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**Does Coal Mining in West Virginia Produce or Consume Water? A net water balance of seven coal mines in Logan County, West Virginia, an aquifer assessment, and the policies determining water quantities**

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# Does Coal Mining in West Virginia Produce or Consume Water? A net water balance of seven coal mines in Logan County, West Virginia, an aquifer assessment, and the policies determining water quantities

**by**

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Dedicated to my Grandpa Pat and Grandma Carol Sue for their encouragement, love, and support along the way, I wouldn't be here without you.

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**Does Coal Mining in West Virginia Produce or Consume Water? A net water balance of seven coal mines in Logan County, West Virginia, an aquifer assessment, and the policies determining water quantities**

Faith Martinez Smith, M.S.E.E.R., M.G.P.S.
The University of Texas at Austin, 2016

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This work evaluates whether coal mining in Logan County, West Virginia is a net consumer or producer of water at seven mines in Logan County, West Virginia. Water is used at each step in the coal mining process, making it important to understand the quantity of water that might be consumed. Geologic conditions and production procedures exist such that water might be produced from coal mining. Through steps such as dewatering mines and using water for on-site dust control, water is discharged from aquifers, which adds to the local waterways and affects the water table. The total discharge for each mine was quantified from 2014 discharge permits, which were curated from fillings with regulatory agencies. Water withdrawal values were provided by the West Virginia Department of Environmental Protection. This is a quantitative inventory of water outflows or a net water balance. Net balance refers to the total difference between water discharged and withdrawn. This analysis suggests that the seven mines analyzed for this work discharge significantly more water than they withdraw from the surrounding watersheds. Thus, on balance, these mines are net producers of water. However, the water quality of those discharges are

typically significantly different. The volume of discharge from these mines can be comparable to the water usage of many cities in the United States.

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# Chapter 1

# Introduction

The primary focus of this research is on water quantity in coal mining. Water quality research in industrial activities, including water quality in coal mining is robust. However, few studies have been completed linking regional water quantity or quantitative inventories of water as related to water consumption in coal mining. Water discharge from coal mines are generally monitored by the United States Environmental Protection Agency through the National Pollutant Discharge Elimination System, a permitting process required to evaluate and maintain proper levels of chemical constituents present in the waterways (EPA, n.d.). The purpose of these permits is to ensure that water quality remains a priority even when anthropogenic activity is added to the system, including coal mining and other industrial activities. Research specific to coal mining and water quality as related to flow or discharge typically focuses on *acid mine drainage*, where sulfur bearing minerals are "exposed and react with air and water to form sulfuric acid and dissolved iron," which can precipitate into nearby streams where mine drainage or discharge occurs and can "dissolve heavy metals into ground or surface water" (EPA,n.d.). In most cases the concerns surrounding *acid mine drainage* and dewatering or discharging of coal mines is monitored to prevent potential impacts caused by *acid mine drainage*. This is due to quality being the top priority for water and coal related issues. However, the total quantity of water discharged from mines is unknown for the majority of mining companies. Mining companies are primarily interested in the volume of coal produced as opposed to the water consumed in production processes. Because of this, a quantitative inventory of water flows was calculated for Logan County, West Virginia.

Water is critical to mining within West Virginia, both as an input and an impacted resource. Water is used as an input in coal mining through the maintenance of equipment, dust suppression, longwall panels, and continuous miners. Water use volumes vary in coal mining, with the frequency of washing or rinsing of equipment as needed, for dust suppression on property, and within the mine to prevent combustion of coal dust (Union of Concerned Scientists, 2013). The future of coal mining, coal preparation plants, and coal-fired electricity generation are likely to affect local water resources.

The state Code of West Virginia requires "large quantity users" to report water withdrawals from the state owned waterways, such as surface water, if an entity withdraws "over three hundred thousand gallons of water in any thirty-day period" (WVC Chapter 22). "Large quantity users" report an estimate of total volume, in gallons, of water withdrawn annually (WVC Chapter 22). While "large quantity users" are required to report total water withdrawn, there is no limitation in the amount of water they are allowed to remove as long as it for "beneficial use," which includes the use of water for coal mining (WVC Chapter 22). The West Virginia Code considers water withdrawn for coal mining, or water encountered and then diverted in mining, to be non-consumptive uses of water. The definitional guidelines for water use in the state of West Virginia exclude the requirement of monitoring for the discharge of water, and for water that is diverted in coal mining.

Water use and water impacts tend to be a contentious topic amongst industry, environmental groups, and regulatory agencies. The majority of concerns regarding water impacts, tend to focus on water quality issues. Water impacts related to coal mining usually involve chemical or toxic spills of settling ponds, *acid mine drainage*, or the contamination of surrounding streams from mountaintop removal mining (Union of Concerned Scientists, 2013). In the United States (U.S.), it is estimated that over 256 billion short tons of recoverable coal still exists (EIA, 2015). However, recent policy changes prioritize the decarbonization of the power sector, indicate a future with reduced coal consumption domestically. Because the relationship is non-obvious, research is needed to determine the life cycle water requirements and impacts of coal. If decarbonization is considered, a decrease in coal mining could lead to a change in the quantity of both water withdrawn and water discharged from mining activity. This work seeks to contribute to that base of knowledge by analyzing seven actively producing mines in West Virginia's Kanawha formation.

Questions also arise when considering the implications of the Clean Power Plan (CPP) and its impacts on coal mining. If the U.S. Environmental Protection Agency (EPA) is able to implement the CPP, coal mining may cease in the region due to the quality of coal and the cost of production for an undesired product. The CPP's focus is on reducing carbon dioxide emissions from power plants, the single largest source of carbon dioxide emissions through Section III of the Clean Air Act (EPA, 2015). Many traditional coal fired generators will not be able to meet the standards required by each state to comply with the CPP, resulting in reduced consumption of coal, which is expected to affect the amount of coal mined in the United States. West Virginia's coal contains a higher concentration of sulfur, than some other coals, a compound that requires flue-gas desulfurization to meet sulfur dioxide emission standards. Because of the higher sulfur content, coal may be sought from other markets, such as the Powder River Basin in Wyoming if it is used for power generation (EIA Glossary, 2016).

This thesis is organized into five additional sections, beginning with background information related to the region and previous data related to coal mining and water. The methods and analysis section will include how the primary data was gathered, processed, and analyzed to determine whether Logan County's coal mines are producing or consuming water. The results and discussion section illustrates the activity of the seven operations regarding their individual net water withdrawals and discharges as well as a brief overview of regional aquifers related to the mining activity. Lastly, conclusions of this study and potential future work of net water for the life cycle of coal will be discussed.

# Chapter 2

# Background

Even though coal mining has been a prominent activity in West Virginia since the latter half of the 19th century, very little data exist in the public literature that describe the volume of water consumed and produced at coal mines. The majority of prior work that examines water and coal connectivity focuses on water quality, specifically regarding chemical spills and contamination of water (Schlanger, 2014). *Acid mine drainage*, AMD, is a primary concern for water quality, and is heavily monitored. AMD has been studied by the United States Department of the Interior, the United States Geological Survey and the Environmental Protection Agency (EPA, n.d., DOI and USGS, 2000). *Acid mine drainage* is monitored under the National Water-Quality Assessment Program (USGS, 2016). However, water quantity impacts of coal mining are also worth contemplating in addition to the water quality impacts. Similar research areas include prior work for energy demands on water resources for power plants, transportation, and mining (USGAO, 2009; Grubert, et al. 2012; King et al. 2008; Stillwell et al. 2009; Sandia (DOE), 2006).

Public literature contains several studies on the water requirements of power plants and some information regarding water use at mining sites and water storage in abandoned coal mines. The connections between energy and water, such as the water requirements for fuels production, have gained scrutiny in the last ten to fifteen years. For example, Sandia National Laboratories in Albuquerque, New Mexico published a report in 2006 for the United States Congress to further explore the interdependency on water and energy resources. Sandia's report was among the first to identify the water needs for fuels production in the power sector, including the water requirements for coal mining. That report, and many others that followed, looked at water consumed by coal. However, fewer analyses have contemplated the water produced by coal mining nor compared these relative quantities to assess the net water balance.

The United States Government Accountability Office (USGAO) also prepared a report on water use for energy. The USGAO's report was sent to the Chairman of the Committee on Science and Technology within the House of Representatives in October 2009. The USGAO's report focused primarily on trends of water use for power plants, emphasizing the missing link between fuel types used for electricity generation and water quantity used to produce electricity in the United States. This area of research touches on water for coal, but primarily the amount of water used in thermoelectric power generation using coal as the fuel type, with variations in cooling technologies and power plants. The USGAO report discusses the primary challenge with research in this area, the inability to find data or to access data easily. Within this realm, some studies have focused on fuel types and water intensity, which have been conducted by the National Renewable Energy Laboratory (NREL), research groups at The University of Texas at Austin (UT-Austin), and non-profits such as Circle of Blue (COB).

NREL's research surrounding the energy water nexus currently focuses on operational water consumption and withdrawals for electricity generation, primarily water for use in power plants. These studies discuss several areas of concern including implications of climate change, population growth, the use of freshwater for cooling power plants, and the production of water intensive transportation fuels. While water is required in several stages of energy production, most studies are focused on water and electricity production or for use in power plants.

Based on this review, there still appears to be a gap in the literature regarding the mass balance of water coming into and flowing out of actual mines. To help fill that knowledge gap, this research focuses on the net water balance of coal mining regarding total water withdrawn and total water discharged. Water is used in several stages of the coal mining process with variations between surface and underground mining. The primary use of water is in the upkeep of mining operations. For instance, water consumption at a surface mine generally outweighs consumption at an underground mine. The largest demand for water at surface mines is typically dust suppression, while underground mining's largest demand is equipment use (WVGES, 2015).

There are two main types of underground mining, longwall mining and room and pillar mining (Union of Concerned Scientists, n.d.). Longwall mining is where long tunnels are cut into the coal seam, removing the coal with miners, large pieces of equipment that cut coal from the seams (Union of Concerned Scientists, n.d.). A longwall is a incredibly large piece of equipment, which is only moved a few times per year (Union of Concerned Scientists, n.d.). Due to the size of the equipment and the volume of coal removed in mining, hydraulic shields are put into place in order to help hold the ceiling of the overlying rock in place (Union of Concerned Scientists, n.d.). Longwall mining removes almost all of the coal within the seam, leaving negligible amounts of recoverable coal behind (Union of Concerned Scientists, n.d.). Room and pillar mining only partially removes coal, leaving pillars to support the overlying rock (Union of Concerned Scientists, n.d.). Both longwall and room and pillar mining use equipment, such as continuous miners, that require water for use.

Water policy in West Virginia is articulated in the West Virginia Code (WVC), which maintains specific regulations for water use associated with mining. According to the WVC, mining activities are considered to be a beneficial use (WVC, Ch. 22). Additional definitions that are applicable to mining include, but are not limited to: consumptive withdrawal, large-quantity user, discharge non-consumptive withdrawal, water resources, and withdrawal. A mining purpose is a general description for the extraction of mineral resources, specifically coal in West Virginia, but can pertain to oil and gas extraction. Industries that are exempt from water consumption and withdrawal limitations, are considered to be a *beneficial use*, which include coal mining, oil and gas extraction, agriculture, and initial water well drilling.

The State of West Virginia owns surface water rights, similar to western water laws, but permits the use of water to various operations. The West Virginia Department of Environmental Protection (WVDEP), is the regulatory agency in charge of withdrawal permits for *large-quantity users*. The WVDEP permits allow the capture or removal of water from a waterway (stream or river). WVDEP issues permits regarding withdrawals, consumption, and discharge. WVDEP water related permits are determined based on several factors including, but not limited to, size of operation, type of operation, and reporting time frames (WVC, Ch. 22). Withdrawals are defined as any "removal or capture of water" regardless of consumptive or non-consumptive uses (WVC, Ch. 22). However, this guideline exempts coal mining for water encountered during mining operations. That exemption means any produced water from groundwater flows or encounters are not considered withdrawals, assuming the mining company does not divert, consume, or use the water in any capacity (WVC, Ch. 22).

In other states, such as Texas, any water produced or encountered in mining activities is considered a withdrawal (Texas Water Code, Title 2, Ch.11). Essentially, the exact same activity in Texas is considered a withdrawal, whereas in West Virginia, water is produced as a byproduct of mining, according to the WVC. For water withdrawals, permits are issued to large-quantity users, where the total water withdrawn exceeds "three hundred thousand gallons of water in any thirty-day period from the state's waters, excluding agricultural users" (WVC, Ch. 22). In West Virginia, the state typically owns all "water resources," including groundwater, and all surface waters unless it is privately owned or is in a created retainer, such as a farm pond (WVC, Ch. 22). Because of these permitting guidelines, the WVDEP was charged with the responsibility for monitoring large-quantity users by the state legislature. Reported withdrawals are estimated, while water discharges are measured as part of their inclusion in the National Pollutant Discharge Elimination System (NPDES), a program of the EPA.

Water discharge from mining operations is common within the local region, and throughout southern West Virginia. Approximately "66 percent of stream flow in mining areas results from groundwater discharge to streams, while discharge from mine outfalls (outlets) is a substantial proportion of the base flow" for local communities' in McDowell and Fayette Counties water supply (USGS, 2012). Figure 4.1 shows the extensive aquifer system in West Virginia. If mining operations were to cease mining, mines would be sealed, preventing any discharge from entering the local watershed, effectively altering the local watershed. In southern West Virginia and in the western portion of the United States, mining operators manage water in active and inactive or abandoned mines through dewatering or depressurization. In many cases, dewatering is required to access the coal seam safely and efficiently during mining. Some companies may purposely choose to depressurize their mines through the installation of wells, while others remain passive, allowing the water to discharge naturally.

*Produced water* can add additional resources to the local watershed, creating an imbalance between surface and groundwater as well as potentially affecting aquifer recharge rates. This is due to water being removed from the aquifer and discharged as surface water, which can negatively affect recharge as well as the expected groundwater supply. In West Virginia, the diversion of the water encountered during coal mining, is simply a discharge. The definitional guidelines of discharging water or diverting water encountered during mining allows coal mines to *produce* water. This definitional difference, when compared to Texas, leads to the initial assumption that West Virginia coal mines could be producing water. In Texas, and in other mining states, *dewatering*, or diverting the water encountered in coal mining is considered a *consumptive withdrawal*. In Texas, the water diverted from mining activities is considered to be removing or reducing the *beneficial use*, as the water is removed from the aquifer and transferred to surface water. This is primarily due to the reliance of aquifers for water supply, and because Texas has stringent water guidelines - both surface and groundwater resources are monitored and permitted through state agencies. However, in West Virginia, the concept of *beneficial use* is simply transferred to surface water, which assumes that use or benefit does not change.

It is unclear why these definitions are so different between Texas and West Virginia. This definitional difference might be due to the initial structuring of water rights when Texas and West Virginia became states. Texas was originally considered to be a riparian state, where the state owns the water and the user with the most *beneficial use* is granted the use of the water. The concept of riparian water rights is commonly referred to as 'right to use.' West Virginia is still considered to be a state with a riparian water rights system. Texas is now closer to a state with prior appropriation guidelines, where a land owner owns the groundwater and the rights to use the water; surface water rights are permitted and managed through the Texas

Commission on Environmental Quality. This is commonly referred to as “first in time, first in right,” a concept where the individuals with the oldest or most senior water rights have the first claim to the water resources (Texas Water Code, Title 2, Ch. 11). While *beneficial use* definitions may vary among states, in West Virginia, producing water does not appear to be a concern, even thought most people would consider the discharge to be a depletion of the available water resources. Although the local watershed is not currently experiencing duress, the Kanawha formation’s aquifers must be considered throughout the mining processes.

To examine these factors and context in greater details, this work closely looks at seven mines in West Virginia. The seven mines were selected based on available data, mining history, and reliability in reporting information to the WVDEP. These seven mines were consistent in reporting their NPDES requirements over a minimum period of at least five years, providing consistent data for analysis. Mining discharge permits were analyzed, while the total withdrawal information was provided, as voluntarily reported, by the WVDEP, both for the year 2014. To perform a net water assessment, a new database was created after extensive research and communication with government and industry officials. Water balances were then calculated for each mining operation using the methods described below. This paper summarizes current water balancing work for Logan County, West Virginia. To give perspective on the influence of mining operations in West Virginia, Figure 2.1 illustrates the mining permit boundaries for the entire state of West Virginia for the year 2014, and Table 2.1 provides a summary of the seven mining operations.

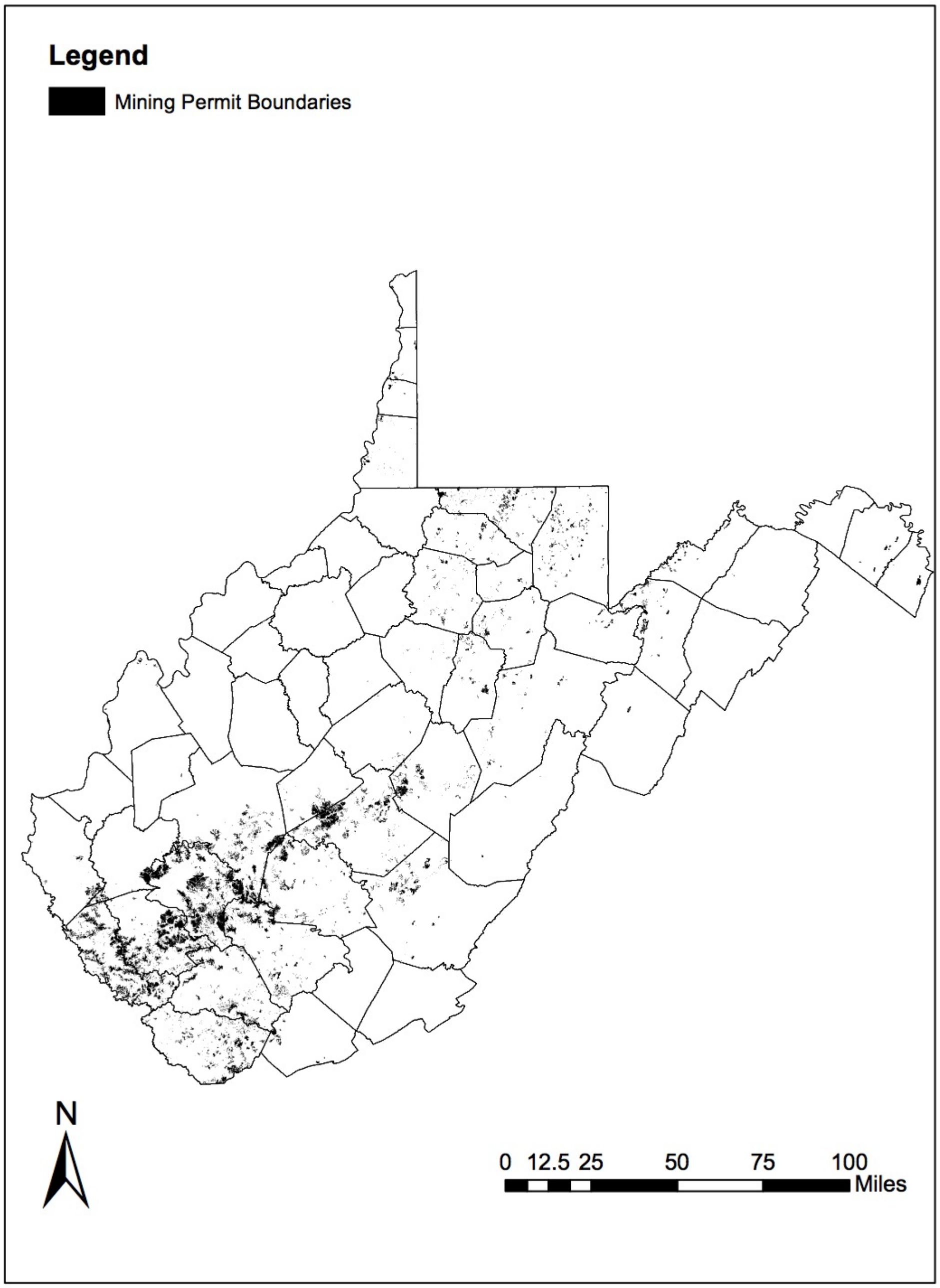


Figure 2.1: This figure illustrates the *Mining Permit Boundaries* for the state of West Virginia with counties outlined for reference. Data: WVGES. Map: Copyright Faith Martinez Smith, UT Austin, 2016

Table 2.1: Operation Names, Locations, and Total Acres Under Permit

| Operation Name | Total Acres Under Permit | County of Operation |
|---|---|---|
| Apogee Coal Company | 35 | Logan |
| Bandmill Coal Corporation | 235 | Logan |
| Rum Creek Coal Sales | 209 | Logan |
| Highland Mining Company | 668 | Logan |
| Aracoma Coal | 9 | Logan |
| Aracoma Laurel | 22 | Logan and Mingo |
| Alex Energy | 530 | Logan |

# Chapter 3

# Methods

No connections were directly found between withdrawal and discharge data for West Virginia coal mining operations. To gather and access this data, two onsite visits to the headquarters of WVDEP in Charleston, West Virginia were required. Although these data were assumed to be publicly available, access had to be given to the WVDEP's online *water query function* with a guest username and password. Data collected for this research comes primarily from individual NPDES permits and WVDEP water withdrawal permits. NPDES permits are reported monthly and WVDEP withdrawal information is reported annually. Data from the year 2014 was collected and analyzed. Data curation was necessary to organize monthly data from each operation's NPDES permit for flow of water leaving the permitted property. Each operation's NPDES permit contained several outlets, or discharge points, all of which were included in the curation. Flow rates were converted from cubic feet per second to gallons per minute, as necessary. Formatting was made consistent to ensure accuracy of flow rate values and organization of the data was required to make it suitable for analysis. The process chart and table shown below (Figure 3.2 and Table 3.1) provide a visual description of the steps used in this process, and to show what inputs are measured, such as groundwater.

NPDES is primarily focused on water quality of U.S. waterways and watersheds. The permits contain water flow rates, from each discharge or outlet point, which can be used for this research. The discharge points are specific locations where water discharges from a permitted property to surface waters, such as streams and rivers. Reporting for these permits primarily differ in reporting times; NPDES is a monthly report while WVDEP withdrawals are an annual report. The reports are compiled by individual operations, which gives the WVDEP close estimations of water withdrawn from surface waters according to pumping gages. Permitting information is not made available to the public, which reduces the ability to quantify water allocation in mining. Consequently, water quantity withdrawals are estimated by each operation and reported to the WVDEP. However, as a result of monthly reporting according to NPDES guidelines at each outlet, the total volume of discharged water for individual mining locations is unclear. As shown in Figure 3.1, the pins indicate the withdrawal location for each operation, based on coordinates within each operation's individual permits. Multiple outlet, or discharge locations exist to ensure all acreage of the property is monitored, as operators are responsible for the quality of all water discharged to waterways. There are multiple discharge points to ensure more accurate monitoring, including encountered water, and preventing consumptive losses on withdrawal permits.

These operations are listed in Table 2.1, and are shown in Figure 3.1. These operations are typical and therefore representative of typical operations in Logan County.

Within Logan County, surface and underground mining operations exist. Several operations have preparation plants on site, which are the mid-stage of coal, where coal is cut and washed to meet specific criteria as requested by the purchaser (WVDEP). As of 2014, the year from which data were collected for analysis, there were over thirty-five active mines, with current permits, all of which are assumed to be operating. Mining began in 1905 in the Logan Coal Field, where the geology is rich

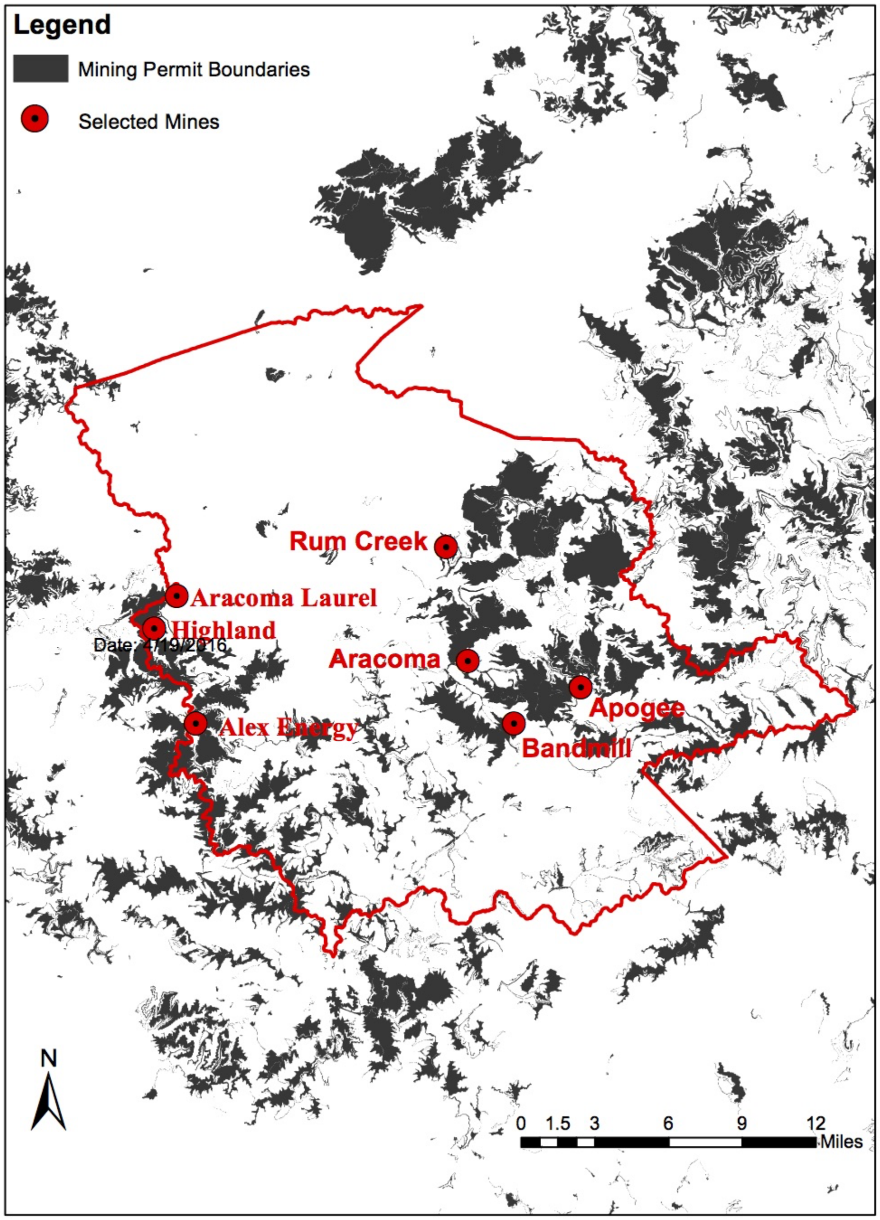


Figure 3.1: Locations of Selected Mining Operations in Logan County West Virginia. Copyright Faith Martinez Smith, UT Austin, 2016

with vast coal reserves, and is currently the second highest producer of coal within West Virginia (WVGES, 2015). Net water was calculated, as defined in the equations found below, at each individual mining operation, beginning with the *outlet average*, and then the calculation of the *total yearly flow.* The net water can be calculated from the *total yearly flow* or the *total mine discharge.*

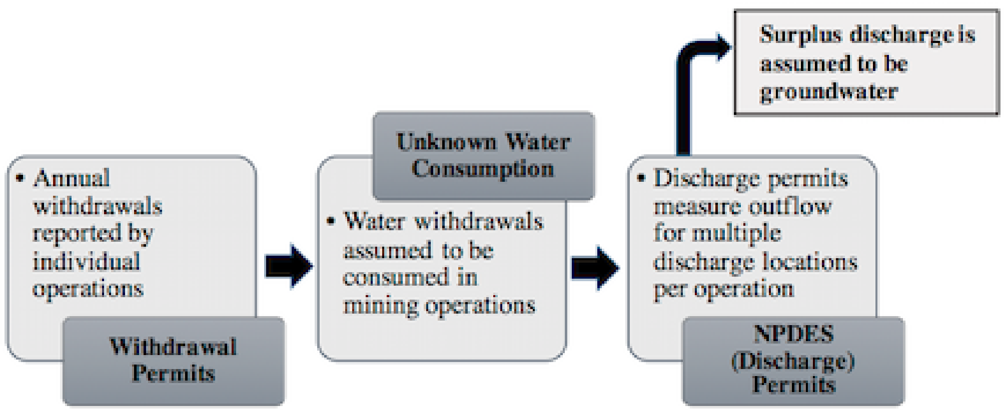


Figure 3.2: This chart illustrates the flow of water in coal mining operations beginning with withdrawals and ending with discharges. Copyright Faith Martinez Smith, UT Austin, 2016

Table 3.1: Quantitative inventory of water outflows Copyright Faith Martinez Smith, UT Austin, 2016

| Permit Type | Source of Data | Data Description |
|---|---|---|
| Withdrawal | WVDEP | Estimated yearly surface water withdrawals as reported by individual operations (Total Mine Withdraw) |
| NPDES | WVDEP | Calculated discharge from multiple outlet points at individual operations (Total Mine Discharge) |

The following calculations were used to determine Total Mine Discharge, where withdrawal was given. Table 3.2 defines all variables used in the calculations described.

Table 3.2: Definitions of Net Water Balance Equations Variables Copyright Faith Martinez Smith, UT Austin, 2016

| Variable | Definition |
|---|---|
| A | Outlet Average |
| S | Sum |
| N | Number of Outlets |
| GPY | Gallons Per Year |
| TMD | Total Mine Discharge |
| TYF | Total Yearly Flow |
| NWB | Net Water Balance |

$$A = \frac{S}{N} \rightarrow A \times GPY = \frac{OutletAverage}{Year} \tag{3.1}$$

where A is Outlet Average, S is sum, N is number of outlets, average of gallons per year is abbreviated as GPY (where GPY = 525,600, assuming a flow rate of 1 Gallon Per Minute).

$$\frac{TMD}{Year} = \sum \frac{TYF}{Year} \tag{3.2}$$

where Total Mine Discharge (TMD) = Total Yearly Flow (TYF).

After determining the TMD, the Net Water Balance (NWB) was calculated using the withdrawal information. The NWB determines if the operation is a net producer or a net consumer. If the TMD is greater than the Total Mine Withdraw (TMW), the operation is a net producer, and if the TMD is less than TMW, the operation is a net consumer.

$$NetWaterBalance = TMD - TMW \tag{3.3}$$

$$TMD > TMW = \textit{Producing Water} \tag{3.4}$$

$$TMD < TMW = \textit{Consuming Water} \tag{3.5}$$

The WVDEP's NPDES monthly reports were analyzed for discharge rates at each discharge point, or *outlet* for every operation's permit. For context, operations typically encompass all activities on one permit. In some cases, there were a few properties that had additional or extended permits for the same physical operation. These extended permits may be approved for a number of reasons, but most commonly it is because of additional growth of the mine or through an easement, where access to adjacent properties is allowed. With extensions of mining permits for operations, permitting also increases to ensure environmental concerns are accounted for, encompassing additional discharge and withdrawal permits for an operation.

Each discharge point's values were recorded in the curated database, from the NPDES and withdrawal permits. The database curation included the following assumptions: one specific discharge value per month was determined to be the recorded average; only reported information was considered; and additional geological and hydro-geological information was not considered. In several cases, individual outlets had more than one discharge value; each value was recorded and reported for the same month.

Outlet flow was converted from cubic feet per second to gallons per minute, when necessary. Each yearly outlet total was determined by averaging all of the individual outlet flow rates multiplied by gallons per year to determine each outlet's gallons per year equivalent. All averaged yearly outlet values were then summed, determining the total flow per mine for the year 2014.

# Chapter 4

# Results and Discussion

Overall, these mining operations are *producing* or *encountering* water based on the definitions found in the WVC. Figure 4.1 and Tables 4.1 and 4.2 illustrate the total water withdrawals, as reported to the WVDEP. The total water discharged, is calculated for the individual outlet points over the course of one year (2014). Figure 4.1 is shown with no modification to the scale, illustrating the vast differences present between withdrawals and discharges, indicating a vast amount of water discharged from the operations. Tables 4.1 and 4.2 detail the specific values shown in Figure 4.1. These values are shown in billions of gallons for the year 2014 in Figure 4.1, while Tables 4.1 and 4.2 indicate the volume in billions of gallons and acre-feet, respectively.

Table 4.1: Flow in Billions of Gallons for Withdrawals and Discharges in 2014 for Selected Operations. Copyright Faith Martinez Smith, UT Austin, 2016

| Operation Name | Withdrawal | Discharge |
|---|---:|---:|
| Apogee Coal Company | .317 | 6.5 |
| Bandmill Coal Corporation | .032 | 25 |
| Rum Creek Coal Sales | .008 | 8.2 |
| Highland Mining Company | .005 | 16 |
| Aracoma Coal | .025 | 26 |
| Aracoma Laurel | .261 | 11.6 |
| Alex Energy | .128 | 10.3 |

It is very possible that water is *encountered* through the impact of mining on the aquifer, meaning the aquifer might be accessed, releasing water from the surrounding environment. This discharge also suggests that the water was only *encountered and then diverted*, following the WVC's definition of allowable circumstances.

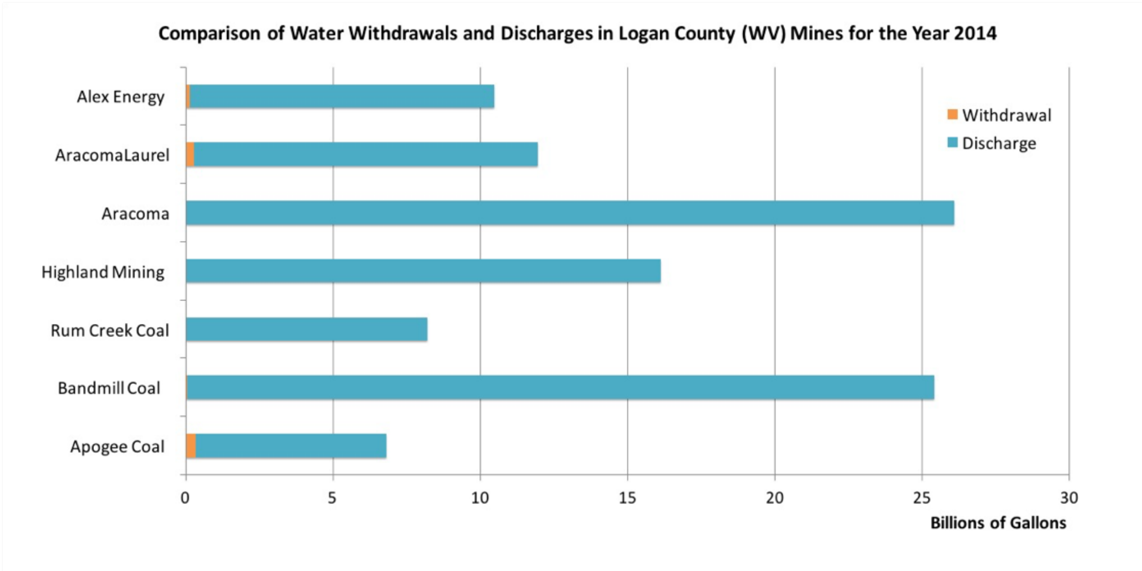


Figure 4.1: This figure shows water withdrawals and calculated discharges for seven mines in Logan County, West Virginia. Copyright Faith Martinez Smith, UT Austin, 2016

Table 4.2: Flow in Thousand Acre-Feet (AC-FT) for Withdrawals and Discharges in 2014 for Selected Operations. Copyright Faith Martinez Smith, UT Austin, 2016

| Operation Name | Withdrawal | Discharge |
|---|---|---|
| Apogee Coal Company | .972 | 19.9 |
| Bandmill Coal Corporation | .098 | 76.7 |
| Rum Creek Coal Sales | .024 | 25.1 |
| Highland Mining Company | .015 | 1649.1 |
| Aracoma Coal | .077 | 79.75 |
| Aracoma Laurel | .801 | 35.6 |
| Alex Energy | .393 | 31.6 |

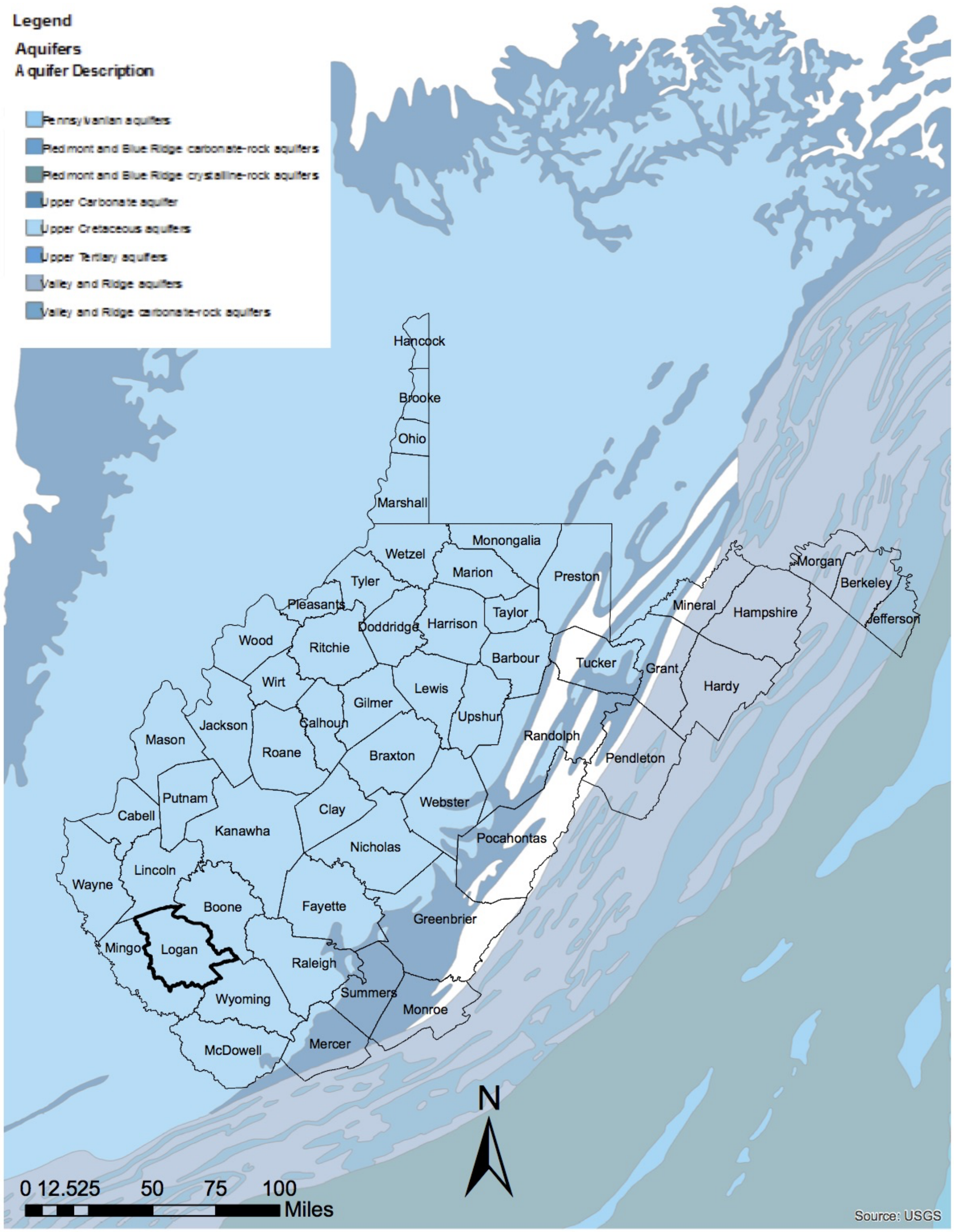


Figure 4.2: This figure illustrates the extensive aquifers present in Appalachia with West Virginia outlined for context Copyright Faith Martinez Smith, UT Austin, 2016

Under "steady-state conditions, groundwater discharge as base flow to streams is equivalent to the rate at which groundwater is replenished or recharged" (Fetter, 2001). Groundwater moves down and laterally. Due to high runoff and evaporation, only a small portion of precipitation will infiltrate the ground for recharge of groundwater (USGS, 2001). Natural factors contributing to groundwater flow are the hydraulic properties of the rock, geologic structure, and topography of the region (USGS, 2012). The main "human-induced factor in controlling groundwater flow is coal mining, specifically underground mining, but surface mining can also impact groundwater flow" (USGS, 2012). The concept of "steady-state" may not be applicable in areas with extensive underground mining, as there may be "substantial interbasin transfer of groundwater via abandoned mine workings, which could result in mine discharges that potentially comprise as much as 50-80 percent of stream flow in receiving streams" (Borchers, et. al., 1984). It is common that hydrologic connections are made between older mines, even if they are not abandoned. In many cases, coal miners generally notice the amount of water discharging, and that the greatest volume is near the surface or portal, which is due to "stress-relief fracture recharge" considered to also be a large source of recharge for the aquifer and surrounding strata (USGS, 2012). Coal is considered to be "the most permeable rock type" found within the region, suggesting a direct connection between aquifer flow and coal seams (Harlow and LeCain, 1993). Logan County sits in the Appalachian Plateau, where groundwater flow in coal mine aquifers is a result of "higher hydraulic conductivity of the strata in the horizontal direction, rather than vertical connections with adjacent sandstone, siltstone or shale layers" (Harlow and LeCain, 1993).

Transmissivity of coal seams appear to be "one to two orders of magnitude greater than that of associated rock types, while transmissivity of coal seams decreases with depth" (Zipper et. al., 1997). Underground coal mining types are generally: partial extraction, room and pillar or high-extraction, or longwall. Longwall mining can cause the overlying rock to become unsupported, which can result in the collapse of overburden materials, potentially affecting the overlying aquifers (Zipper et. al., 1997). As the amount of coal removed increases, the higher potential for subsidence also increases, which can impact water supply even beyond the immediate region. Several studies have suggested that coal mining subsidence affects groundwater hydrology (Zipper et. al., 1997). Figure 4.3 shows the vast coal fields present in West Virginia. Groundwater flow can be affected by the removal of a rock layer, including coal seams, which can short circuit the natural fracture flow processes (USGS, 2012; Winters and Capo, 2004). This means that groundwater flow can be controlled by human-induced factors, such as coal mining.

A study was conducted on three underground coal mines in northern West Virginia to examine the hydrologic impacts of longwall mining on groundwater (Dixon and Rauch, n.d.). The use of longwall panels in underground coal mining is normally associated with adverse environmental impacts on water resources (Dixon and Rauch, n.d.). Mining may affect groundwater resources, however, mining is not solely responsible for affecting groundwater flow. Longwall mining typically requires dewatering of the mine, which occurs "adjacent to the areas of total coal extraction" where water takes the place of the recently removed coal seam (Dixon and Rauch, n.d.). In the same study of longwall mining, the authors concluded that the yield of water was variable and the mining sites with highest discharge were also the site with the least amount of rock coverage or overburden, suggesting that deeper mines may be below the recharge zones or aquifers (Dixon and Rauch, n.d.).

Other major sources of groundwater in West Virginia include the *Upper and Lower Pennsylvanian Aquifers* of the Pennsylvanian age and the units are "nearly

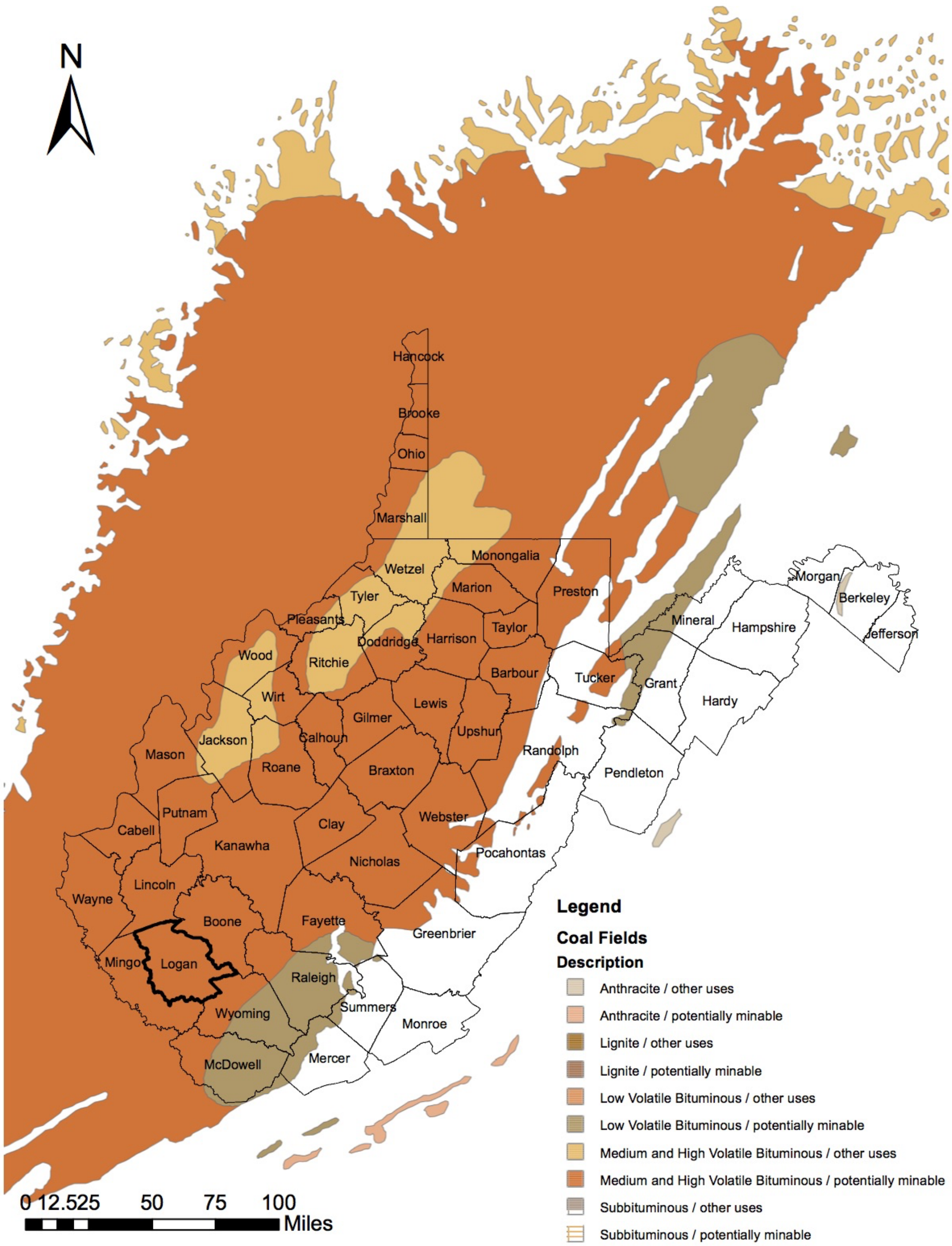


Figure 4.3: This figure shows the coal seams in West Virginia Data: USGS, Map: Copyright Faith Martinez Smith, UT Austin, 2016

horizontal layers" (USGS, 2001). These aquifers are known to be extensive and can range in permeability (Wilmoth, 1968). The Pennsylvanian Aquifers flow throughout western West Virginia, and are the primary aquifers flowing in Logan County. The *Pennsylvanian Aquifers* consist primarily of "limestone and sandstone with a sequence of beds, beginning with the bottom: underclay, coal, gray shale or black platy shale, freshwater limestone, and sandstone or silty shale" (USGS, n.d.). This list is not exhaustive and in many cases not all beds are present in each cycle (USGS, n.d.). Of these layers, the most productive aquifers are limestone and sandstone. Within Logan County, the *Pennsylvanian Aquifers* are sometimes referred to as the *Upper Pennsylvanian Aquifers* and are a part of the Monongahela and Conemaugh Groups (USGS, n.d.). These groups, the Monongahela and Conemaugh Groups, sometimes consist of interbedded shale, silt, coal, and sandstone (USGS, n.d.). The *Pennsylvanian Aquifer* system, consists of Lower Pennsylvanian age beds, which are similar in lithology to the Monongahela and Conemaugh Groups. Lower Pennsylvanian age beds within the Kanawha Formation have extremely high transmissivities, which is on average 270,000 feet$^2$ per day (USGS, n.d.).

According to previous studies on groundwater in abandoned coal mines nearby in Elkhorn West Virginia, a small community in McDowell County, groundwater flow within this region "occurs predominantly within coal strata" (USGS, 2012). The same study discussed pumping groundwater from sealed underground mines for use as public water supply. On average, these specific mines in Elkhorn West Virginia, discharge more than 500 gallons per minute (USGS, 2012). The Cities of Fayetteville and Welch in Fayette and McDowell Counties, respectively, use significant amounts of mine water each day. The City of Welch's average pumping rate is 500,000 gallons per day (1.5 AC-FT), while the City of Fayetteville averages 400,000 gallons per day (1.2 AC-FT), both of which come from abandoned mine workings (USGS, 2001). This region is similar to Logan County, due to it's geology, hydrogeology, and one hundred year mining history. Within the region, "underground mining has the potential to impact the hydrology of aquifers in the Appalachian Plateaus on a relatively large scale" (USGS, 2012). The United States Geological Survey's (USGS) study indicated the components making up the rock, "would have contributed relatively high porosity values due to the microporous nature of the grains and clays, however, visually, permeability was considered to be very low due to compaction of clays, ductile rock fragments and micas in existing pore spaces creating 'log jams,' except in areas with microfractures or grain plucking" (USGS, 2012). The USGS' 2012 report suggests that the same formation in Logan County would also have comparable permeability. The study also included an emphasis on structural geology, indicating the existence of subtle folds, which are important for controlling groundwater discharge from the abandoned mine and its relation to topography and mining seams (USGS, 2012).

Abandoned "underground coal mines are a dominant pathway for groundwater flow, as they short-circuit the natural fracture flow processes in significant ways, even aggregating groundwater flow over large areas, even from adjacent surface water drainages" (USGS, 2012; Winters and Capo, 2004). This concept directly relates to Logan County and the discharge of water from active mining, where the discharge from the mine workings is comparable to Fayette and McDowell counties, both in volume and hydrogeology. Logan County coal mines appear to be discharging water from the *Pennsylvanian Aquifers*, at a rate that "short circuits the natural fracture flow processes in significant ways" (USGS, 2012). Figure 5 is an overlay of the aquifer map onto the coal fields map in West Virginia. The overlay illustrates how the two systems are in parallel with each other, and aquifers that are within the coal seams.

Coal mining does have an impact on "stored water in rocks that overly mines,

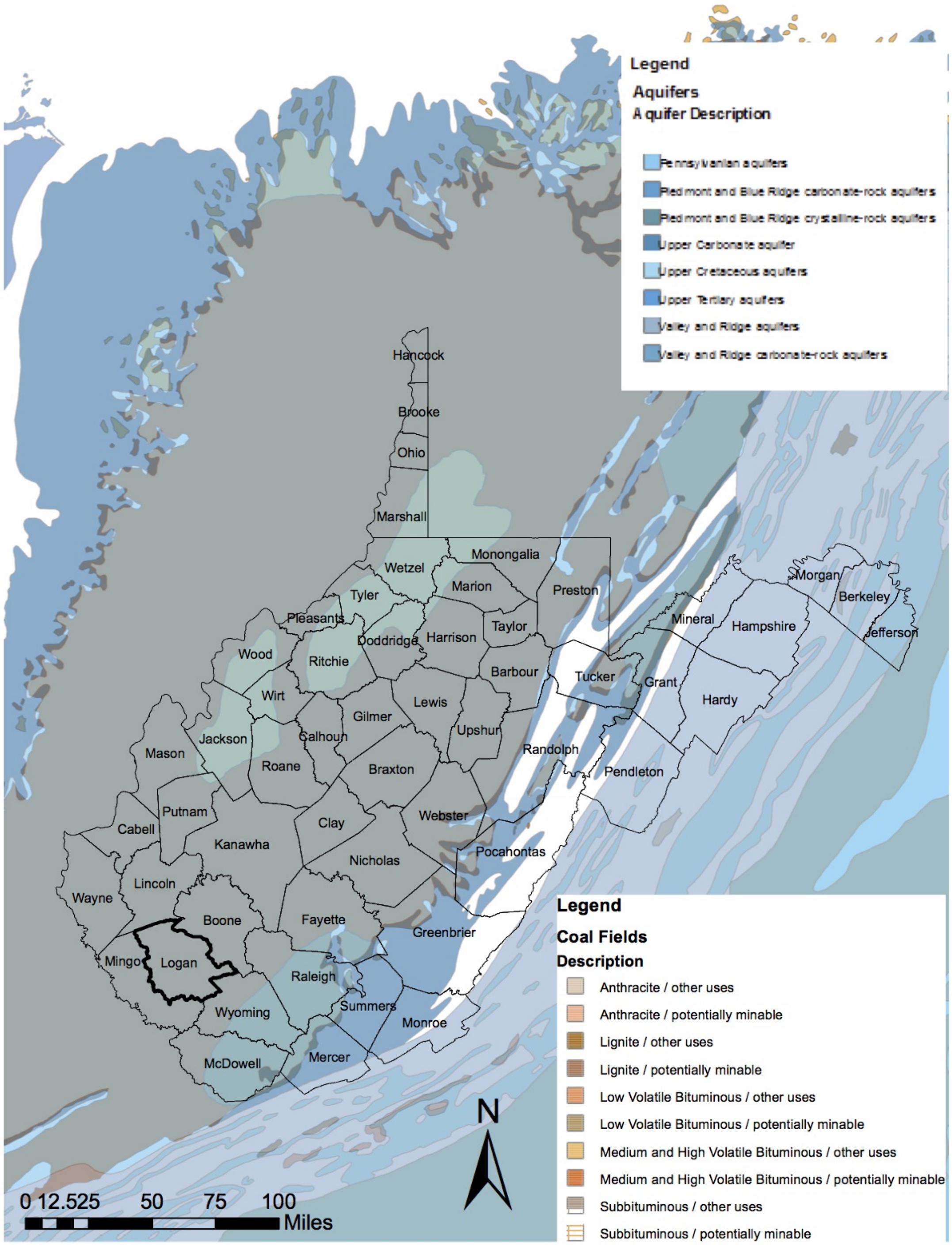


Figure 4.4: This figure illustrates an overlay of aquifers onto the coal seams in West Virginia, indicating their parallel nature. Data from USGS. Map: Copyright Faith Martinez Smith, UT Austin, 2016

and groundwater storage changes appear after final phases of mining has been completed, as well as the recharge of aquifers from precipitation and migration of water between mine workings" (Wilmoth, 1968; Winters and Capo, 2004). Mining not only alters discharge, but recharge pathways are also affected. Subsidence from mining can also increase the permeability of the overburden and storability, affecting the hydrogeological system (Winters and Capo, 2004). Analysis of the Pittsburgh Coal Seam in northern West Virginia shows roughly 26.7 percent of total precipitation is diverted from the watershed due to mining impacts, where the water is assumed to be flowing into the mines (Winters and Capo, 2004). Recharge rates for aquifers do vary in different regions and geologies. In the Pittsburgh Coal Seam recharge is expected to be at 26 percent of the total precipitation for shallow mines and 12 percent for deeper mines (Winters and Capo, 2004). Recharge is typically from overlying strata, while in deeper mines the recharge comes from shallow overburden around the water basin's perimeter (Winters and Capo, 2004). It is not uncommon for coal basins throughout the world to be flooded. However, in most cases they are not usually considered as a water resource due to the "complexity of post mining hydraulic relations that develop within regional basins" (Winters and Capo, 2004).

McDowell and Fayette counties in West Virginia are not the only examples of flooded coal basins. Domestic water supply options from coal mine workings have been considered in Virginia, and are currently used in the Central Coal Basin of Asturias, Spain. In Spain, an old mining site is used as a storage reservoir, where the groundwater flows through the mine shafts and is pumped out to access the mine and the local community receives the water (Loredo et. al., 2012). Dewatering of the mine is done primarily to access the mine, but researchers believe that using the dewatering process to drive hydropower could be an additional alternative energy source for the region (Loredo et. al., 2012).

The West Virginia Bureau for Public Health within the Office of Environmental Health Services believes that alluvial aquifers, those within the western portion of the state, "are the best sources of groundwater for public supply and industrial use, due to the high yields that can be obtained" (USGS, 2001). Their primary concern is on quality of groundwater resources, but they also focus on major sources of groundwater and the implications of those resources. Their research has found that coal mining does impact groundwater, but it is mostly due to the "characteristics of the coal and the overburden materials" (USGS, 2001). Groundwater has been degraded from both surface and underground coal mining with quality of the water improving as distance from the mine increases (McCurry and Rauch, 1986; O'Steen and Rauch, 1983). In the southern coal fields of West Virginia, water from the mines is used for public, industrial, and commercial supplies. In many cases, the water quality does not exceed drinking-water standards before treatment, but water from the mines is treated to "reduce iron and manganese content" (USGS, 2001).

If active coal mining stops in West Virginia, the connectivity between mining discharge or dewatering will need to be addressed as the resources should be managed to ensure safe water pressures of sealed mines, reducing potential hazards of flooding risk (Wilmoth, 1968). If population increases as well as industrial activity, the groundwater resources would become more valuable, resulting in a bigger portion of water supply. Current growth and water supply rates, as of 2016, do not indicate any concerns for a shortage of water.

In Texas, lignite mining occurs in within with a major aquifer, the *Wilcox Group*, which is heterogeneous and flows from north to south along Central Texas. Groundwater can be affected in any process of surface mining of lignite, but there has been little evidence of "consequent impacts on groundwater" (Fogg and Charbeneau, n.d.). Low permeability "sediments around the lignite reduce and, in some cases, eliminate the need for mine dewatering," where groundwater flow rates are generally very slow (Fogg and Charbeneau, n.d.). However, as mining continues, it will increase in depth, increasing the impact of lignite mining on groundwater. This could "threaten or deplete groundwater resources due to dewatering," with the potential of altering the aquifer permeabilities, a long-term impact on groundwater circulation (Fogg and Charbeneau, n.d.). While it may be assumed that groundwater impacts from mining are only a concern for common mining states like West Virginia or Wyoming, Texas might also consider their impacts on groundwater resources as population increases and water scarcity becomes more prevalent.

# Chapter 5

# Conclusions and Future Work

This study has shown the balance between total water withdrawn and total water discharged in the Logan County Watershed via coal mining activity. All of these operations show much higher discharge rates than withdrawals shown below in Table 5.1, which displays the ratio between withdrawal and discharge. Of the seven mines, three mines have withdrawal values that are greater than 1 percent of their respective discharge values, this includes Apogee Coal Company, Aracoma Laurel, and Alex Energy. The four other mines have withdrawal ratios that are less than 1 percent of the volume the mines are discharging. In all cases, these results indicate a vast difference between withdrawal and discharge quantities. If mines were sealed in Logan County, base stream flow would be severely affected.

Table 5.1: Ratios between Withdrawal and Discharge (shown as percentages) Copyright Faith Martinez Smith, UT Austin, 2016

| Operation Name | Ratio (Withdrawal:Discharge) |
|---|---:|
| Apogee Coal Company | 4.9 |
| Bandmill Coal Corporation | 0.13 |
| Rum Creek Coal Sales | 0.09 |
| Highland Mining Company | 0.03 |
| Aracoma Coal | 0.9 |
| Aracoma Laurel | 2.3 |
| Alex Energy | 1.2 |

This difference in discharge to withdrawal indicates that these mines are producing water, as defined by the WVC. The amount of discharge is significant, as this water has the potential to affect the local water table and the watersheds. Each of these operations is discharging more than 4.5 billion gallons (13,803.68 acre-feet, AC-FT) of water in one year. For perspective, the City of Austin, Texas' population is roughly one million people. In Austin, the average total water usage in gallons per capita per day for 2014 was 125 (gallons per day, .000383 AC-FT) (Austin Water, 2014). For one year, that equates to 45,625 gallons (.1399 AC-FT) per person, or for the entire population, an estimated 4.5 billion gallons (13,803.68 AC-FT) of water consumption (Austin Water, 2014). The greater City of Austin's population is almost the same size as the population of the entire state of West Virginia, roughly one and a half million people (TWDB, 2010; U.S. Census Bureau, 2015). That means, just one of these mining operations could provide the necessary quantity of water for a major city such as Austin. Because of this, the impact of the seven operations in this study suggests that local municipal water supply is connected to mining activity. If mining activity were to cease in the region, water loss could affect local and regional communities that may unknowingly rely on these surface water resources. According to local watershed research in West Virginia, analyzing aquifer discharge rates and flow in community water storage or water supply, can be used to determine if there is a correlation between the total discharges from the *outlets* at each mine (USGS, 2001). As the future of coal mining is uncertain, there are several options to consider for the source of the discharge water including: mine drifts, aquifers that run in parallel with the coal seam, or water seepage from interconnected mines underground.

This study was only an analysis covering a small portion of the work necessary to answer the question regarding the net water use in coal. Although, it appears that in Logan County, there is significantly more discharge of water than the amount withdrawn from the watershed, it does not guarantee that coal mining *produces* or *encounters* water.

Additional work is needed to understand the full implications of water and coal mining. Net water assessments of additional mines in West Virginia should be conducted to determine if Logan County is an accurate representation of coal mining and water use in West Virginia. Additional work should be conducted in other mining regions, including Texas, the Powder River Basin in Wyoming, Kentucky, Eastern Utah, and Western Colorado. An assessment including additional coal producing states may shed light on whether other states encounter water to the same degree as found in this study of Logan County, West Virginia. It could be expected that other mining operations also dewater before and during mining, but that state water codes are more stringent in their requirements for water use and diversion. Texas is a prime example where the definitions found within the water code are detrimental to mining activity.

For states with water codes similar to West Virginia, with exceptions made for mining, or oil and gas, water could become a more important resource. If water were truly valued, coal mines in West Virginia may have an additional production stream with the potential to benefit the community. Other research regarding water management looks at alternative water resources, or using formation water in oil and gas for additional applications such as agriculture or hydraulic fracturing (NETL, 2010). Within the study area, "67 percent of the population has inadequate wastewater treatment," leaving local residents to suffer from using organically contaminated water resources, while groundwater is less likely to be contaminated (USGS, 2012). Discharge from formation water is not directly related, but the idea of using water from production could be implemented in a region where inadequate wastewater treatment plants exist and surface water is heavily contaminated. For a case such as this, mining operators could sell or offset their water withdrawals by using their produced water. Operators could choose to instead consider the use of saline groundwater for equipment upkeep and divert produced water to water treatment facilities or to irrigators. The produced water, could provide a clean source of water, which has the potential to create an additional revenue stream for mining companies. The *Pennyslvanian Aquifers* have the potential to be used for cities, communities, agriculture, or industry with variation in permeability from "poor to excellent," (Wilmoth, 1968).

If the mining operations chose to use alternative water resources, such as saline groundwater for water withdrawals for use in mining operations, they could offset their water expenses by selling the *produced water* to mitigate any costs encountered in obtaining alternative water resources (USGS, 2012). All of these options have benefits and consequences, including the environment, where aquifers could be permanently impacted, including, but not limited to changes in hydraulic conductivities and induced strains (Elsworth and Liu, 1995). The companies have the potential to exist as water companies if the CPP is enacted, in addition to selling or reallocating their water rights.

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# Vita

Faith Martinez Smith is originally from Utah. She graduated from Carbon High School, and represented the district as Science Sterling Scholar in 2009. She received the Bachelor of Science degree in Environmental Science from Westminster College (Salt Lake City) in 2013. She interned at the Utah Attorney General's Office for the Department of Natural Resources, and as a research assistant at the University of Utah through the McNair Scholars Program at Westminster College during college. Shortly after college, and before attending the University of Texas at Austin, she worked for Rio Tinto Kennecott Utah Copper on their Energy Programs Team, helping the team with water and energy planning and management. Faith began her graduate career at the University of Texas at Austin in August 2013 as a dual-master's student in the Energy and Earth Resources Program within the Jackson School of Geosciences, and in the Global Policy Studies program at the Lyndon B. Johnson School of Public Affairs.

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