Coal and Power Systems

Internet Based, GIS Catalog of Non-Traditional Sources of Cooling Water for Use at America's Coal-Fired Power Plants

Final Scientific/Technical Report

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ABSTRACT

On-line Catalog of Alternative Sources of Water for Coal Fired Power Plants

In recent years, rising populations and regional droughts have caused coal-fired power plants to temporarily curtail or cease production due to a lack of available water for cooling. In addition, concerns about the availability of adequate supplies of cooling water have resulted in cancellation of plans to build much-needed new power plants. These issues, coupled with concern over the possible impacts of global climate change, have caused industry and community planners to seek alternate sources of water to supplement or replace existing supplies. The Department of Energy, through the National Energy Technology Laboratory (NETL) is researching ways to reduce the water demands of coal-fired power plants. As part of the NETL Program, ALL Consulting developed an internet-based Catalog of potential alternative sources of cooling water. The Catalog identifies alternative sources of water, such as mine discharge water, oil and gas produced water, saline aquifers, and publicly owned treatment works (POTWs), which could be used to supplement or replace existing surface water sources. This report provides an overview of the Catalog, and examines the benefits and challenges of using these alternative water sources for cooling water.

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Executive Summary

The objective of this project is to minimize high quality freshwater withdrawal and consumption requirements by creating an internet-based, GIS catalog of non-traditional sources of cooling water for coal-fired power plants. The project was designed to share available data to allow the economic beneficial use of oil and gas produced water, abandoned coal mine water, municipal waste water, and lower quality ground water.

All Consulting (ALL) has developed a nation-wide catalog of publicly available data on the location, quantity and quality of non-traditional water sources relative to power plants. The Catalog identifies the location and capacity of each coal-fired power plant in the lower 48 states. The inventory also identifies, to the extent possible, the location, volume, and quality of the various alternate water sources near those plants across the nation. The application is available over the internet. By simply clicking a power plant location on a map, the user can see the various potential water sources that exists near-by, the quality of the water, the volumes available, and the distance to those waters. This allows evaluation of options for using alternative water sources and allows an assessment of the costs of accessing these waters to supplement or replace current supply on a short-term or long-term basis.

The application, called the Alternate Water Source Information System (AWSIS) has been completed and posted on the internet. The application can be accessed through the project web-site at http://www.all-llc.com/projects/coal_water_alternatives/. Through the use of a Google Earth interface, the user is able to select a power plant by clicking on a map symbol or by searching for a particular power plant by plant name or operator (See example screen captures in Navigating AWSIS Section). Clicking on the map symbol will display a pop-up balloon with some basic plant information. Additional power plant information and a summary of any alternative water sources available within a 24.14-km (15-miles) radius can be viewed by clicking "View Plant & Water Summary Data" in the pop-up balloon. If the summary data indicates that data for alternative water sources in the 24.14-km (15-miles) radius are present, the detailed dataset can be viewed by clicking on the appropriate data tab. Clicking on the tab will display the available location, volume, and quality data for each of the alternative water sources present within the 24.14-km (15-miles) radius. Users may also change the search radius by clicking on the Water Search Radius drop-down arrow and selecting the desired radius. For each radius selected, the application will locate and display data for alternative water sources within that search radius. At any time, the user may click "Return to Map" to return back to the opening page and select or search for another power plant. This application allows users to quickly assess the publicly available data for alternative water sources that could potentially be used to supplement or replace existing cooling water sources.

Throughout the project, work progressed on schedule, all milestones were met, and all project deliverables were submitted on time. The on-line system, Alternative Water Source Information System (AWSIS) was completed and posted to the internet ahead of schedule. System testing and incorporation of feedback by the PAC and other stakeholders was completed in July of 2011.

Approach

ALL Consulting has performed the following tasks in accordance with the approved SOPO, and the system is currently being reviewed, with updates to the system being made as needed.

Task 1: Project Management and Planning

Under this task, ALL Consulting completed and submitted the Project Management Plan (PMP) for this project. The PMP was submitted on November 15, 2008, in advance of the scheduled milestone date of November 30, 2008. Other project management activities planned for this task were also completed. All work for this task is completed.

Task 2: Collect and Compile Data on power Plant Cooling Water Requirements

ALL Consulting's partner for this project, the Ground Water Protection Council (GWPC) was assigned the lead role for gathering data on this task. GWPC worked through its members and through the Project Advisory Council (PAC) to identify data sources for this information. All work progressed according to schedule.

Task 3: Collect and Compile Data on Non-traditional Sources of Water

ALL Consulting has collected data on non-traditional sources of water. ALL worked with other NETL contractors where possible, in order to take advantage of existing data. ALL initiated contact with State officials to identify what data may exist regarding water volumes and water quality. As part of this task, ALL gathered data on power plant locations. This was a milestone due to be completed by 3/31/09. This milestone was completed on time.

In the fourth quarter, work continued on schedule with data collection proceeded as planned. One milestone was completed ahead of schedule as shown in the Milestone Completion Table. All project tasks and milestones were completed on schedule.

Task 4: Data Analysis and Standardization

Under this task, ALL Consulting compiled and analyzed the data collected in Budget Period 1. The data were standardized into Microsoft Access data tables with common field names and attributes. All work for this task is completed.

Task 5: Develop System Specifications and Requirements

ALL Consulting developed specifications for the system based on Google Earth interface requirements. ALL created routines that allow the system to automatically retrieve and display data as well as data summaries. ALL created multiple search options and various data layer choices for the user and established requirements for system performance. All work for this task is completed.

Task 6: Application Development

The application, called the Alternate Water Source Information System (AWSIS) has been completed and posted on the internet. The application can be accessed through the project web-site at http://www.all-llc.com/projects/coal_water_alternatives/. Through the use of a Google Earth interface, the user is able to select a power plant by clicking on a map symbol or by searching for a particular power plant by plant name or operator (See example screen captures in Navigating AWSIS Section). Clicking on the map symbol will display a pop-up balloon with some basic plant information. Additional power plant information and a summary of any alternative water sources available within a 24.14-km (15-miles) radius can be viewed by clicking "View Plant & Water Summary Data" in the pop-up balloon. If the summary data indicates that data for alternative water sources in the 24.14-km (15-miles) radius are present, the detailed dataset can be viewed by clicking on the appropriate data tab. Clicking on the tab will display the available location, volume, and quality data for each of the alternative water sources present within the 24.14-km (15-miles) radius. Users may also change the search radius by clicking on the Water Search Radius drop-down arrow and selecting the desired radius. For each radius selected, the application will locate and display data for alternative water sources within that search radius. At any time, the user may click "Return to Map" to return back to the opening page and select or search for another power plant. This application allows users to quickly assess the publicly available data for alternative water sources that could potentially be used to supplement or replace existing cooling water sources. All work under this task has been completed.

Task 7: System Implementation

The system was posted to the internet ahead of schedule. The system was updated based on feedback from the PAC and industry reviewers on 7/31/2011.

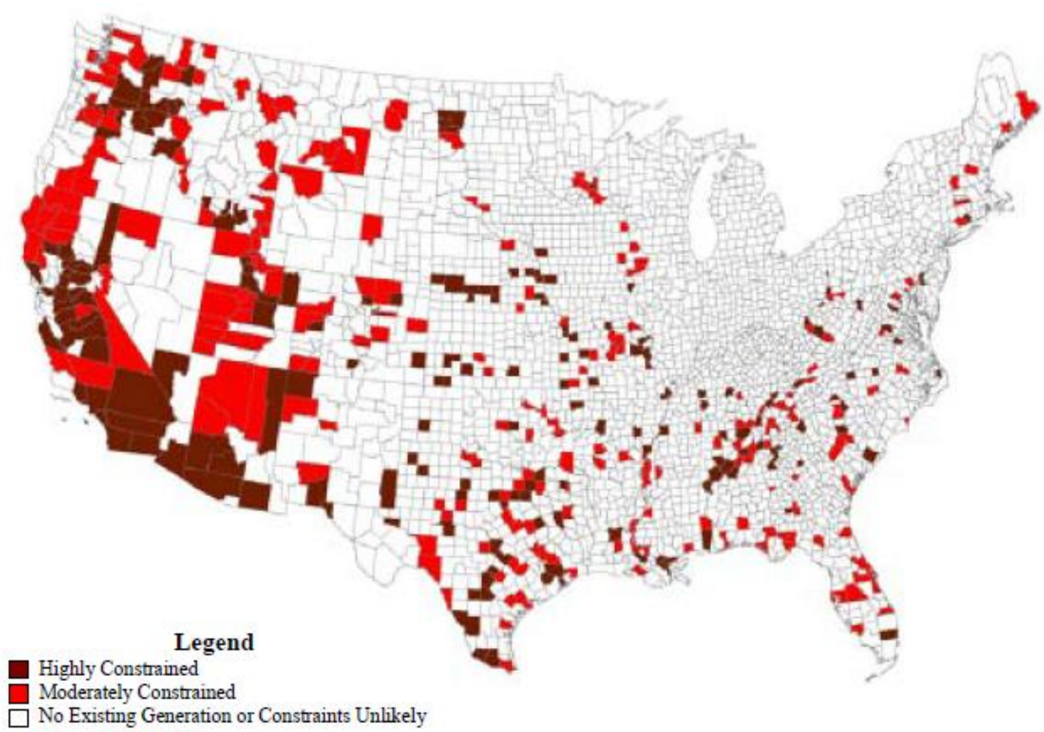
Results and Discussion

With a national freshwater withdrawal rate of 511 billion liters/day (135 billion gallons per day [BGD]), thermoelectric power generation relies heavily on a constant supply of surface and groundwater to supply consumers with a continuous source of electricity (USGS 2000). In recent years, rising populations, regional droughts, and diminishing groundwater levels have forced coal-fired power plants to temporarily curtail or cease energy production for lack of available cooling water. The current strain and escalating demand for the freshwater supplies has led industry and community planners to identify alternative water sources in an effort to reduce the electric power industry's demand on the nation's freshwater resources.

As part of the National Energy Technology Laboratory's (NETL) research program that focuses on reducing freshwater demands at coal-fired power plants, ALL Consulting has developed an internet-based GIS catalog that will identify non-traditional water sources that could be used to supplement or replace the use of traditional water sources. The data collected for the catalog has been incorporated into a GIS-based application (referred to as the "Tool") that will allow the identification of potential alternative water sources for coal-fired thermoelectric power plants throughout the United States. The following discusses the necessity of an alternative water source at power plants, the expected benefits of the Tool, and recent findings regarding the applicability of utilizing mine pool water, oil- and gas-produced water, and saline groundwater as a means towards reducing freshwater withdrawal and consumption at coal-fired power plants.

Fresh Water Supply Concerns:
Rising populations and regional droughts create competition between domestic, industrial, and agricultural water consumers for the nation's freshwater resources. Since 1950, the world's population has increased by 162 percent to over 6.7 billion people in 2008 (Census 2008). It is projected that within the next 25 years, the United States' population will increase by another 70 million individuals with most of the growth occurring in the already water-strained areas of the southwest (Exhibit 1) (EPRI 2007). As national and regional populations multiply, the growing need for energy and agricultural production-- the two largest water withdrawing industries in the nation--will continue exerting pressure on strained freshwater resources.

Exhibit 1: Water Constrained Areas of the United States



EPRI 2007

As surface water becomes scarce, power plants turn to groundwater to fill freshwater water needs. Groundwater overuse is observed at both the regional and national levels. In the United States' high plains region, groundwater levels have diminished by 30.5 m (100 feet) and in Houston, Texas, the levels have been reduced by 121.9 m (400 feet) (EPRI 2007). On a national scale, approximately 681.4 trillion liters (180 trillion gallons) of groundwater have been depleted in the U.S. during the 20th Century alone (Konikow and Kendy 2005).

Referred to as part of the "Energy-Water Nexus," thermoelectric power generation is highly dependent on the availability of water, either for steam generation or cooling water at coal-fired power plants. In some instances, power plants have been forced to reduce energy production due to a lack of available water resources. In 2007, the southeastern United States experienced drought conditions that caused the Tennessee Valley Authority to curtail production, or entirely shut down, both nuclear and coal-fired power plants in the region (DOE 2009). During prolonged and intense droughts, a power plant faces a three-fold problem in the energy-water nexus. First, reduced river volumes require power plant operators to curtail energy production to decrease the volume of withdrawals from the river. Secondly, as most droughts occur during the warmer months of the year, the reduced river volume and increased ambient temperatures could cause warming of the river until it is no longer a viable source of cooling water. Lastly, the increased temperatures causing the drought could also drive an increase in energy demand due in part to residential and commercial air-conditioning usage (DOE 2009).

Power Plant Water Usage

Several types of thermoelectric power plants exist that differ by the type of fuel utilized to drive the turbine generator. Common fuel sources are nuclear power, natural gas, oil, and coal, each possessing a unique balance of availability, cost, and environmental concerns in relation to power generation. However, due to coal's domestic abundance and relatively low cost (EPA, 2009d), coal-fired thermoelectric power plants comprise 49 percent of the power generation industry (EIA 2009). In a coal-fired thermoelectric power plant, heated boiler water is converted to steam to rotate a turbine which generates electricity. After the steam exits the turbine it passes through a condenser, where tubes filled with cooling water condense the steam to water, before returning it to the boiler. As cooling water comprises 77 percent of the total water consumption at a thermoelectric power plant (DOE 2007), this report focuses on alternative water sources for use in a power plant's cooling system. Coal-fired power plants utilize two main systems, known as "once-through" and "closed-loop", to continuously supply cooling water to the power plant.

In a once-through cooling system, cooling water is withdrawn from a nearby source such as a river, passed through the condenser, and then returned to its original source. Closed-loop systems rely on an on-site reservoir to feed cooling water to the plant's condenser. After leaving the condenser, the cooling water is sprayed into a cooling tower where ambient air is either mechanically or naturally drawn through the tower to cool the water to its original temperature before it is returned to the reservoir to repeat the cycle. In general, a coal-fired power plant requires 297,533.4 – 743,833.5 l/min (78,600-196,500 gallons per minute (gpm)[1]) to condense the steam, which is equal to approximately 757,082.4 l/min (200,000 gpm) at a 500 megawatt (MW) power plant (EPRI 2002). A power plant utilizing a once-through cooling system will withdraw approximately 45.4 million liters (12 million gallons) of water every hour (DOE 2008). Although a large volume of water is being withdrawn from the source, very little of this water is consumed through evaporation during the cooling process; therefore, nearly all of the cooling water withdrawn will be returned to the source. However, the cooling water is returned to the river at an elevated temperature, due to the heat it accepted from the boiler water in the condenser; therefore, even though little water is consumed within the once-through cooling system itself, further evaporative losses of approximately 4,463 l/min (1,179 gpm[1]) will occur downriver (EPRI 2007).

Unlike once-through systems, closed-loop cooling systems rely on a reservoir to recycle the cooling water as opposed to continuously withdrawing 45.4 million l/hr. (12 million gallons per hour [gph]) from the source. However, consumptive losses due to blowdown and evaporation in the cooling tower require some make up water be withdrawn in the amount of 7,438-8,926 l/min (1,965-2,358 gpm[1]) (EPRI 2002). Blowdown is the amount of water that is released from the system to prevent the buildup of minerals and sediment in the cooling water. In the case of coal-fired power plants, approximately 1,472.5 l/min (389 gpm[1]) of water will be released from the system as blow down and approximately 7,139 l/min (1,886 gpm[1]) of water will be consumed by evaporation in the cooling tower (DOE 2007, EPRI 2002). According to U.S. Geological Survey (USGS), once-through systems withdraw over 598 billion liters/day (158 BGD) more water than closed-loop systems. A chart comparing the water use at closed-loop and once-through cooling systems is included in Exhibit 2.

Exhibit 2: Water Withdrawal and Consumption at Coal-Fired Power Plants

Cooling System	Withdrawals (l/min|gpm)	Cooling Tower Blowdown	Consumption (l/min|gpm)	
			Down-River	Cooling Tower Evaporation
Once-Through	297,533.4–743,833.5 | 78,600-196,500[1]	-	4,463 | 1,179[1]	-
Closed-Loop	7,438-8,926 | 1,965-2,358[1]	1,472.5 | 389[2]	-	7,139 | 1,886[1]

The gpm data is calculated from the gallons per megawatt hour (gal/MWH) data listed by the cited source. The calculation is based on the approximate average MW (aMW) output of a 500 MW coal-fired power plant as derived from Platts 2006.
[1] EPRI 2002, [2] DOE 2007

Internet-Based GIS Catalog:

In order to ease the strain on the nation's freshwater resources, it is imperative to find an alternative source of cooling water to feed the approximately 15,898.7 l/min (4,200 gpm) raw water usage of a closed-loop 500MW coal-fired power plant (DOE 2007). Developing an interactive application that allows power plant operators to quickly and easily identify the available sources of non-traditional cooling water would ensure the preservation of freshwater resources for other consumers. ALL Consulting has developed a publicly available, internet-based GIS catalog to allow power plant operators, or any other interested persons, unlimited access to the information. This tool employs a Google Earth interface allowing users to select the particular power plant they are interested in. Once the power plant is selected, the user is presented with information

[1] *The gpm data is calculated from the gal/MWH data listed by the cited source. The calculation is based on the approximate aMW output of a 500 MW coal-fired power plant as derived from Platts 2006.*

regarding sources and estimated volumes of available sources non-traditional cooling water within a 24.14-km (15-mile) radius of the selected power plant.

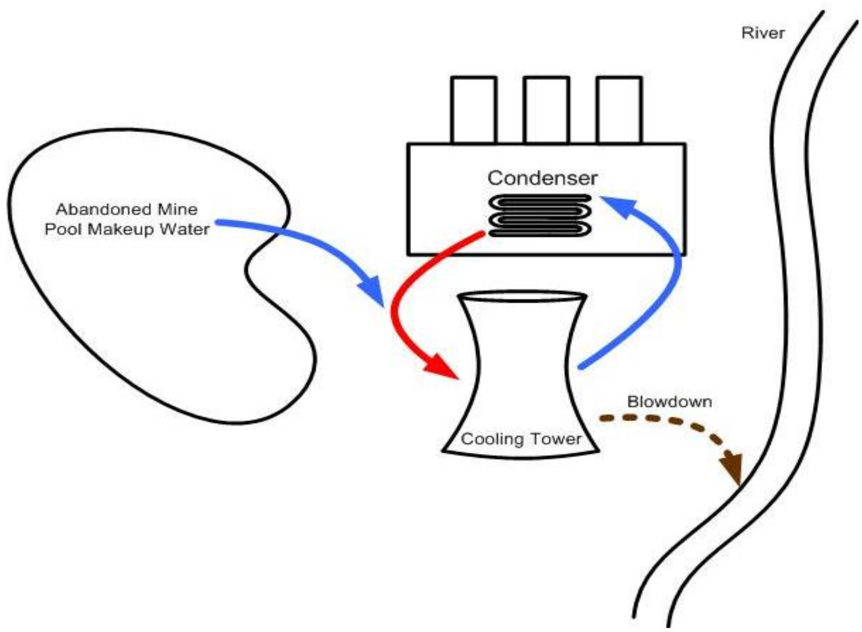
Non-Traditional Water Sources:

There are several considerations when identifying non-traditional cooling water sources; the water's quality, available quantity, and location are all factors. Regarding quality, the concentration of total dissolved solids (TDS) and pH of the alternative water source will be the biggest obstacles for suitability. Cooling water requires a pH range between 6 and 9, while the TDS concentration should be approximately 2,000 parts per million (ppm) for optimum performance (Vidic 2007c, Superchill). As a majority of the alternative water sources will contain TDS concentrations or pH levels outside of the optimum range for power plant usage, nearly all of the non-traditional sources of water will need to be treated to some extent prior to intake and usage. The economic viability of treating lower quality water should increase as traditional freshwater resources dwindle, allowing consideration of a wider range of non-traditional water sources for use at coal-fired power plants. An alternative water source should provide at least 20 percent of the raw water usage at a 500MW closed-loop power plant (15,898.7 l/min | 4,200 gpm (DOE 2008)) to be considered a practical water source for power plants; therefore only sources that can provide over 3,785.4 l/min (1,000 gpm) will be included. Several potential non-traditional sources of cooling water meeting these basic requirements are abandoned mine pools, oil and gas produced water, and saline aquifers.

Abandoned Mine Pools:

Since the mid-1800s, coal mining has been a major part of the nation's energy production (EIA 2009). The vast networks of tunnels dug during coal production are infiltrated by water that is constantly pumped out to keep the mine dry. Once coal production ceases and the water is no longer being pumped out, the underground voids fill with groundwater and form abandoned mine pools. To utilize this alternative water source, the mine pool would likely be incorporated into a closed-loop cooling system as a reservoir to provide makeup water to the power plant, as shown in Figure 3. In this scenario, the mine pool would only need to supply the 15,898.7 l/min (4,200 gpm) lost as blowdown and through evaporation as opposed to supplying the 757,082.4 l/min (200,000 gpm) that is required by a once-through power plant (DOE 2007, DOE 2008).

Exhibit 3: Closed-loop Cooling Using Mine Pool Water

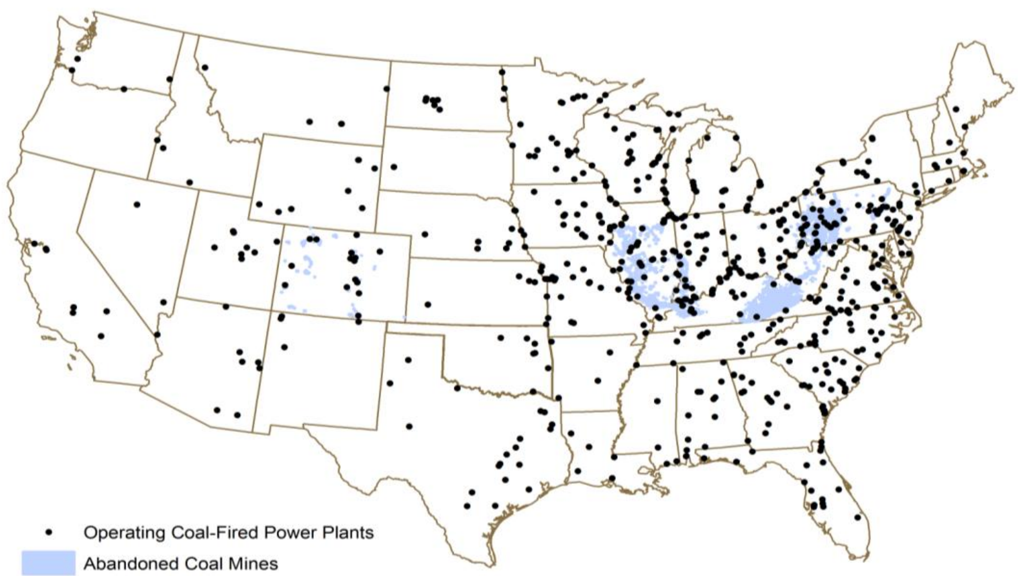


Modified from Veil 2003

Although this largely untapped resource presents a potentially viable source of water for coal-fired power plants, issues such as the quality and volume of the available mine pool water, and the ability to accurately locate flooded mines must be taken into account before reaching a determination of suitability.

The quality of water found within abandoned mines varies greatly, thus suitability of use is dependent on several factors including geographic location, the length of time the mines have been flooded, and whether or not the mines have had their first-flush. For instance, if the mine has not had its first-flush, the initial discharge will be more acidic, and mines that have been recently flooded tend to display greater sulfate levels as compared to those that have been static for a longer period of time (Vidic 2007c and Ziemkiewicz et al 2004). Generally, the constituents found in abandoned mine pools consist of heavy metals such as copper, lead, and mercury, although iron tends to be the most prominent metal in the water (Vidic 2007c). The pH of the mine pool water typically displays a bimodal distribution at a pH of 2-4 and 6-7 and the TDS has been shown to range from 200-10,000 TDS (Veil 2003, Cravotta et al 2009). Although nearly all of the mine pool water to be used at a power plant will need to be treated for pH, metals, and TDS, in most cases the mine pool water will be of suitable quality for use at power plants.

Exhibit 4: Locations of Abandoned Coal Mines vs Power Plants



Modified from Platts 2006

The Pennsylvania Department of Environmental Protection (PADEP) and West Virginia Geological and Economic Survey (WVGES) estimate that there are approximately 15,000 abandoned underground mines in Pennsylvania and another 100,000 abandoned underground mines in West Virginia (Veil 2003). These abandoned mines in the Pittsburg Coal Seam could potentially produce 359,614 l/min (95,000 gpm), which would be enough water to supply all of the make-up water for approximately twenty-two 500-MW coal-fired power plants utilizing a closed-loop cooling system (Ziemkiewicz et al).

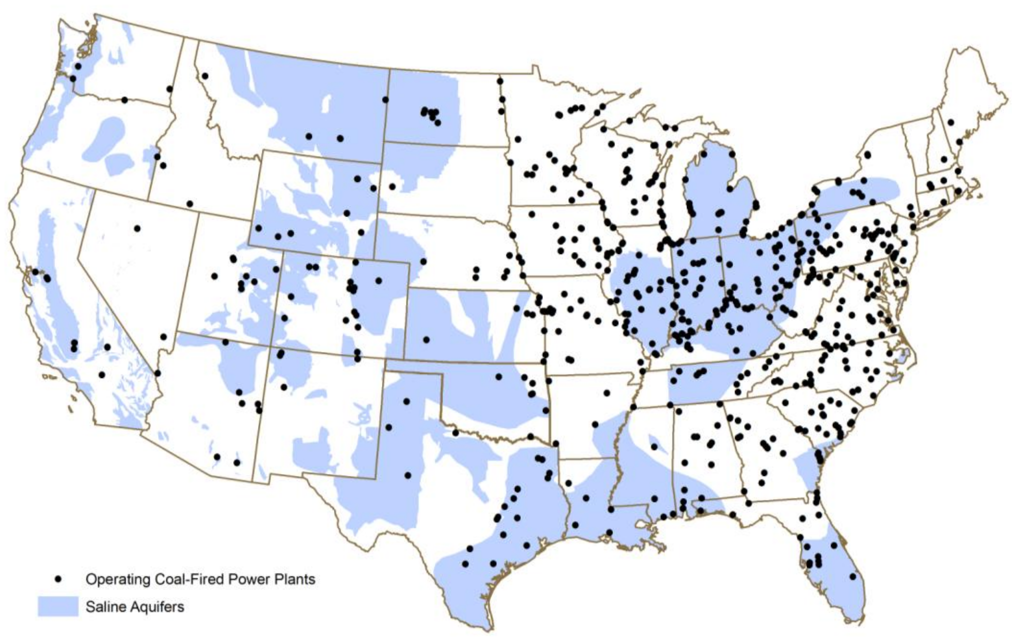
This project utilizes data from several organizations to map the locations of abandoned coal mines throughout the United States. For instance, the West Virginia Water Research Institute has documented the probable locations and quality of mine pools found throughout the Pittsburgh Coal Seam (Ziemkiewicz et al 2004). Additionally, the Mine Safety and Health Administration allocated approximately $3.9 million to 13 states to digitize existing mine maps throughout the United States (DOL 2009). This study was initiated in 2003, and many states are still making progress toward collecting and digitizing abandoned mine maps in their area. Combining the data from these programs will allow the GIS application identify potential locations of mine pool water for use at thermoelectric power plants.

Saline Aquifers:

As surface water supplies become strained, thermoelectric power plant operators are turning to groundwater to fill their never ending need for water. According to USGS, thermoelectric power plants withdraw over 738 billion/l/day (195 BGD) of water, only 30 percent of which is saline; thus over 511 billion/l/day (135 BGD) of freshwater withdrawn at power plants could go towards domestic use. Thermoelectric power plants are currently responsible for approximately 96 percent of all saline water withdrawals in the country (approximately 227 billion/l/day [60 BGD]), but this number could be much greater if they were able to access the expanse of saline groundwater that underlies large portions of the United States (Exhibit 4) (USGS 2000). While several government agencies including USGS and Department of Energy (DOE) generate current national groundwater data, there is no single data set containing the location, quality, and quantity data necessary to determine the availability of saline groundwater for use at thermoelectric power plants.

The map of the nation's saline groundwater basins, collected by NETL as a part of the National Carbon Sequestration Database and Information System (NatCarb), displays many quality parameters and the aerial extent of the saline aquifers, although the total water volume or flow rate is not documented (NETL 2008a).

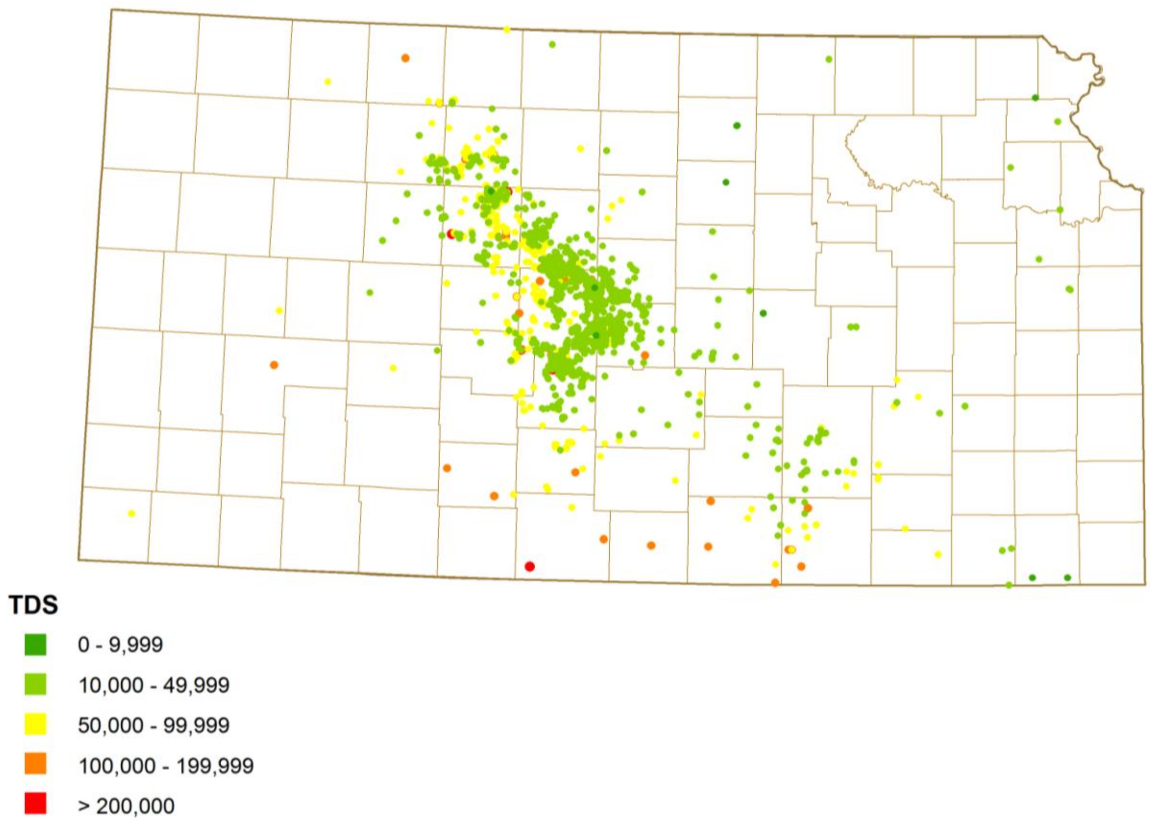
Exhibit 4: Locations of Saline Aquifers and Coal Fired Power Plants



Modified from NETL 2008a and Platts 2006

While several data sets exist allowing operators the ability to identify potential sources of saline groundwater near their power plant, no single database has all of the information necessary to make the determination of whether saline groundwater is a practical source of water at a particular location. An application that has the ability to integrate information from several of the data sets can play a pivotal role in helping power plant operators reduce their use of freshwater.

Exhibit 5: TDS Trend in Arbuckle Aquifer



NETL 2008b

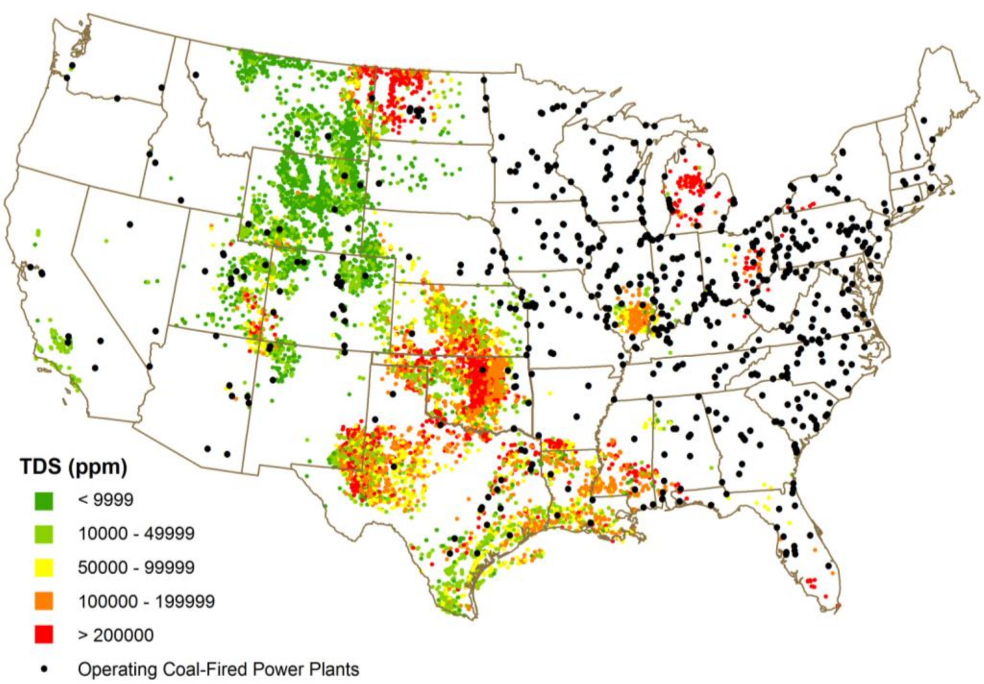
As with mine pool water, the quality of the saline aquifers varies greatly even within a given region. For instance, the average TDS concentration in the Arbuckle Formation is approximately 42,000 ppm, and the concentrations range from 1,500 to nearly 350,000 ppm, as shown by the map of TDS levels in the Arbuckle Formation of Kansas (Exhibit 5) (NETL 2008b). The spatial variability of TDS levels in saline aquifers will likely make it difficult for operators to predict whether the groundwater near their power plant is of usable quality. Although the TDS levels within the Arbuckle aquifer make some of the water impractical for use, the average pH of the groundwater is 7.11, which is within the optimum pH range for use at a power plant (NETL 2008b). The neutral pH values along with treatable levels of TDS demonstrate that a large portion of the water contained within saline aquifers would be of adequate quality for use at a thermoelectric power plant.

Produced Water

Water trapped in underground geologic formations and brought to the surface during oil and gas production is called "produced water." Produced water is regarded as a potential non-traditional source of water for power plants because large volumes are generated throughout many regions of the United States and a majority of the water contains treatable TDS concentrations.

Even with 15.9 billion/l (4.2 billion gallons) of produced water being generated every day, the inconsistency of quality from basin to basin creates uncertainty that produced water is usable in all areas of the nation for power plant water needs (Veil et al 2004). Composition and quality of produced water varies based on its originating basin, formation, and depth. As shown by data from the USGS Produced Water Database (Exhibit 6), produced water throughout the Rocky Mountain region tends to have TDS levels below 10,000 ppm while basins in the central and southern United States display a frequent occurrence of TDS levels at 200,000 ppm and above (USGS 2002).

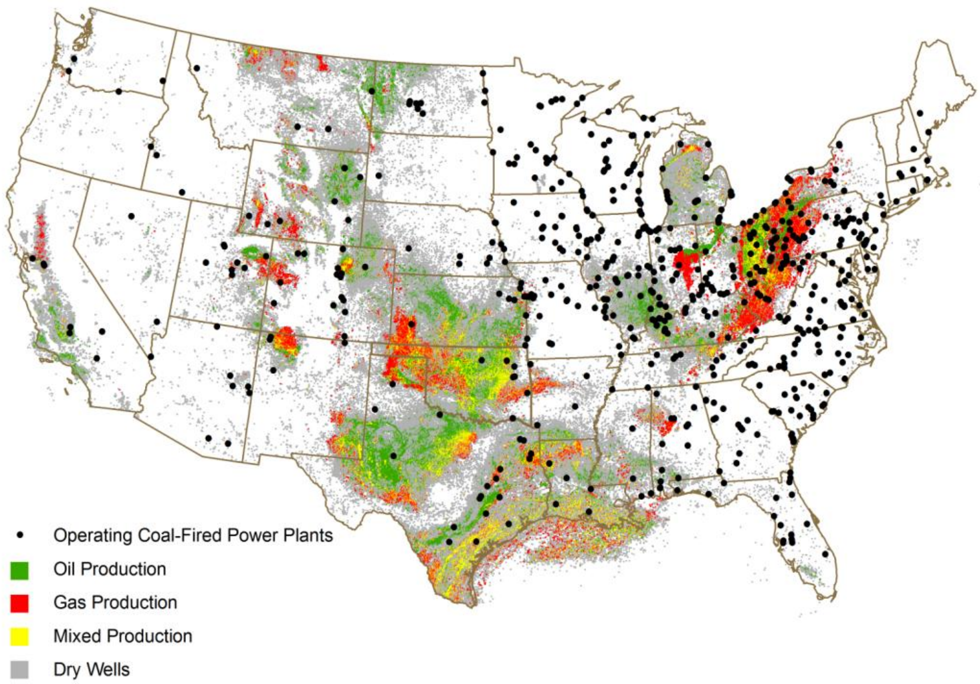
Exhibit 6: Trends in Produced Water TDS vs.Coal Fired Power Plant Locations



Modified from USGS 2002b and Platts 2006

Although approximately 9.5 barrels of water are produced for every barrel of oil in the United States, the locations of the produced water and coal-fired power plants do not necessarily coincide. As shown in Exhibit 7, for many power plants located along the east coast and elsewhere, produced water is an impractical alternative water source due to the power plants' distances from areas of oil and gas production. Alternatively, for power plants in the Rocky Mountain region and the central United States, produced water could be a plentiful and economically feasible alternative water source.

Exhibit 7: Oil and Gas Production and Coal Fired Power Plant Locations



Modified from USGS 1995 and Platts 2006

AWSIS Overview:

Through the use of integrated and innovative research, NETL established a program with the goal of reducing the effect of power plant water usage on the nation's fresh water resources. To achieve this goal, NETL's program includes research in the areas of non-traditional sources of water, water reuse and recovery, advanced cooling technology, and waste water treatment and detection. In an effort to facilitate the use of non-traditional sources of water at coal-fired power plants, ALL developed an internet-based GIS catalog of non-traditional water sources throughout the U.S.

The objective of AWSIS is to allow power plant operators to locate non-traditional water sources that may be available in the vicinity of their power plant. Through the use of an interactive on-line application, the user is able to click on the power plant of interest and be presented with data on the available quantity, quality, and location of non-traditional water sources within 24.14-km (15-miles). A radius of 24.14-km (15-miles) was chosen as an assumed economically feasible limit to transport the water. Due to the variability of circumstances at each power plant, this radius is adjustable to allow for an increased or decreased search for non-traditional water sources. Additionally, the data are filtered to include only the water sources with a minimum flow rate of 3,785.4 l/min ([1,000 gpm] 1.44 mgd), based on the assumption that a reasonable water source should supply at least 20% of the water needs at a 500-MW closed loop, coal-fired power plant.

Produced Water
In the process of gathering data for produced water, locations for both the source and destination of produced water were pursued. States' departments of oil and gas, natural resources, and environmental protection which typically contain databases for oil and gas data were searched for produced water and oil and gas location information. Databases specifically detailing the location, volume, and quality of produced water were identified for only a few states; therefore, due to a lack of consistent data this information was not used in the application.

The next step was to search state departments for data regarding oil and gas locations. It was expected that since produced water volumes would not be available through these databases, an average produced water volume would be calculated and applied to each well, and the wells would be grouped into zones that had an expected produced water volume of 3,785.4 l/min ([1,000 gpm] 1.44 mgd). As oil and gas location data was gathered, the databases were filtered to only show oil and gas wells that were listed as active, completed, and producing. During the formatting phase it was discovered that the data and their attributes were inconsistent from state to state. As opposed to gathering data from the individual states, it was decided that the oil and gas location data would be retrieved from the 1995 U.S. Geological Society's (USGS) National Oil and Gas Assessment database. Due to only containing estimated volumes of produced water, and the lack of produced water quality data, these sources were not used to define the available and useable produced water for the application.

Data was gathered on the destination of the produced water in the form of Class II injection wells. Some state agencies keep records on the types of injection wells as well as the volume of water that is injected. Records from the databases were filtered to include only active disposal wells; however, some of the injection well databases did not differentiate between disposal, general injection, and enhanced oil recovery wells. Due to the inability to filter the data to show only disposal wells and the lack of water quality information, this data was not included in the application.

In 2002, the U.S. Geological Survey (USGS) published the Produced Water Database which contains both the locations and various quality parameters for nearly 60,000 produced water locations throughout the U.S (USGS 2002). Although the 2002 Produced Water Database does not list volumes for each location, this data set was chosen for the application based on the presence and consistency of location and volume information for produced water across the U.S. The data were filtered to include produced water locations with TDS concentrations of 50,000 mg/L or less.

Abandoned Mine Pool Water
Data was gathered from several organizations in an attempt to map the locations of abandoned coal mines throughout the United States. For instance, the West Virginia Water Research Institute has documented the probable locations and quality of mine pools found throughout the Pittsburgh Coal Seam (Ziemkiewicz et al 2004). Water volumes of the mine pools were not identified so it unknown which areas may contain enough water to support the water needs of a power plant; therefore, this data was not used in the application.

The Mine Safety and Health Administration (MSHA) allocated approximately $3.9 million to 13 states to digitize existing mine maps throughout the United States (DOL 2009). This study was initiated in 2003, and many states are still making progress toward collecting and digitizing abandoned mine maps in their area. Although the abandoned mine maps collected as a part of the MSHA project may help power plant operators identify potentially flooded mines, no data has been gathered specific to the water in the abandoned mines.

The Pennsylvania Department of Environmental Protection (DEP) maintains a database of mine discharges which contains the location, rate of flow, and several quality parameters for each discharge (PADEP 2010). Due to the presence of these parameters, this database was used in the application to identify locations that maybe able supply adequate volumes of water to a power plant. The abandoned mine discharge data was in dbf format and was converted to Microsoft Access database. The data includes 324 discharge points across Pennsylvania and were filtered to only display discharges with a TDS concentration of 50,000 mg/L or less.

Publicly Owned Treatment Works

POTW water discharge information was accessed through EPA's National Pollutant Discharge Information System, Permit Compliance System. The POTW data includes the location and quantity of water for approximately 60,000 discharge locations; however, data regarding the quality of the discharges is not available. The data is in Microsoft Excel format and was converted into a Microsoft Access Database. In Microsoft Access, the data were filtered to display only those discharges with a flow rate of 3,785.4 l/min ([1,000 gpm] 1.44 mgd). Additionally, the data were filtered to only include those facilities listed as municipal treatment plants (SIC Code 4952).

Saline Groundwater

The data of the nation's saline groundwater aquifers, collected by NETL as a part of the National Carbon Sequestration Database and Information System (NatCarb), displays many quality parameters and the aerial extent of the saline aquifers, although the total available water volume or flow rate is not documented (NETL 2008a). The NatCarb saline groundwater data was received in Microsoft Access format and contained approximately 125,000 data points. The data was filtered to include water samples with TDS levels of 50,000 ppm or less.

Selection of the Application Platform:

To deliver the AWSIS application, the project team opted for a Microsoft platform featuring Windows Server, Microsoft Structured Query Language (SQL) Server and the Microsoft .NET Framework. Google Earth was integrated with Microsoft's .NET Framework using the Google Earth API. Windows Server version 2003, and later, fully supports the .NET Framework version 3.5, and the use of Microsoft SQL Server allows reliable central data storage while integrating directly with Microsoft's .NET Development tools. Google earth supplies an interactive 3-D map based on coordinate data housed within the AWSIS database.

Platform Reasoning, Benefits, and Limitations

The AWSIS application is intended to deliver its payload to a public audience with a potentially wide range of computer systems. To help simplify the distribution of AWSIS, making the core system accessible by supported browsers over the internet helps to lessen installation pitfalls. The Google Earth Plug-in is available for free from a trusted source (Google) and is installed directly from the opening webpage using Google's plug-in installer. The Google plug-in installation has been tested by numerous developers and end users. Additionally, the Google Earth plug-in is available on both PC and Mac platforms, and within a number of widely distributed web browsers.

Making AWSIS available via supported web browser helps make distribution easy; however, web based applications in general, offer some limitations. AWSIS is no different in this regard. These limitations include the need to have an internet connected computer; a supported browser; and appropriate browser configuration settings.

Benefits of the web based AWSIS application go beyond the distribution of the system and expanded platform availability. Having AWSIS deployed to a managed web server allows system updates to be quickly deployed and immediately accessible to all users. Data collected from the numerous sources utilized can be transformed, consolidated, and centralized within a Microsoft SQL Server database. This data centralization allows for data updates and corrections to be immediately available to users of the system.

Development of the AWSIS Application:

AWSIS employs a blend of technologies from both Microsoft and Google to create the end user experience provided by the application. Microsoft provides the server platform, developer integrated development environment (IDE), and programming interface. Google Earth is integrated to provide the 3-D map controls used throughout the system. During the development of AWSIS, some specific technologies and processes were used to complete the system. These technologies and processes allow AWSIS to provide meaningful information help to promote efficient application development.

As discussed previously, the raw data that were compiled for use within the AWSIS application came from different sources and had some different formats, mostly including MS Excel and MS Access. The available data was analyzed and a SQL Server table structure designed and developed to house the applicable data. Utilizing SQL queries and data import routines helped identify invalid data and keep the transformation of data into a SQL Server database simple and repeatable.

Consolidating and centralizing the raw data through the SQL Server allowed LINQ, Language-Integrated Query, technology to be implemented within the application. LINQ is utilized behind the scenes within the AWSIS application as a way to query SQL Server data into objects for consumption by the application programming. Additionally, it serves as a way to query and filter in-memory caches of data to speed up data access by applying multi-stage data filtering techniques. Here is an example of LINQ in action within AWSIS; a query to find produced water within a given distance of a coal-fired power plant:

```
querypw = (from pw in dc.ProducedWaters
                where (pw.LATITUDE > latforcalc1 || pw.LATITUDE < latforcalc2)
                && (pw.LONGITUDE > lonforcalc1 || pw.LONGITUDE > lonforcalc2)
                && (pw.TDS <= 50000)
                select pw).ToList();
```

Once the data has been pulled from the external SQL Server database, there are some important processes that take place to present that data to the end user in a usable fashion. One such process was written in order to calculate the radius in miles from a given latitude and longitude.

Calculating radius is an important step in determining the alternative water sources within a select distance from the coal fired power plant selected by the user. In order to calculate the distance between two latitude and longitude coordinates, latitude and longitude was converted to radians and used in the Great Circle Distance Formula. The radius of the earth was assumed at 6,377.83 km (3,963 miles). To calculate the distance between two locations, the resulting calculation is:

```
radiusfrompoint = radofearth * Math.Acos((Math.Sin(_lat1) * Math.Sin(ilat)) +
(Math.Cos(_lat1) * Math.Cos(ilat) * Math.Cos(ilon - _lon1)));
```

Integrating Google Earth by way of the Google Earth API gives another important process to improve functionality and usability of the AWSIS application. Google Earth utilizes JavaScript, which can be initiated within C# code for an ASP.NET page. As an example, zooming to a specific selected power plant and drawing the appropriate balloon is done as follows:

```
protected void ZoomToPowerPlant(double lat, double lon)
    {
        // Define the name and type of the client scripts on the page
        string gescript = "GoogleEarthLoadScript";
        string getext = BuildGoogleScript(lat, lon);
        Type getype = this.GetType();

        // Get a ClientScriptManager reference from the Page class.
        ClientScriptManager cs = Page.ClientScript;

        if (!cs.IsStartupScriptRegistered(getype, gescript))
        {
            cs.RegisterClientScriptBlock(getype, gescript, getext, true);
        }
    }
```

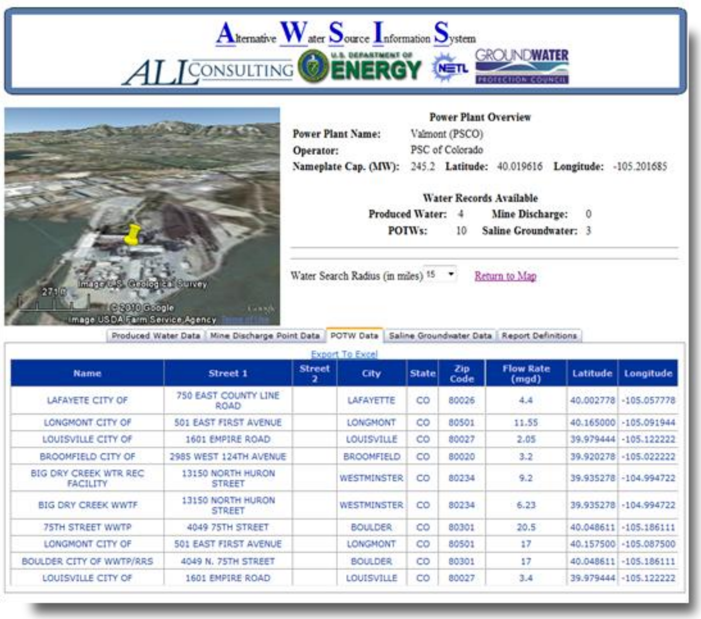
Navigating AWSIS:

The AWSIS application is available online and can be accessed at http://www.allconsulting.net/awsis/. Background information and details of the project are available by clicking the "GIS Catalog (AWSIS)" link on the project portal (http://www.all-llcc.com/projects/coal_water_alternatives). AWSIS is optimized for internet explorer; therefore, using Google Chrome or Firefox may reduce functionality of the program.

The Google Earth interface on the opening screen is fully interactive and displays a map of the United States that is loaded with each of the 599 coal-fired power plants, as indicated by a square. The green squares represent power plants with an alternative water source within 24.14-km (15-miles) and the yellow squares represent power plants that do not lie within 24.14-km (15-miles) of an alternative water source. From this page, the user may search for an individual power plant by typing the power plant name or operator name into the appropriate text box, or through a manual search by scrolling and zooming in on the Google Earth map. **The figure above** presents a screenshot of the opening page of the AWSIS application.

Once the power plant has been selected, Google Earth zooms into a street level view of the facility. Clicking on the power plant symbol displays a pop-up box with a summary of the power plant's information including the power plant name, operator, nameplate capacity, and an indication of the presence or absence of alternative water sources within 24.14-km (15-miles). Additionally, this pop-up box displays a hyperlink which directs the user to the alternative water source summary page for the power plant. The figure below shows a screen shot of the pop-up box of a selected power plant.

The power plant's alternative water summary page allows the user to view the number and type of alternative water sources available to the power plant within a 24.14-km (15-miles) radius. The complete data set for each available alternative water source is displayed at the bottom of the page in a spreadsheet format. Additionally, users may also change the search radius by clicking on the "Water Search Radius" drop-down arrow and selecting the desired radius. For each radius selected, the application will locate and display



data for alternative water sources within the appropriate search distance. Once the search radius has been selected and the data has loaded in the webpage, the data can be exported to an Excel spreadsheet, via the 'Export to Excel" link, for further analysis and assessment. At any time, the user may click "Return to Map" to return back to the opening page and select or search for another power plant. The left figure presents a screen shot of the alternative water source summary page within AWSIS.

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List of Acronyms and Abbreviations

ALL	ALL Consulting
API	Application Programming Interface
AWSIS	Alternative Water Source Information System
BGD	Billion Gallons Day
DOE	Department of Energy
EPA	Environmental Protection Agency
GIS	Geographic Information System
gpm	Gallons Per Minute
GWPC	Ground Water Protection Council
IDE	Integrated Development Interface
km	Kilometer
l	Liter
l/min	Liters per Minute
LINQ	Language Integrated Query
MGD	Million Gallons per Day
MSHA	Mine Safety and Health Administration
MW	Megawatt
NatCarb	National Carbon Sequestration and Information System
NETL	Nation Energy Technology Laboratory
PAC	Project Advisory Council
PADEP	Pennsylvania Department of Environmental Protection
PMP	Project Management Plan
POTW	Public Owned Treatment Works
PPM	Parts Per Million
SQL	Structured Query Language
TDS	Total Dissolved Solids
U.S.	United States
USGS	United States Geological Society
WVGES	West Virginia Geological and Economic Survey

Figure 1: Milestone Completion Table

Budget Period	Milestone Description	Planned Completion Date	Actual Completion Date
I	Submit completed project management plan	11/30/08	11/15/08
	Identify locations for existing and planned power plants	03/31/09	03/15/09
	Complete collection of data on power plant cooling requirements and collection of data on non-traditional sources of water	09/30/2009	9/15/09
II	Complete data standardization	12/31/09	12/14/09
	Complete Application development	09/30/10	6/09/10
III	Post application on line	12/31/10	6/10/10
	Update application as needed based on feed-back from PAC and DOE	07/31/11	07/31/11

Figure 2: COST PLAN STATUS

Baseline Reporting Quarter	YEAR 1 Start: 10/01/08 End: 09/30/09				YEAR 2 Start: 10/01/09 End: 09/30/10				YEAR 3 Start: 10/01/10End: 09/30/11			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Baseline Cost Plan (from SF-424A)												
Federal Share	20,000	42,860	42,860	42,860	41,155	41,155	41,155	38,839	34,546	34,546	34,546	34,552
Non-Federal Share	2,000	23,200	23,200	23,200	15,387	15,387	15,387	15,387	11,025	11,025	11,025	11,025
Total Planned (Federal and Non-Federal)	22,000	66,060	66,060	66,060	56,542	56,542	56,542	54,226	45,570	45,570	45,570	45,570
Cumulative Baseline Cost	22,000	88,060	154,120	220180	276,722	333,264	389,806	446,348	491,918	537,488	583,058	628,628
Actual Incurred Costs												
Federal Share	9,752	39,329	13,184	85,708	55,332	15,408	32,376	58,974	36,237	26,221	26,221	72,480
Non-Federal Share	1,260	14,744	28,756	46,200	0	25,000	21,200	26,376	25,000	0	0	36,900
Total Incurred Cost-Quarterly (Federal and Non-Federal)	11,012	54,073	41,940	131,906	55,332	40,408	53,576	85,350	36,237	26,221	26,221	111,404
Cumulative Incurred Costs	11,012	65,085	104,813	239,540	55,332	95,739	149,316	248,880	36,237	62,458	88,678	200,083
Variance												
Federal Share	10,248	3,531	23,961	(65,846)	(14,756)	25,168	8,200	(20.135)	22,803	7,819	7,819	(35,665)
Non-Federal Share	740	8,456	(10,856)	(23,000)	15,387	(9,613)	(5,813)	(10,989)	(13,975)	11,025	11,025	(25,875)
Total Variance-Quarterly (Federal and Non-Federal		11,987	13,105	(65,846)	632	15,555	2,387	(31,123)	8,828	18,843	18,844	(61,540)
Cumulative Variance	10,988	22,975	51,977	(19,360)	632	16,187	4,574	(26,763)	8,828	27,672	46,515	(13,507)

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