydrogeologic Unit**

| Western Unit | Depth (ft) | Yield (gpm) | Static DTW (ft) | Casing Length (ft) |
|---|---|---|---|---|
| Mean | 278 | 19 | 46 | 52 |
| Std. Dev. | 163 | 25 | 33 | 41 |
| Median | 260 | 10 | 40.41 | 42 |
| Max | 800 | 200 | 224 | 286 |
| Min | 0 | 0 | 1.96 | 0 |

| Central Unit | Depth (ft) | Yield (gpm) | Static DTW (ft) | Casing Length (ft) |
|---|---|---|---|---|
| Mean | 273 | 32 | 66 | 69 |
| Std. Dev. | 137 | 98 | 32 | 44 |
| Median | 245 | 20 | 64 | 63 |
| Max | 900 | 2000 | 300 | 283 |
| Min | 0 | 0 | 4.8 | 0 |

| Eastern Unit | Depth (ft) | Yield (gpm) | Static DTW (ft) | Casing Length (ft) |
|---|---|---|---|---|
| Mean | 351 | 14 | 94 | 83 |
| Std. Dev. | 143 | 22 | 49 | 68 |
| Median | 316 | 8 | 85 | 61.5 |
| Max | 800 | 300 | 300 | 504 |
| Min | 0 | 0 | 7 | 0 |

## Western Unit Histograms

**Yield (gpm)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 10 | 134 | 50.95% |
| 25 | 73 | 27.76% |
| 50 | 38 | 14.45% |
| 100 | 15 | 5.70% |
| More | 3 | 1.14% |
| Count | 263 | |

**Depth (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 100 | 32 | 12.26% |
| 200 | 62 | 23.75% |
| 300 | 61 | 23.37% |
| 400 | 52 | 19.92% |
| 500 | 32 | 12.26% |
| More | 22 | 8.43% |
| Count | 261 | |

**Casing Length (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 25 | 56 | 23.43% |
| 40 | 32 | 13.39% |
| 60 | 63 | 26.36% |
| 100 | 61 | 25.52% |
| 150 | 22 | 9.21% |
| More | 5 | 2.09% |
| Count | 239 | |

**Static DTW (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 10 | 16 | 6.30% |
| 20 | 49 | 19.29% |
| 30 | 33 | 12.99% |
| 40 | 28 | 11.02% |
| 60 | 69 | 27.17% |
| 80 | 31 | 12.20% |
| More | 28 | 11.02% |
| Count | 254 | |

## Central Unit Histograms

**Yield (gpm)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 10 | 175 | 31.31% |
| 25 | 202 | 36.14% |
| 50 | 130 | 23.26% |
| 100 | 35 | 6.26% |
| More | 17 | 3.04% |
| Count | 559 | |

**Depth (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 100 | 27 | 4.83% |
| 200 | 145 | 25.94% |
| 300 | 210 | 37.57% |
| 400 | 93 | 16.64% |
| 500 | 45 | 8.05% |
| More | 39 | 6.98% |
| Count | 559 | |

**Casing Length (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 40 | 160 | 29.04% |
| 60 | 101 | 18.33% |
| 100 | 168 | 30.49% |
| 150 | 103 | 18.69% |
| More | 19 | 3.45% |
| Count | 551 | |

**Static DTW (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 10 | 6 | 1.25% |
| 20 | 19 | 3.97% |
| 30 | 25 | 5.22% |
| 40 | 39 | 8.14% |
| 60 | 133 | 27.77% |
| 80 | 149 | 31.11% |
| More | 108 | 22.55% |
| Count | 479 | |

## Eastern Unit Histograms

**Yield (gpm)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 10 | 192 | 64.00% |
| 25 | 73 | 24.33% |
| 50 | 27 | 9.00% |
| 100 | 7 | 2.33% |
| More | 1 | 0.33% |
| Count | 300 | |

**Depth (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 100 | 4 | 1.33% |
| 200 | 21 | 7.00% |
| 300 | 94 | 31.33% |
| 400 | 92 | 30.67% |
| 500 | 37 | 12.33% |
| More | 52 | 17.33% |
| Count | 300 | |

**Casing Length (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 40 | 64 | 21.40% |
| 60 | 88 | 29.43% |
| 100 | 71 | 23.75% |
| 180 | 53 | 17.73% |
| More | 23 | 7.69% |
| Count | 299 | |

**Static DTW (ft)**

| *Upper Range* | *Frequency* | *Per Cent* |
|---|---|---|
| 10 | 2 | 0.70% |
| 20 | 4 | 1.40% |
| 30 | 6 | 2.10% |
| 40 | 16 | 5.59% |
| 60 | 39 | 13.64% |
| 80 | 66 | 23.08% |
| More | 153 | 53.50% |
| Count | 286 | |

**Analysis of Variance (Single Factor)**

This report calculated different mean values for well yield, static DTW, depth and casing length for the Western, Central, and Eastern Hydrogeologic Units. A single factor analysis of variance (ANOVA) was used to verify that the differences between the means of each variable are statistically significant. The analysis was completed using commercial spreadsheet software. A single factor ANOVA was run for each of the four variables. The null hypothesis was that the means of the four variables (yield, static DTW, depth, and casing length) for each hydrologic unit are equal to each other. The null hypothesis is rejected at the 95% confidence level for P values less than 0.05.

The ANOVA test results on the following page indicate that the P value for each of the four tests is below 0.05; therefore, the mean yield, mean static DTW, mean depth, and mean casing length for each of the three units are probably significantly different from each other.

## Single Factor Analyses of Variance (ANOVA)

**1. Well Yield**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Western | 263 | 4910 | 18.6692 | 604.0466 |
| Central | 559 | 18066 | 32.31843 | 9624.662 |
| Eastern | 300 | 4118 | 13.72667 | 486.7612 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 77792.31 | 2 | 38896.16 | 7.670429 | 0.000491 | 3.003767 |
| Within Groups | 5674363 | 1119 | 5070.923 | | | |
| | | | | | | |
| Total | 5752155 | 1121 | | | | |

**2. Well Depth**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Western | 261 | 73221 | 280.5402 | 26048.15 |
| Central | 549 | 152849 | 278.4135 | 17850.24 |
| Eastern | 296 | 105198 | 355.3986 | 18971.22 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 1262829 | 2 | 631414.6 | 31.44109 | 5.25E-14 | 3.003883 |
| Within Groups | 22150957 | 1103 | 20082.46 | | | |
| | | | | | | |
| Total | 23413786 | 1105 | | | | |

**3. Static Depth-to-Water**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Western | 254 | 11631.31 | 45.79256 | 1087.471 |
| Central | 479 | 31464.61 | 65.68812 | 1024.918 |
| Eastern | 286 | 26816.16 | 93.7628 | 2432.916 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 317272.5 | 2 | 158636.3 | 110.5129 | 3.75E-44 | 3.004583 |
| Within Groups | 1458422 | 1016 | 1435.455 | | | |
| | | | | | | |
| Total | 1775694 | 1018 | | | | |

**4. Casing Length**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Western | 239 | 13640 | 57.07113 | 1561.444 |
| Central | 513 | 37760 | 73.60624 | 1665.243 |
| Eastern | 285 | 23666 | 83.0386 | 4582.763 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 89161.34 | 2 | 44580.67 | 18.25071 | 1.62E-08 | 3.004428 |
| Within Groups | 2525733 | 1034 | 2442.682 | | | |
| | | | | | | |
| Total | 2614894 | 1036 | | | | |

# APPENDIX B.

## Methods of Recharge Estimation

## Appendix B-1. Recharge Calculations

# Appendix B-1. Recharge Calculations

| Western Unit | | |
|---|---|---|
| **Total Area** | 1,778,143,870.50 ft2 | |
| | 40,820.40 acres | |
| | 30.17% | |
| **Recharge Zone** | | |
| | 1,600,132,767.81 ft2 | |
| | 36,733.85 acres | |
| **Per Cent of Total** | 90.0% | |
| | Normal (in/yr) | Drought (in/yr) |
| **Recharge Rate** | 9.9 | 5.9 |
| | Normal (ft/yr) | Drought (ft/yr) |
| | 0.825 | 0.492 |
| **Recharge Volume** | Normal (ft3/yr) | Drought (ft3/yr) |
| | 1,320,109,533 | 786,731,944 |
| | Normal (gal/yr) | Drought (gal/yr) |
| | 9,875,079,365 | 5,885,148,308 |

| Central Unit | | |
|---|---|---|
| **Total Area** | 3,418,175,335 ft2 | |
| | 78,470 acres | |
| | 57.99% | |
| **Recharge Zone** | | |
| | 3,078,997,494 ft2 | |
| | 70,683.78 acres | |
| **Per Cent of Total** | 90.1% | |
| | Normal (in/yr) | Drought (in/yr) |
| **Recharge Rate** | 9.3 | 5.6 |
| | Normal (ft/yr) | Drought (ft/yr) |
| | 0.775 | 0.467 |
| **Recharge Volume** | Normal (ft3/yr) | Drought (ft3/yr) |
| | 2,386,223,058 | 1,436,865,497 |
| | Normal (gal/yr) | Drought (gal/yr) |
| | 17,850,141,585 | 10,748,472,352 |

| Eastern Unit | | |
|---|---|---|
| **Total Area** | 698,263,447 ft2 | |
| | 16,030 acres | |
| | 11.85% | |
| **Recharge Zone** | | |
| | 537,123,371 ft2 | |
| | 12,330.61 acres | |
| **Per Cent of Total** | 76.9% | |
| | Normal (in/yr) | Drought (in/yr) |
| **Recharge Rate** | 9.1 | 5.5 |
| | Normal (ft/yr) | Drought (ft/yr) |
| | 0.758 | 0.458 |
| **Recharge Volume** | Normal (ft3/yr) | Drought (ft3/yr) |
| | 407,318,556 | 246,181,545 |
| | Normal (gal/yr) | Drought (gal/yr) |
| | 3,046,946,461 | 1,841,561,048 |

| County Total | | |
|---|---|---|
| **Total Area** | 135,320 acres | |
| **Recharge Zone** | 119,748.23 acres | |
| **Per Cent of Total** | 88.5% | |
| **Recharge Volume** | Normal (gal/yr) | Drought (gal/yr) |
| | 30,772,167,410.50 | 18,475,181,708.25 |

## Appendix B-2. Local Recharge Rates in the Literature

Recharge estimates are typically obtained from field data using several methods. Kozar and others (1990) utilized a “gradient method” which uses as its factors (1) the hydraulic gradient of shallow groundwater over a large area that supports baseflow to a stream segment and (2) the discharge volume of the stream. More common methods are known as hydrograph separation techniques, in which the storm event-related component (“quick flow or direct flow”) of stream discharge are graphically or chemically identified and separated from the component provided by groundwater seepage (“baseflow”).

Applying the gradient method to discharges and drainage areas of the North Fork of Long Marsh Run and an upper reach of Bullskin Run in southern Jefferson County (both in the Folded Carbonate Central Unit), Kozar and others (1990a) reported calculated recharge rates of 11.1 inches per year and 7.1 inches per year, respectively, for these carbonate rocks. Applying the same method to another portion of Bullskin Run, Kozar and others (1990) suggested a “most probable” annual recharge rate of 10 inches. This estimated rate was lower than the method’s result because of site conditions that probably led to overestimates in the calculated recharge.

Yager and others (2008) developed a flow model for the entire Shenandoah Valley, in which it reported a mean recharge rate for the whole valley to be 7.5 in/yr; however, the authors noted that recharge rates vary significantly between locations. Using statistical methods, Yager and others (2008) reported estimated recharge rates for the various rock types ranging from 5.47 in/yr in clastic rocks (i.e, shale), and 9.05 in/yr in metamorphic rocks (i.e., siltstones, sandstones, and metabasalt), to 9.72 in/yr in carbonate rocks (p. 14). Vinciguerra (2008) reported highly variable recharge estimates using hydrograph separation techniques on stream data from a mountain watershed in the eastern panhandle of West Virginia that is underlain by sandstone aquifers in the higher elevations and limestone in the lower elevations.

The Harpers Ferry Source Area Protection Plan (SWAP), prepared by the West Virginia Rural Water Association in 2006, used 9.5 inches of annual recharge to apply to the associated source area which is located predominantly in the Folded Carbonate Central Unit. Largely based on the SWAP, the Groundwater Resource Analysis of the Jefferson Utilities Valley Water System (2010) used 9 inches as a conservative estimate for normal annual effective recharge.

Kozar and Weary (2009) developed a flow model for the Opequon Creek watershed, which includes most of the major rock types found in Jefferson County. Analyzing stream hydrographs from six USGS stream gauges in the Opequon Creek watershed, the authors assigned a recharge rate for carbonate and shale areas in their flow model to be 11.02 in/yr and 5.9 in/yr, respectively. To model drought conditions, these recharge rates were reduced by 40 per cent (the reduction in annual precipitation that would define a drought). Accordingly, Kozar and Weary (2009) assigned drought recharge rates to carbonate and shale aquifers to be 6.6 in/yr and 3.54 in/yr.

To obtain an effective recharge rate for the Western Unit, estimates in the literature from studies done within the unit were reviewed. For example, Kozar and others (2007), using hydrograph separation techniques, reported a recharge rate estimate of 16.5 inches per year for the Hopewell Run watershed near Leetown, which is located within the Western Unit; however, it is noted in Evaldi and others (2009) that this result is probably not representative of the area because the highly faulted karst geology is likely to cause inter-basin transfer of groundwater into the Hopewell Run watershed. For example, Evaldi and others (2009) reported an adjacent watershed to Hopewell Run has no stream runoff. Hopewell Run is underlain mostly by densely faulted karst systems (Conococheague and Stonehenge) in its upper reaches. To obtain a more representative recharge estimate, the estimated recharge rate of 9.9 for the Opequon Creek watershed reported in Evaldi and others (2009) will be assigned to the Western Unit, which is located in the Opequon Creek watershed.

Recharge rates for study sites ("gradient method") in the Central Unit were reported in Kozar and others (1990) to be 7.1 in/yr and 11.0 in/yr. Yager and others (2008) reported an estimate of 9.72 in/yr for purely carbonate rocks in the Shenandoah Valley. The average of these values from the literature is 9.3 in/yr, which is the recharge rate assigned to the Central Unit.

While no recharge values in the literature were found that appeared to be associated with study sites within the Eastern Unit, other nearby sites in similar metamorphic rocks provide applicable results. Yager and others (2008) identified three USGS gaging stations in the Shenandoah Valley whose drainage basins were predominantly underlain by metamorphic rocks, such as those that make up the Eastern Unit. These were Back Creek (Lyndhurst, VA), White Oak Run (near Grottoes, VA), and Happy Creek (Front Royal, VA). The data from the Back Creek site were not used by the authors because baseflow per area was anomalously high. White Oak Run and Happy Creek had measured recharge rates of 9.01 in/yr and 9.17 in/yr, respectively (Table 3, pp. 12-13). These numbers appear to support the statistical estimate for a recharge rate in metamorphic rocks (9.05 in/yr) in the same report. Nelms and others (1997) reported highly variable recharge rates for the "Northern Blue Ridge" Physiographic Province in Virginia, ranging from 6.31 in/yr to a maximum of 33.07 in/yr; however, most of the gaging stations analyzed in Nelms and others (1997) were not located near the Jefferson County region, and likely to have some differences in topography and precipitation, and therefore were not utilized for the Eastern Unit. Based on the applicable data in the literature, a recharge value of 9.08 is assigned to the Eastern Unit which represents an average of the three identified recharge rates identified above (9.01, 9.05, and 9.17 inches per year).

# APPENDIX C.

## Applicable Standards of Water Usage Estimates

## Public Groundwater Usage

$G_m = 13{,}987C_r - 7{,}816C_c$

Where:

$G_m$ is the total water usage, in gallons per month,
$C_r$ is the number of residential connections, and
$C_c$ is the number of commercial connections.

Given: $C_r = 3{,}748$ and $C_c = 154$

Then:
$G_m = 13{,}987(3{,}748) - 7{,}816(154)$
$G_m = 51{,}219{,}612$
Daily usage = $G_m$ / 30 = 1.24 Mgal/day

Annual usage = 1.24 Mgal/day or 452.6 Mgal/yr

## Domestic groundwater usage

Given:
Total county population = 53,498;
Total Public Water Supply Population = 30,295

Then:
Domestic Supply Population = County - PWS = 53,498 - 30,295 = 23,203

*Water use coefficient = 80 gal/day/person*

Domestic Supply Use = 80 gal/day/person*23,203 persons =1.86 Mgal/day or 678.9 Mgal/yr

## Industrial groundwater usage

Reported Annual Average Water Use for Industrial Facilities

| Industrial User | Mgal/yr |
|---|---|
| National Center for Cool & Cold Water Aquaculture* | 446,273,059 |
| Ox Paperboard** | 36,611,033 |
| The Conservation Fund Freshwater Institute* | 337,141,000 |
| UFP Atlantic Division, LLC | 6,999,906 |
| **Total Estimate (Mgal/yr)** | **827,024,998** |

** aquaculture sites understood to have low consumption*
*** Site use understood to consist of both surface water and groundwater*

**Irrigation Groundwater Usage**

Reported Usage Volumes
Cress Creek: 13,735,000 gal/yr
Locust Hill: 51,398,666 gal/yr
Total 65,133,666 gal/yr

Sleepy Hollow Golf Course: 18 holes
Assume 5.37 gallons/hole/day * 365 days/yr
5.37*18 holes/day *365 days/yr = 35,280.90 gal/yr

Total Estimated Irrigation Usage
13,735,000 + 51,398,666 + 35,281 = **65,168,947 gal/yr**

**Estimate of Commerical Groundwater Usage**

2004 population = 47,663
2010 population = 53,498

12.25% increase in population since 2004

2004 commercial use = 88,000 gpd
2010 commercial use (assume 88,000 gpd)
88,000 gpd * (1.1225) = 98,773 gpd *365 days/yr = **36,052,194.8 gal/yr**

**Mining Groundwater Usage**

Utilized previous published values (Atkins, 2004)

**36.5 Mgal/year** for mining water use in Jefferson County.

# APPENDIX D.

## Copy of West Virginia Water Resources Protection and Management Act

**WEST VIRGINIA CODE**
**CHAPTER 22. ENVIRONMENTAL RESOURCES.**
**ARTICLE 26. WATER RESOURCES PROTECTION ACT.**

§22-26-1. Short title; legislative findings.
(a) Short title. -- This article may be known and cited as the Water Resources Protection and Management Act.

(b) Legislative findings. --

(1) The West Virginia Legislature finds that it is the public policy of the State of West Virginia to protect and conserve the water resources for the state and to provide for the public welfare. The state's water resources are vital natural resources of the state that are essential to maintain, preserve and promote quality of life and economic vitality of the state.

(2) The West Virginia Legislature further finds that it is the public policy of the state that the water resources of the state be available for the benefit of the citizens of West Virginia, consistent with and preserving all other existing rights and remedies recognized in common law or by statute, while also preserving the resources within its sovereign powers for the common good.

(3) The West Virginia Legislature further finds that the water use survey conducted by the Department of Environmental Protection is a valuable tool for water resources assessment, protection and management.

(4) The West Virginia Legislature further finds that the water resources of this state have not been fully measured or assessed and that a program to accurately measure and assess the state's water resources is necessary to protect, conserve and better utilize the water resources of this state.

(5) The West Virginia Legislature further finds that the survey information collected and analyzed by the Department of Environmental Protection has identified the need for a statewide water resources management plan.

(6) The West Virginia Legislature further finds that the development of a state water resources management plan is in the best interest of the state and its citizens and will promote the protection of this valuable natural resource; promote its use for the public good; and enhance its use and development for tourism, industry and other economic development for the benefit of the state and its citizens.

(7) The West Virginia Legislature further finds that incomplete data collection from an inadequate groundwater monitoring system continues to hamper efforts to study, develop and protect the state's water resources and will be a major obstacle in the development of a water resources management plan.

§22-26-2. Definitions.
For purposes of this article, the following words have the meanings assigned unless the context indicates otherwise:

(a) "Baseline average" means the average amount of water withdrawn by a large quantity user over a representative historical time period as defined by the secretary.

(b) "Beneficial use" means uses that include, but are not limited to, public or private water supplies, agriculture, tourism, commercial, industrial, coal, oil and gas and other mineral extraction, preservation of fish and wildlife habitat, maintenance of waste assimilation, recreation, navigation and preservation of cultural values.

(c) "Commercial well" means a well that serves small businesses and facilities in which water is the prime ingredient of the service rendered.

(d) Community water system" means a public water system that pipes water for human consumption to at least fifteen service connections used by year-round residents or one that regularly serves at least twenty-five residents.

(e) "Consumptive withdrawal" means any withdrawal of water which returns less water to the water body than is withdrawn.

(f) "Farm use" means irrigation of any land used for general farming, forage, aquaculture, pasture, orchards, nurseries, the provision of water supply for farm animals, poultry farming or any other activity conducted in the course of a farming operation.

(g) "Industrial well" means a well used in industrial processing, fire protection, washing, packing or manufacturing of a product excluding food and beverages or similar nonpotable uses.

(h) "Interbasin transfer" means the permanent removal of water from the watershed from which it is withdrawn.

(i) "Large quantity user" means any person who withdraws over seven hundred fifty thousand gallons of water in a calendar month from the state's waters and any person who bottles water for resale regardless of quantity withdrawn.

(j) "Maximum potential" means the maximum designed capacity of a facility to withdraw water under its physical and operational design.

(k) "Noncommunity nontransient water system" means a public water system that serves at least twenty-five of the same persons over six months per year. (l) "Nonconsumptive withdrawal" means any withdrawal of water which is not a consumptive withdrawal as defined in this section.

(m) "Person", "persons" or "people" means an individual, public and private business or industry, public or private water service and governmental entity.

(n) "Secretary" means the Secretary of the Department of Environmental Protection or his or her designee.

(o) "Transient water system" means a public water system that serves at least twenty-five transient people at least sixty days a year."

(p) "Test well" means a well that is used to obtain information on groundwater quantity, quality, aquifer characteristics and availability of production water supply for manufacturing, commercial and industrial facilities.

(q) "Water resources", "water" or "waters" means any and all water on or beneath the surface of the ground, whether percolating, standing, diffused or flowing, wholly or partially within this state, or bordering this state and within its jurisdiction and includes, without limiting the generality of the foregoing, natural or artificial lakes, rivers, streams, creeks, branches, brooks, ponds, impounding reservoirs, springs, wells, watercourses and wetlands: Provided, That farm ponds, industrial settling basins and ponds and waste treatment facilities are excluded from the waters of the state.

(r) "Watershed" means a hydrologic unit utilized by the United States Department of Interior's geological survey, adopted in one thousand nine hundred seventy-four, as a framework for detailed water and related land-resources planning.

(s) "Withdrawal" means the removal or capture of water from water resources of the state regardless of whether it is consumptive or nonconsumptive: Provided, That water encountered during coal, oil, gas, water well drilling and initial testing of water wells, or other mineral extraction and diverted, but not used for any purpose and not a factor in low-flow conditions for any surface water or groundwater, is not deemed a withdrawal.

§22-26-3. Waters claimed by state; water resources protection survey; registration requirements; agency cooperation; information gathering.

(a) The waters of the State of West Virginia are hereby claimed as valuable public natural resources held by the state for the use and benefit of its citizens. The state shall manage the quantity of its waters effectively for present and future use and enjoyment and for the protection of the environment. Therefore, it is necessary for the state to determine the nature and extent of its water resources, the quantity of water being withdrawn or otherwise used and the nature of the withdrawals or other uses: Provided, That no provisions of this article may be construed to amend or limit any other rights and remedies created by statute or common law in existence on the date of the enactment of this article.

(b) The secretary shall conduct an ongoing water resources survey of consumptive and nonconsumptive surface water and groundwater withdrawals by large quantity users in this state. The secretary shall determine the form and format of the information submitted, including the use of electronic submissions. The secretary shall establish and maintain a statewide registration program to monitor large quantity users of water resources of this state beginning in two thousand six.

(c) Large quantity users, except those who purchase water from a public or private water utility or other service that is reporting its total withdrawal, shall register with the Department of Environmental Protection and provide all requested survey information regarding withdrawals of the water resources. Multiple withdrawals from state water resources that are made or controlled by a single person and used at one facility or location shall be considered a single withdrawal of water. Water withdrawals for self-supplied farm use and private households will be estimated. Water utilities regulated by the Public Service Commission pursuant to article two, chapter twenty-four of this code are exempted from providing information on interbasin transfers to the extent those transfers are necessary to provide water utility services within the state.

(d) Except as provided in subsection (f) of this section, large quantity users who withdraw water from a West Virginia water resource shall comply with the survey and registration requirements of this article. Registration shall be maintained by every large quantity user by certifying, on forms and in a manner prescribed by the secretary, that the amount withdrawn in the previous calendar year varies by no more than ten percent from the users' baseline average or by certifying the change in usage.

(e) The secretary shall maintain a listing of all large quantity users and each such user's baseline average water withdrawal.

(f) The secretary shall make a good faith effort to obtain survey and registration information from persons who are withdrawing water from in-state water resources, but who are located outside the state borders.

(g) All state agencies and local governmental entities that have a regulatory, research, planning or other function relating to water resources, including, but not limited to, the State Geological and Economic Survey, the Division of Natural Resources, the Public Service Commission, the Bureau for Public Health, the Commissioner of the Department of Agriculture, the Division of Homeland Security and Emergency Management, Marshall University, West Virginia University and regional, county and municipal planning authorities may enter into interagency agreements with the secretary and shall cooperate by: (i) Providing information relating to the water resources of the state; (ii) providing any necessary assistance to the secretary in effectuating the purposes of this article; and (iii) assisting in the development of a state water resources management plan. The secretary shall determine the form and format of the information submitted by these agencies.

(h) Persons required to participate in the survey and registration shall provide any reasonably available information on stream flow conditions that impact withdrawal rates.

(i) Persons required to participate in the survey and registration shall provide the most accurate information available on water withdrawal during seasonal conditions and future potential maximum withdrawals or other information that the secretary determines is necessary for the completion of the survey or registration: Provided, That a coal-fired electric generating facility shall also report the nominal design capacity of the facility, which is the quantity of water withdrawn by the facility's intake pumps necessary to operate the facility during a calendar day.

(j) The secretary shall, to the extent reliable water withdrawal data is reasonably available from sources other than persons required to provide data and participate in the survey and registration, utilize that data to fulfill the requirements of this section. If the data is not reasonably available to the secretary, persons required to participate in the survey and registration are required to provide the data. Altering locations of intakes and discharge points that result in an impact to the withdrawal of the water resources by an amount of ten percent or more from the consecutive baseline average shall also be reported.

(k) The secretary shall report annually to the Joint Legislative Oversight Commission on State Water Resources on the survey results. The secretary shall make a progress report every three years on the development of the state water resources management plan and any significant changes that may have occurred since the survey report was submitted in two thousand six.

(l) In addition to any requirements for completion of the survey established by the secretary, the survey must accurately reflect both actual and maximum potential water withdrawal. Actual withdrawal shall be established through metering, measuring or alternative accepted scientific methods to obtain a reasonable estimate or indirect calculation of actual use.

(m) The secretary shall make recommendations to the joint legislative oversight commission created in section five of this article relating to the implementation of a water quantity management strategy for the state or regions of the state where the quantity of water resources are found to be currently stressed or likely to be stressed due to emerging beneficial or other uses, ecological conditions or other factors requiring the development of a strategy for management of these water resources.

(n) The secretary may propose rules pursuant to article three, chapter twenty-nine-a of this code as necessary to implement the survey registration or plan requirements of this article.

(o) The secretary is authorized to enter into cooperative agreements with local, state and federal agencies and private policy or research groups to obtain federal matching funds, conduct research and analyze survey and registration data and other agreements as may be necessary to carry out his or her duties under this article.

§22-26-4. Confidentiality.
(a) Information required to be submitted by a person as part of the water withdrawal survey and registration that may be a trade secret, contain protected information relating to homeland security or be subject to another exemption provided by the state freedom of information act may be deemed confidential. Each such document shall be identified by that person as confidential information. The person claiming confidentiality shall provide written justification to the secretary at the time the information is submitted stating the reasons for confidentiality and why the information should not be released or made public. The secretary has the discretion to approve or deny requests for confidentiality as prescribed by this section.

(b) In addition to records or documents that may be considered confidential under article one, chapter twenty-nine-b of this code, confidential information means records, reports or information, or a particular portion thereof, that if made public would:

(1) Divulge production or sales figures or methods, processes or production unique to the submitting person;

(2) Otherwise tend to adversely affect the competitive position of a person by revealing trade secrets, including intellectual property rights; or

(3) Present a threat to the safety and security of any water supply, including information concerning water supply vulnerability assessments.

(c) Information designated as confidential and the written justification shall be maintained in a file separate from the general records related to the person.

(d) Information designated as confidential may be released when the information is contained in a report in which the identity of the person has been removed and the confidential information is aggregated by hydrologic unit or region.

(e) Information designated as confidential may be released to governmental entities, their employees and agents when compiling and analyzing survey and registration information and as may be necessary to develop the legislative report required by this section or to develop water resources plans. Any governmental entity or person receiving information designated confidential shall protect the information as confidential.

(f) Upon receipt of a request for information that has been designated confidential and prior to making a determination to grant or deny the request, the secretary shall notify the person claiming confidentiality of the request and may allow the person an opportunity to respond to the request in writing within five days.

(g) All requests to inspect or copy documents shall state with reasonable specificity the documents or type of documents sought to be inspected or copied. Within ten business days of the receipt of a request, the secretary shall: (1) Advise the person making the request in writing of the time and place where the person may inspect and copy the documents which, if the request addresses information claimed as confidential, may not be sooner than twenty days following the date of the determination to disclose, unless an earlier disclosure date is agreed to by the person claiming confidentiality; or (2) deny the request, stating in writing the reasons for denial. If the request addresses information claimed as confidential, then notice of the action taken pursuant to this subsection shall also be provided to the person asserting the claim of confidentiality.

(h) Any person adversely affected by a determination regarding confidential information under this article may appeal the determination to the appropriate circuit court pursuant to the provisions of article five, chapter twenty-nine-a of this code. The filing of a timely notice of appeal shall stay any determination to disclose confidential information pending a final decision on appeal. The scope of review is limited to the question of whether the portion of the records, reports, data or other information sought to be deemed confidential, inspected or copied is entitled to be treated as confidential under this section. The secretary shall afford evidentiary protection in appeals as necessary to protect the confidentiality of the information at issue, including the use of in camera proceedings and the sealing of records when appropriate.

§22-26-5. Joint Legislative Oversight Commission on State Water Resources.
(a) The President of the Senate and the Speaker of the House of Delegates shall each designate five members of their respective houses, at least one of whom shall be a member of the minority party, to serve on a joint legislative oversight commission charged with immediate and ongoing oversight of the water resources survey, registration and development of a state water resources management plan. This commission shall be known as the Joint Legislative Oversight Commission on State Water Resources and shall regularly investigate and monitor all matters relating to the water resources survey and plan.

(b) The expenses of the commission, including the cost of conducting the survey and monitoring any subsequent strategy and those incurred in the employment of legal, technical, investigative, clerical, stenographic, advisory and other personnel, are to be approved by the Joint Committee on Government and Finance and paid from legislative appropriations.

§22-26-6. Mandatory survey and registration compliance.
(a) The water resources survey and subsequent registry will provide critical information for protection of the state's water resources and, thus, mandatory compliance with the survey and registry is necessary.

(b) All large quantity users who withdraw water from a West Virginia water resource shall complete the survey and register such use with the Department of Environmental Protection. Any person who fails to complete the survey or register, provides false or misleading information on the survey or registration, or fails to provide other information as required by this article may be subject to a civil administrative penalty not to exceed five thousand dollars to be collected by the secretary consistent with the secretary's authority pursuant to this chapter. Every thirty days after the initial imposition of the civil administrative penalty, another penalty may be assessed if the information is not provided. The secretary shall provide written notice of failure to comply with this section thirty days prior to assessing the first administrative penalty.

§22-26-7. Secretary authorized to log wells; collect data.
In order to obtain important information about the state's surface and groundwater, the secretary is authorized to collect scientific data on surface and groundwater and to enter into agreements with local and state agencies, the federal government and private entities to obtain this information.

(1) Any person who installs a community water system, noncommunity nontransient water system, transient water system, commercial well, industrial or test well, shall notify the secretary of his or her intent to drill a water well no less than ten days prior to commencement of drilling. The ten-day notice is the responsibility of the owner, but may be given by the drilling contractor.

(2) The secretary has the authority to gather data, including driller and geologist logs, run electric and other remote-sensing logs and devices and perform physical characteristics tests on nonresidential and multifamily water wells.

(3) The drilling contractor shall submit to the secretary a copy of the well completion forms submitted to the Division of Health for a community water system, noncommunity nontransient water system, transient water system, commercial well, industrial or test well. The drilling contractor shall provide the well GPS location on the well report.

(4) Any person who fails to notify the secretary prior to drilling a well or impedes collection of information by the secretary under this section is in violation of the Water Resources Protection and Management Act and is subject to the civil administrative penalty authorized by section six of this article.

(5) Any well contracted for construction by the secretary for groundwater or geological testing must be constructed at a minimum to well design standards as promulgated by the Division of Health. Any wells contracted for construction by the secretary for groundwater or geological testing that would at a later date be converted to a public use water well must be constructed to comport to state public water design standards.

§22-26-8. State Water Resources Management Plan; powers and duty of secretary.
(a) The Secretary of the Department of Environmental Protection shall oversee the development of a State Water Resources Management Plan to be completed no later than the thirtieth day of November, two thousand thirteen. The plan shall be reviewed and revised as needed after its initial adoption. The plan shall be developed with the cooperation and involvement of local and state agencies with regulatory, research or other functions relating to water resources including, but not limited to, those agencies and institutions of higher education set forth in section three of this article and a representative of large quantity users. The State Water Resources Management Plan shall be developed utilizing the information obtained pursuant to said section and any other relevant information available to the secretary.

(b) The secretary shall develop definitions for use in the State Water Resources Management Plan for terms that are defined differently by various state and federal governmental entities as well as other terms necessary for implementation of this article.

(c) The secretary shall continue to develop and obtain the following:

(1) An inventory of the surface water resources of each region of this state, including an identification of the boundaries of significant watersheds and an estimate of the safe yield of such sources for consumptive and nonconsumptive uses during periods of normal conditions and drought.

(2) A listing of each consumptive or nonconsumptive withdrawal by a large quantity user, including the amount of water used, location of the water resources, the nature of the use, location of each intake and discharge point by longitude and latitude where available and, if the use involves more than one watershed or basin, the watersheds or basins involved and the amount transferred.

(3) A plan for the development of the infrastructure necessary to identify the groundwater resources of each region of this state, including an identification of aquifers and groundwater basins and an assessment of their safe yield, prime recharge areas, recharge capacity, consumptive limits and relationship to stream base flows.

(4) After consulting with the appropriate state and federal agencies, assess and project the existing and future nonconsumptive use needs of the water resources required to serve areas with important or unique natural, scenic, environmental or recreational values of national, regional, local or statewide significance, including national and state parks; designated wild, scenic and recreational rivers; national and state wildlife refuges; and the habitats of federal and state endangered or threatened species.

(5) Assessment and projection of existing and future consumptive use demands.

(6) Identification of potential problems with water availability or conflicts among water uses and users including, but not limited to, the following:

(A) A discussion of any area of concern regarding historical or current conditions that indicate a low-flow condition or where a drought or flood has occurred or is likely to occur that threatens the beneficial use of the surface water or groundwater in the area; and

(B) Current or potential in-stream or off-stream uses that contribute to or are likely to exacerbate natural low-flow conditions to the detriment of the water resources.

(7) Establish criteria for designation of critical water planning areas comprising any significant hydrologic unit where existing or future demands exceed or threaten to exceed the safe yield of available water resources.

(8) An assessment of the current and future capabilities of public water supply agencies and private water supply companies to provide an adequate quantity and quality of water to their service areas.

(9) An assessment of flood plain and stormwater management problems.

(10) Efforts to improve data collection, reporting and water monitoring where prior reports have found deficiencies.

(11) A process for identifying projects and practices that are being, or have been, implemented by water users that reduce the amount of consumptive use, improve efficiency in water use, provide for reuse and recycling of water, increase the supply or storage of water or preserve or increase groundwater recharge and a recommended process for providing appropriate positive recognition of such projects or practices in actions, programs, policies, projects or management activities.

(12) An assessment of both structural and nonstructural alternatives to address identified water availability problems, adverse impacts on water uses or conflicts between water users, including

potential actions to develop additional or alternative supplies, conservation measures and management techniques.

(13) A review and evaluation of statutes, rules, policies and institutional arrangements for the development, conservation, distribution and emergency management of water resources.

(14) A review and evaluation of water resources management alternatives and recommended programs, policies, institutional arrangements, projects and other provisions to meet the water resources needs of each region and of this state.

(15) Proposed methods of implementing various recommended actions, programs, policies, projects or management activities.

(d) The State Water Resources Management Plan shall consider:

(1) The interconnections and relationships between groundwater and surface water as components of a single hydrologic resource.

(2) Regional or watershed water resources needs, objectives and priorities.

(3) Federal, state and interstate water resource policies, plans, objectives and priorities, including those identified in statutes, rules, regulations, compacts, interstate agreements or comprehensive plans adopted by federal and state agencies and compact basin commissions.

(4) The needs and priorities reflected in comprehensive plans and zoning ordinances adopted by a county or municipal government.

(5) The water quantity and quality necessary to support reasonable and beneficial uses.

(6) A balancing and encouragement of multiple uses of water resources, recognizing that all water resources of this state are capable of serving multiple uses and human needs, including multiple uses of water resources for reasonable and beneficial uses.

(7) The distinctions between short-term and long-term conditions, impacts, needs and solutions to ensure appropriate and cost-effective responses to water resources issues.

(8) Application of the principle of equal and uniform treatment of all water users that are similarly situated without regard to established political boundaries.

(e) In November of each year, the secretary shall report to the Joint Legislative Oversight Commission on State Water Resources on the State water Resources Management Plan. The report on the water resources plan shall include benchmarks for achieving the plan's goals and time frames for meeting them.

(f) Upon adoption of the State Water Resources Management Plan by the Legislature, the report requirements of this article shall be superceded by the plan and subsequent reports shall be on the survey results and the water resources plan. If the plan is not adopted a detailed report discussing the provisions of this section as well as progress reports on the development of the plan shall be submitted every three years.

§22-26-9. Regional water resources management plans; critical planning areas.
(a) As part of the State Water Resources Management Plan, the secretary may designate areas of the state as regional or critical water planning areas for the development of regional or critical area water resources management plans.

(b) The secretary shall establish a timetable for completion of regional and critical area plans which may be developed.

(c) The secretary shall identify all federal and state agencies, county commissions, municipal governments and watershed associations that should be involved in the planning process and any compacts or interstate agreements that may be applicable to the development of a regional or critical area water resource management plan.

(d) The secretary shall establish the minimum requirements for any issues to be addressed by regional and critical area plans within twelve months of the amendment and reenactment of this article during the two thousand eight regular session of the Legislature. The plan requirements and issues to be addressed by regional and critical area plans shall be consistent with the state plan requirements of this article.

(e) The secretary shall establish timetables for the completion of tasks or phases in the development of regional and critical area plans. County commissions and municipal governments may recommend changes in the order in which the tasks and phases must be completed. The secretary shall have final authority to determine the schedule for development of a plan.

(f) Any county or municipal government may enter into an agreement with the secretary to designate a local planning area and develop a local plan which may include all or part of a region. The secretary shall assist in development of any such plan to the extent practicable with existing staff and funding.

(g) Plans developed by a county or municipal government shall comply with the secretary's requirements and shall be filed as part of the State Water Resources Management Plan.

Note: WV Code updated with legislation passed through the 2011 4th Special Session

# APPENDIX E.

## Draft Groundwater Assessment Standards

# DRAFT GROUNDWATER ASSESSMENT STANDARDS

## 1.0 Water Well Systems

The following draft groundwater assessment standards are being submitted for the county commissioner's review and consideration. These standards are not intended to supersede existing West Virginia Bureau for Public Health regulatory guidelines, but are to generate supplemental but useful information concerning planned uses of groundwater with the goal of promoting sustainable groundwater utilization and long term groundwater protection.

### 1.1 Private Individual Wells

A well completion report prepared by the well driller, including latitude and longitude coordinates, will be submitted to the Jefferson County Engineering Department in addition to the Jefferson County Health Department for all private individual wells. Submittal of the well completion report is a recommended prerequisite for the issuance of a building permit.

### 1.2 Public Water System Wells and Large Quantity Users

A water supply well that serves a public or community water system (as defined in Title 64 of the West Virginia Bureau of Public Health Series 19 "Water Well Regulations") and a facility that withdrawals more than 750,000 gallons of groundwater per month must complete a Hydrogeologic Study and Report as described in Section 2.0 below.

## 2.0 Hydrogeologic Study

*1.0 Preliminary Hydrogeologic Report*

The planned water user (applicant) shall submit a preliminary hydrogeologic report to the Jefferson County Engineering Department for review and approval. Preliminary hydrogeologic reports must be certified by either a Professional Geologist (PG) or Professional Engineer (PE) who has demonstrated an adequate knowledge and understanding of hydrogeology in the study area. The report will be prepared so as to include the following:

1) A base map should be prepared utilizing United States Geological Survey (USGS) quadrangle mapping or digital equivalent, 1:24,000 scale or larger.
2) Property plats including plans for each proposed lot.
3) Geologic map showing unit contacts and major structural features on the site and surrounding areas.
4) Summary of available well data (yield, casing length, total depth…etc.) for private and public water supply wells located within ½ mile of the subject site.
5) Fracture fabric analysis including the completion of fracture trace mapping on the site. While the completion of high resolution geophysical resistivity surveys is not mandated by the assessment standards, completion of such surveys is highly recommended.

6) A map illustrating the proposed production well targets and proposed monitor well location(s).
7) Anticipated withdrawal rates and usage (consumptive or non-consumptive, industrial, community, etc.)

## *2.0 Aquifer Testing*

Each production well:

1) Shall be placed, drilled, and constructed in accordance with all West Virginia Bureau of Health regulations for public water supply wells.
2) A geologist will log the well and collect at a minimum one (1) rock cutting sample from each geologic formation, and a minimum of one sample per twenty (20) feet depth interval. The geologist will also document the yield of each water-bearing zone (e.g., by air lift) encountered during the completion of the well. The well log will be certified by a Professional Geologist.
3) Drillers should conduct a one (1) hour air lift yield test following the completion of the well. Well yield measurements (gallons per minute) should be collected at fifteen (15) minute intervals.
4) A copy of the well completion report, including latitude and longitude coordinates (WGS84 coordinate system), submitted to the West Virginia Bureau of Health and Jefferson County Health Department must also be submitted to the Jefferson County Engineering Department.
5) A minimum forty-eight (48) hour constant rate pump test should be performed on the production well. If more than one (1) production well is completed at the site, all wells should be tested simultaneously. The protocol for the 48-hour test should be as follows:
   a) For each production well, static (background) water levels should be measured and documented at one-hour intervals at least 12 hours prior to the initiation of testing.
   b) Near steady state conditions should be achieved for a minimal period of twelve (12) hours prior to the cessation of testing. Steady state conditions are defined as a static pumping water level that varies by less than 5% and a pumping rate that varies by no more than 10%.
   c) The recommended minimal pumping rate for the production well(s) should be equal to one (1) gallon per minute per proposed connection. Actual connections approved for public supply will be determined by West Virginia Bureau of Health.
   d) During the pumping phase of the test, the water level should not encroach within ten (10) feet of any water-bearing zone that contributes twenty-five (25) percent or more to the total well yield.
   e) A recommended guideline for monitoring frequency has been provided in Appendix A. Water levels should be obtained via an electronic water level meter or a down well data logger capable of measuring to 0.01 feet of accuracy.

f) Recovery measurements should be collected until such time as ninety (90) percent of the original static water level is reached.

Each observation well:

1) A minimum of one (1) bedrock observation well will be required per production well. Observation well locations will be proposed in the preliminary report and shall also be located in close proximity to pumping wells with a recommended distance not to exceed 250 feet. Proposed locations will be reviewed/approved by the Jefferson County Engineering Department.
2) Existing wells, in most cases, may be used as observation wells during the aquifer test; however, specific well attribute data (yield, casing length, total depth, etc.) should be obtained and reported for the proposed monitoring point, if available.
3) Water levels should be obtained via an electronic water level meter or down well data logger capable of measuring to 0.01 feet of accuracy. Static water level measurements should be collected at least 12 hours prior to the initiation of the test and at a minimum every four (4) hours during the test, and until ninety (90) percent of recovery to the original static water level is achieved following the test.

IV. Water Quality Analyses

1) All public water supply wells must be sampled in accordance with West Virginia Bureau for Public Health requirements. Sampling and analysis of other wells for parameters included within the US EPA secondary contaminant list is recommended (see Section 1.5 General Information).

## *3.0 Hydrogeologic Report*

A Hydrogeologic Report, including documentation and analysis of the aquifer testing, and the relevant findings of the preliminary report, will be submitted to the Jefferson County Engineering Department. Reports will either be reviewed by designated County staff or by a third party consultant contracted by the County to provide a professional review. The County will have sixty (60) days to review the report in order to assess the submission for completeness and technical content. Should additional information be required, the applicant shall receive written notification of the delinquencies. Upon acceptance of the report, a letter acknowledging approval of the report will be provided by the County. This approval does not imply sustainable water supply or favorable water quality, but rather documents the completion of the report requirements.

1) The report should contain a graphic lithology of each well completed, including all pertinent well information such as yield, casing length, total depth, etc.
2) The report shall include a map, or set of maps, at a scale not greater than 1:6,000 (1”=500’) which should cover the entire proposed development or subdivision. The map(s) should include such information such as completed/proposed water

supply wells, planimetric features, topography, proposed roads, lot lines, domestic structures, surface water features, and proposed septic drainfield locations.

3) A discussion of the following information (including appropriate calculations and supporting documentation) shall be included in the report:
   a) Documentation of theoretical groundwater mass balance and recharge estimates for the study area. This evaluation should include estimates of average recharge for the subject site during normal and extreme drought (estimated as 60% of average annual precipitation value) conditions and include an estimate of the projected net daily water consumption of the facility.
   b) Values for specific capacity, transmissivity, and storativity (if adequate observation well data is available) should be calculated and results compared to published data for similar geologic settings.
   c) Graphics depicting drawdown and recovery of water levels in each testing and monitoring well should be included.
   d) Presentation of results of the water quality analyses.
   e) Contingency plan for water supply should public supply wells not provide adequate yield.

## Appendix A.

### Recommended Water Level Monitoring Schedule

A guideline providing recommended monitoring intervals (both drawdown and recovery phases) for aquifer pump testing has been provided in the table below:

| Frequency, One Measurement Every: | Elapsed Time, For the First: |
|---|---|
| 30 Seconds | 3 Minutes |
| 1 Minute | 3-15 Minutes |
| 5 Minutes | 15-60 Minutes |
| 10 Minutes | 60-120 Minutes |
| 20 Minutes | 2-3 Hours |
| 1 Hour | 3+ Hours |

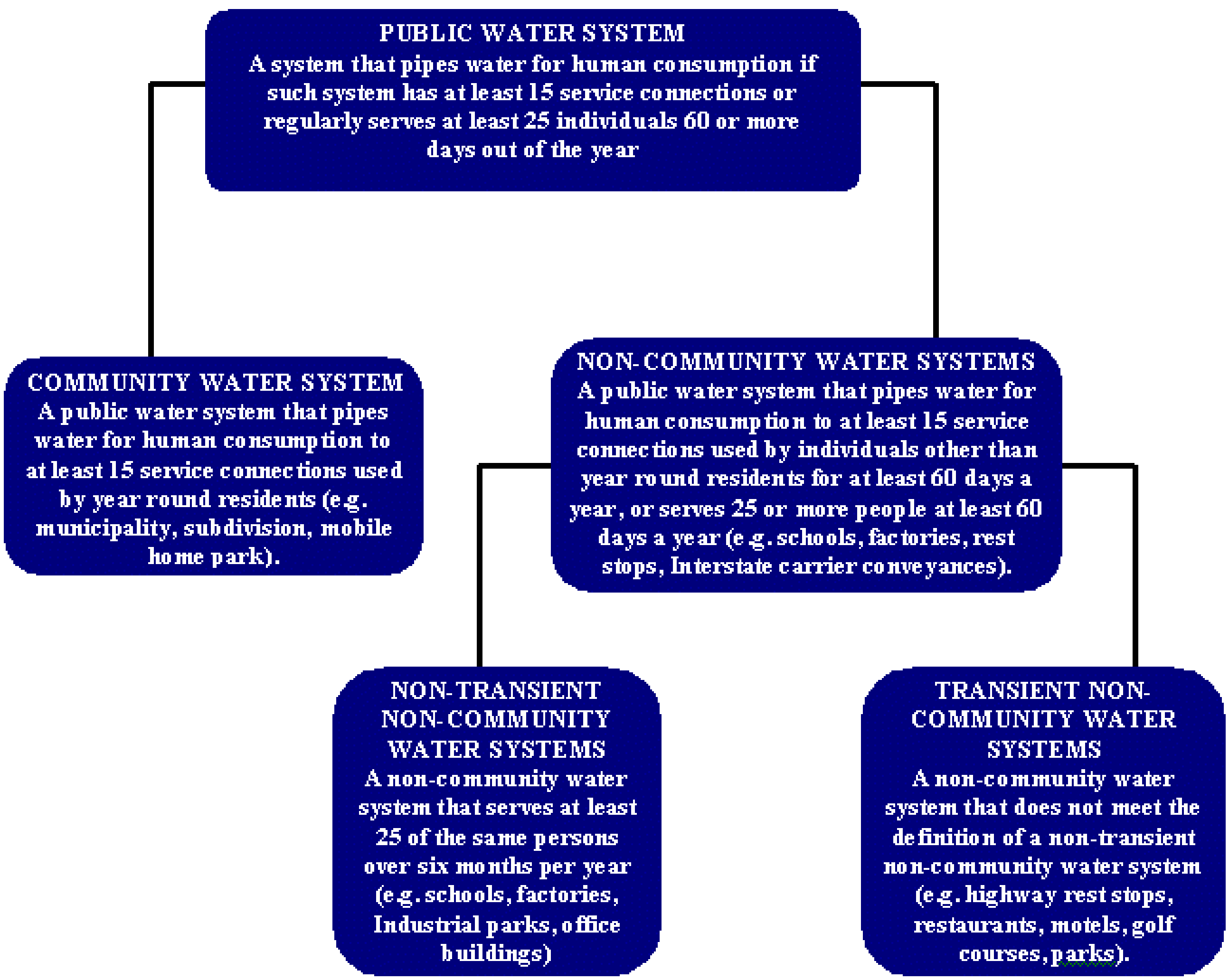
**Appendix B.**

**West Virginia Bureau of Health Definitions**

The following definition of a public water system has been provided by the West Virginia Bureau of Health.

## What is a Public Water System?

A "public water system" has 15 or more service connections or regularly serves at least 25 people 60 or more days a year. A system that serves water 60 or more days a year is considered to "regularly serve" water. Public water systems can be publicly or privately owned. Public water systems are subdivided by regulation into two major categories: community and non-community water systems. This division is based on the type of consumer served and the frequency the consumer uses the water. Basically, a community system serves water to a residential population, whereas a non-community system serves water to a non-residential population. The non-community category is further broken down into two categories: non-transient non-community water system and transient non-community water systems.



## Appendix C.

## USEPA Secondary Drinking Water Regulations

| Contaminant | Secondary Standard |
|---|---|
| Aluminum | 0.05 to 0.2 mg/L |
| Chloride | 250 mg/L |
| Color | 15 (color units) |
| Copper | 1.0 mg/L |
| Corrosivity | noncorrosive |
| Fluoride | 2.0 mg/L |
| Foaming Agents | 0.5 mg/L |
| Iron | 0.3 mg/L |
| Manganese | 0.05 mg/L |
| Odor | 3 threshold odor number |
| pH | 6.5-8.5 |
| Silver | 0.10 mg/L |
| Sulfate | 250 mg/L |
| Total Dissolved Solids | 500 mg/L |
| Zinc | 5 mg/L |

# APPENDIX F.

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