Dobson, E. A. (1987): Using Underground Anthracite Mine Pools for Municipal Water Supplies – Case Study – Mt. Carmel, Pennsylvania. Paper presented at the Annual Eastern Regional Ground Water Conference, Burlington, July 14-16, 1987. – p. 759-770, 5 Abb.; Dublin (National Water Well Association).

USING UNDERGROUND ANTHRACITE MINE POOLS FOR MUNICIPAL WATER SUPPLIES: CASE STUDY - MT. CARMEL, PENNSYLVANIA

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Abstract:

This paper presents the hydrogeologic and economic aspects of utilizing the vast quantities of ground water contained within the abandoned underground deep mines of Pennsylvania's anthracite region as municipal water supplies. Until recently, the aquifer potential of these mine pools has been largely ignored due to the impacts of 150 years of coal mining and the resultant acid mine drainage problems.

A hydrogeologic investigation was conducted for the Borough of Mt. Carmel, Northumberland County, Pennsylvania, to determine if supplemental ground water sources could be added to their water system. The results of the hydrogeologic study showed that yields and water quality of the aquifer formations not associated with coal mining activities were such that development costs were prohibitive. In order to investigate all possible options, a feasibility study for the utilization of the mine pool waters underlying the Borough was undertaken.

Based on the technical and economic studies of the data from the initial investigation, it was determined that it would be economically cost effective and technically feasible to treat the mine waters beneath the Borough for use as a potable water supply.

This study has provided the impetus for further developmental studies utilizing the mine pool water reserves. Mine pool waters can serve as large volumes of either potable or industrial use waters, dependent on the waters' treatability.

Introduction:

Pennsylvania has supplied virtually all of the nation's anthracite coal for the past 150 years. Over the last few decades, the depletion of economically recoverable reserves and the decline in demand for coal has forced the closing of the majority of the underground mines in the anthracite coal fields of northeast Pennsylvania. These abandoned mines have been inundated by ground water, forming vast pools of mine water beneath the towns which developed as a result of the mining industry.

With the ground water resources degraded by mining, it was necessary for the towns to find other sources of potable water. This was usually accomplished by impounding surface runoff or by purchasing and piping water from private water companies whose sources were located miles away from the affected coal basins. The costs involved in providing potable water was considered insignificant, at that time, compared to the revenues generated by the mining industry.

In recent years, the decline in the demand for coal has contributed to the economic hardship of these communities, while the costs of purchasing and maintaining distribution systems have continued to increase. One solution to this problem is to provide these communities with their own ground water supply by utilizing the underground mine pools. Considering certain economic circumstances, present day technology can produce potable water from the acidic mine waters found in the pools, especially if ground water can be obtained close to the recharge zones of these pools.

Background and Purpose:

The Borough of Mt. Carmel, Northumberland County, is typical of the towns which developed in response to the labor needs of the anthracite industry and associated manufacturing operations of the Western Middle Anthracite Field. (Refer to Figure 1.) Historically, the Borough relied on surface waters for potable water and, at one time, maintained several supply wells. The supply wells were abandoned in the early to mid 1900's when it was found that it was less expensive to purchase water rather than to maintain and pump from their own wells. The current average daily usage for the Borough is 504,000 gallons (350 gpm) of which 95% (470,000 gallons) is purchased from a private, independent water company, located approximately 3 miles away. The remaining 26,000 gallons come from three spring-fed reservoirs, which the Borough owns and maintains near the base of Locust Mountain.

During 1985, the gross revenues from the Borough's water customers approached $675,000. The average costs for residential customers was $4.29/1000 gallons ($157.00/year), $2.85/1000 gallons ($387.00/year) for commercial users, and $2.43/1000 gallons ($536.00/year) for industrial users. The cost of water to the Borough has been increased by the private water company five times over the last seven years. With population predictions indicating a continued decline, the Mt. Carmel Water Authority

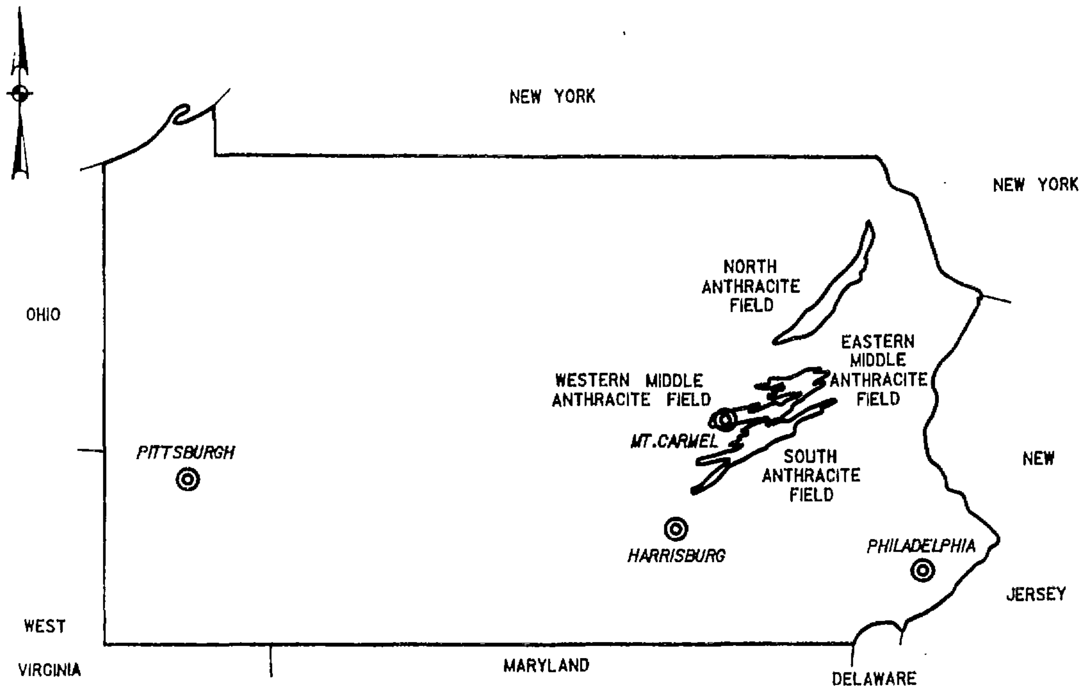

FIGURE I
SITE LOCATION MAP

realized that they would not be able to maintain and upgrade the 33 miles of distribution system without passing on the costs to the consumers.

In 1983, the Water Authority retained Benatec Associates to conduct a hydrogeologic investigation and prepare a feasibility study to determine whether the Borough could decrease the amount of water purchased. Considerations for alternate supplies included drilling and maintaining one or more wells and developing springs. A comprehensive geologic, hydrogeologic and economic study was undertaken to define sources of alternate water supplies.

Once the geologic and hydrogeologic setting was determined, the initial scenario of the study was to determine the suitability of incorporating several additional springs outcropping along Locust Mountain to the reservoir supply and to drill one or more supply wells on Borough property.

Geology of the Study Area:

The geology of the Mt. Carmel area is complex as a result of various stages of the Appalachian Orogeny. The regional structural configuration is a composite synclinal trough, consisting of a series of antiforms and synforms that interchange locally. These folds have a general northeast trend, with the stratigraphic sequences often transected by faults. (Rothrock et al, 1951.)

The rock units in the area belong to the Pennsylvania Age lower Llewellyn and Pottsville Formations and the Mississippian Age Mauch Chunk Formation. The Llewellyn Formation conformably overlies the Pottsville and consists of conglomerates, sandstones, siltstones and most of the economic coal seams. The base of the Llewellyn is placed at the bottom of the Buck Mountain (No. 5) coal seam. The Pottsville Formation conformably overlies the Mauch Chunk Formation and consists of conglomerates interbedded with smaller amounts of gray, green or brown siltstones and sandstones. The Pottsville is characterized by abrupt lateral changes in both lithology and thickness and the formational boundary is the first red beds encountered. The rocks of the Mauch Chunk Formation are predominantly fine-graded, red siltstones, red sandstones and occasional thin red claystone beds. (Arndt et al, 1971.)

There is little published information pertaining to the ground water availability and quality for the Mt. Carmel area. There are no records of wells in the immediate area which produce potable water. It has been generally accepted that when considering small scale development, such as individual private supplies, ground water development in this area was impossible due to the adverse effects of mining to the ground water.

The Mauch Chunk Formation is considered a good aquifer with excellent water quality. (Lohman, 1957.) However, in the Mt. Carmel area, it is overlain by some 800 feet of the Pottsville Formation, thus limiting it's recharge potential and restricting the feasibility of well construction.

The Pottsville Formation has been known to yield up to 120 gpm in regions to the east of Mt. Carmel, where beds are dipping at lower angles. (Lohman, 1957.) In the Mt. Carmel area, however, the beds dip between 30 - 50 degrees and the formation's resistance to weathering causes it to be a ridge former in this area. Wells drilled on these ridges are less productive due to decreased storage potential of the more steeply dipping rocks.

The Llewellyn Formation has generally been overlooked as an aquifer due to the detrimental effects mining has had on the water quality. However, mining has also had some positive effects on the aquifer characteristics. The room and pillar method of mining has greatly increased the secondary porosity and has created vast storage reservoirs. One such reservoir, the Stuartsville mine pool, extends from the base of Locust Mountain, continues north under the Borough and holds an estimated 1.14 billion gallons of mine water. (See Figure 2.) The static water level of the Stuartsville pool approaches 1000 feet above mean sea level (MSL).

Methods and Results for Preliminary Investigation:

The preliminary phase of the study called for the investigation of the suitability of using several springs which outcropped along Locust Mountain and which were not already incorporated into the Borough's surface sources.

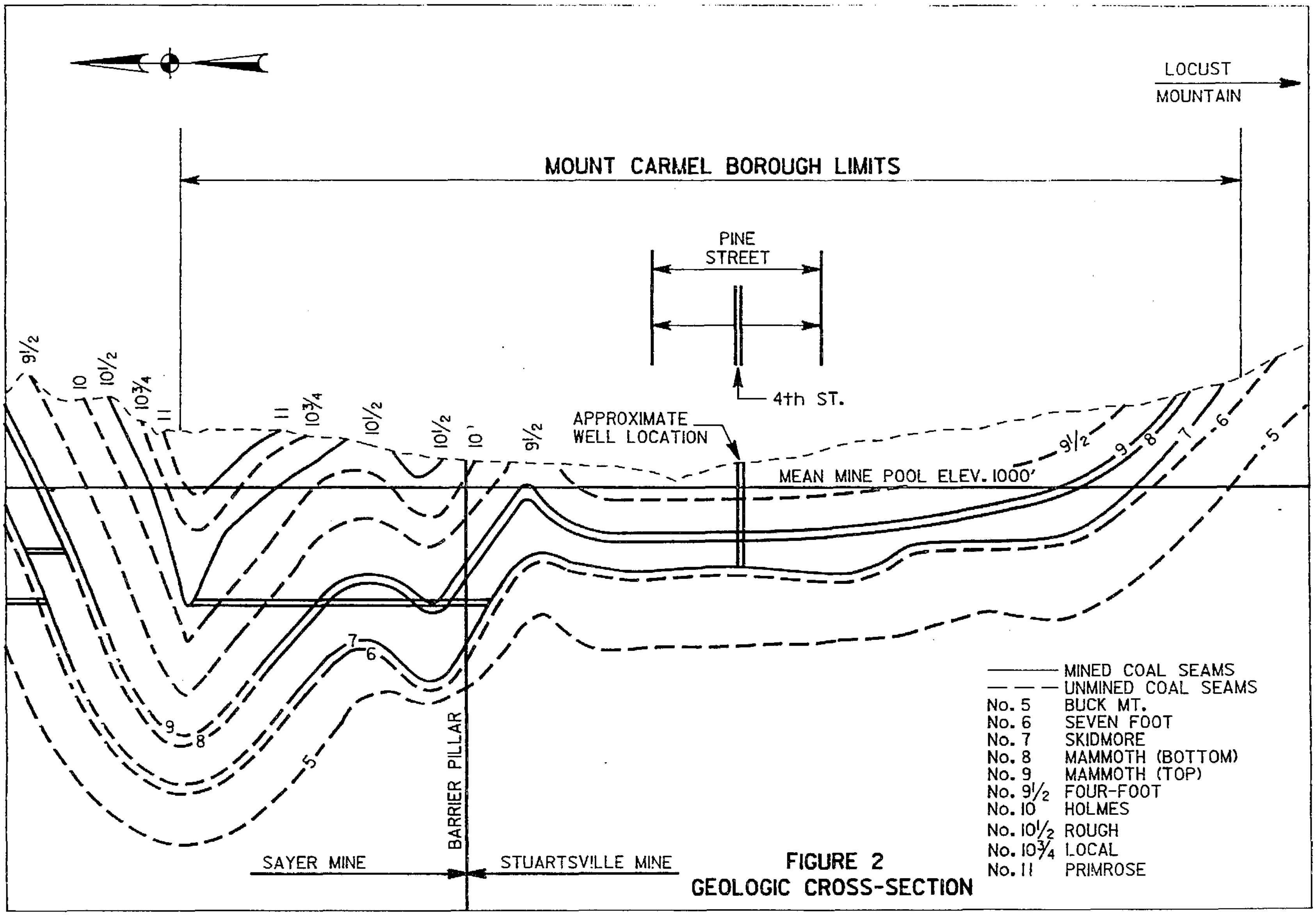

FIGURE 2
GEOLOGIC CROSS-SECTION

In conjunction with the springs, a test well was to be drilled in the vicinity of one of the three existing reservoirs. A well at any of these locations would be outside of the areas affected by mining.

The suitability of using the additional springs proved unfeasible. Seasonal variations in flow and the need for treatment for iron and manganese were cost prohibitive based on the overall contribution they would make to the system.

A 400 foot test well was drilled behind Reservoirs No. 1 and 2. The 48 hour pumping test indicated an inadequate yield of less than 35 gpm. Also, water quality analysis showed that treatment would be needed for the following parameters: Iron (4.93 mg/l); Manganese (0.37 mg/l), and turbidity (8 ntu). An economic evaluation of the costs involved for developing this sources proved that development was prohibitive. Following the attempt to develop the springs and a production well, the decision was made to investigate the feasibility of tapping an underground mine pool.

Methods for Mine Pool Investigation:

The mine maps for the Mt. Carmel area were studied and additional information as to their accuracy was obtained through discussions with the local mining inspector. Based on this information, it was determined that the target "aquifer" would be the Stuartsville mine pool. Thus, in order to define the area of the pool and access its aquifer potential, the seven tasks listed below were undertaken.

1. Literature research on various aspects of abandoned underground mine pools, including water quality, quantity and natural renovation processes.

2. Historical research into the underground mining industry of the Mt. Carmel area.

3. Detailed study of the available mine maps for the workings beneath the Borough and their relation to surface features.

4. Evaluation of data for the Mt. Carmel area mine pools maintained by the Pennsylvania Department of Environmental Resources (PA DER), and the United States Geological Survey (U.S.G.S.). This data includes long term seasonal variations in pool elevations, water quality and quantity.

5. Compiling the findings of Tasks 1 through 4 with the date and information obtained during the preliminary geologic and hydrogeologic evaluation.

6. Conduct a cost/benefit analysis based on the results of the above investigation pertaining to the economic feasibility of utilizing a mine pool as a potable water source.

7. Prepare a report on the results of the study and make recommendations for further action.

Results for the Mine Pool Investigation:

During the literature research, several published reports were found which concluded that the water quality of various mine pools in the anthracite region has gradually improved since the cessation of mining. (Stuart and Simpson, 1961 and Ladwig et al, 1983.) These studies also showed a definite stratification effect within the pools. Ladwig et al (1983) discussed that the more contaminated water tends to sink to the lower levels of the pool, while the better quality water was displaced upward by the denser, contaminated water. This effect was most apparent in areas not subjected to mixing factors such as the existence of multi-level connecting shafts, active dewatering operations, or in areas of large scale recharge zones.

Seasonal variations within the target aquifer were defined using U.S.G.S. monitoring wells. The U.S.G.S. maintains several observation wells in the Mt. Carmel area and has historic data relating to the static water level of the Stuartsville mine pool. The quarterly data recorded over the period of February 1975 to November 1982 showed ground water elevations reflecting the seasonal variations resulting from precipitation and evapo-transpiration rates. The period high was in February 1979 (1021 ft.) and the low was noted in February 1981 (992 ft.). (Refer to Figure 3.) Considering the estimated volume of 1.14 billion gallons of water contained in the pool, the anticipated withdrawal, and the ability to intercept various levels of the mine, it was felt that seasonal variations would have a minimal effect on this source. (Ash et al, 1949.)

Water quality was the next problem that needed to be resolved. A sample taken from a PA DER monitoring well in the northeast section of the Borough provided the following partial quality analysis: Iron - 0.08 mg/l; Manganese - 0.46 mg/l; sulfates - 90 mg/l. The conditions of the source raised many questions as to the ability to maintain the required quality standards for a public supply. There also was a greater risk of contamination from surface sources, as well as the potential effect of illegal dumping in abandoned boreholes and shafts. Thus, a complete analysis of the well waters for EPA priority pollutants and toxic materials was recommended.

Based on the evaluation of the information gathered, the decision was made to site a test well which would intercept the abandoned mine workings of the Stuartsville pool. It was decided that the optimum well site would be to the north of the synclinal axis, where it was not as deeply mined. The production of acid mine drainage would be less in these upper workings because of an overall reduction in both the reactive surface area of the mine, a shorter contact time with the available pyrite, and the dilution effect of the ground water recharge occurring from Locust Mountain. A study of this area indicated that there were no known areas of potential contaminant entry (i.e. boreholes, shafts, etc.). The mine maps were then

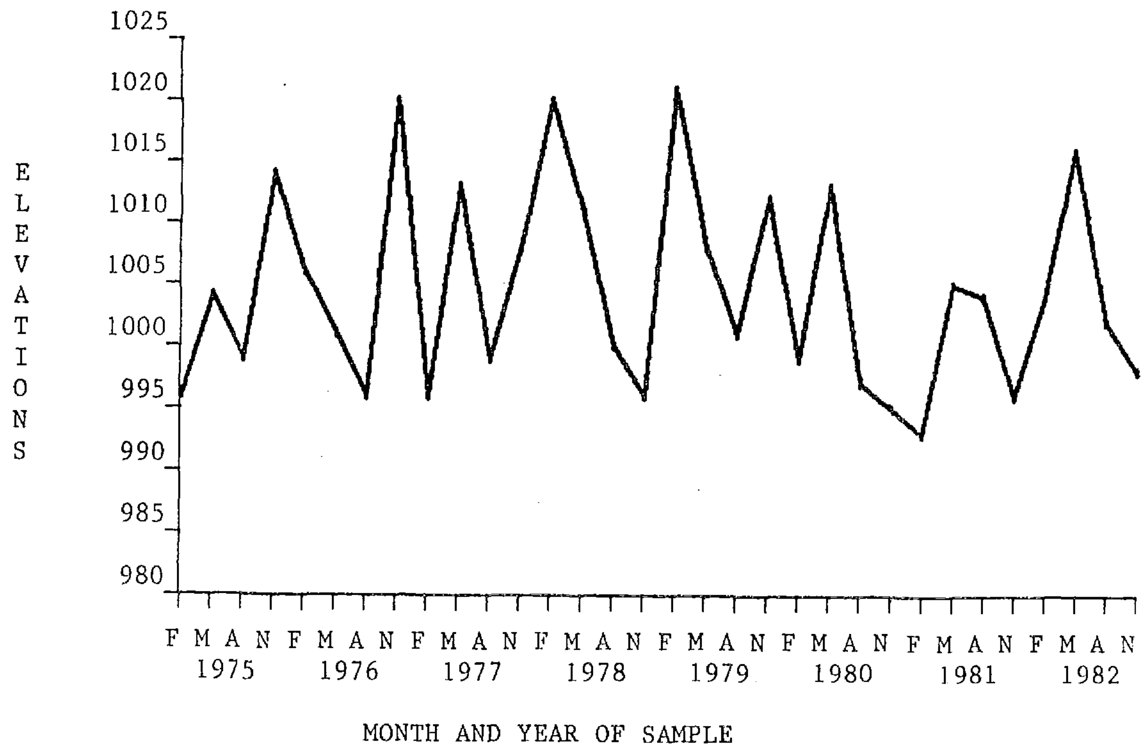

FIGURE 3

SEASONAL VARIATIONS IN MINE POOL
WATER ELEVATIONS

FEBRUARY 1975 - FEBRUARY 1982

correlated to existing Borough plats. A parcel owned by the Borough at Fourth and Pine Streets appeared to overlie a room of the mine.

In April 1984, drilling to intercept the Stuartsville mine pool at Fourth and Pine Streets began. At a depth of 50 feet, a fly ash material was encountered. A further check of the records showed that the area to the east was used for fly ash injection as part of an underground mine fire abatement project. This well was abandoned and a second well site was chosen 50 feet southwest of the first well. During the drilling of the second well, 28 feet of overburden and 60 feet of sandstone were encountered prior to interception of the first mine opening. The 25 foot void encountered at a depth of 88 feet was correlated to the Mammoth vein, the thickest vein in the anthracite region. According to the mine pool elevations, it was decided that this first void could be affected by seasonal variations and could be dry at various times during the year. The periodic dewatering of the void could cause the roof to collapse due to the removal of the support provided by the water. This subsidence would jeopardize the integrity of the well. The Mammoth vein was cased off with 12 inch ductile

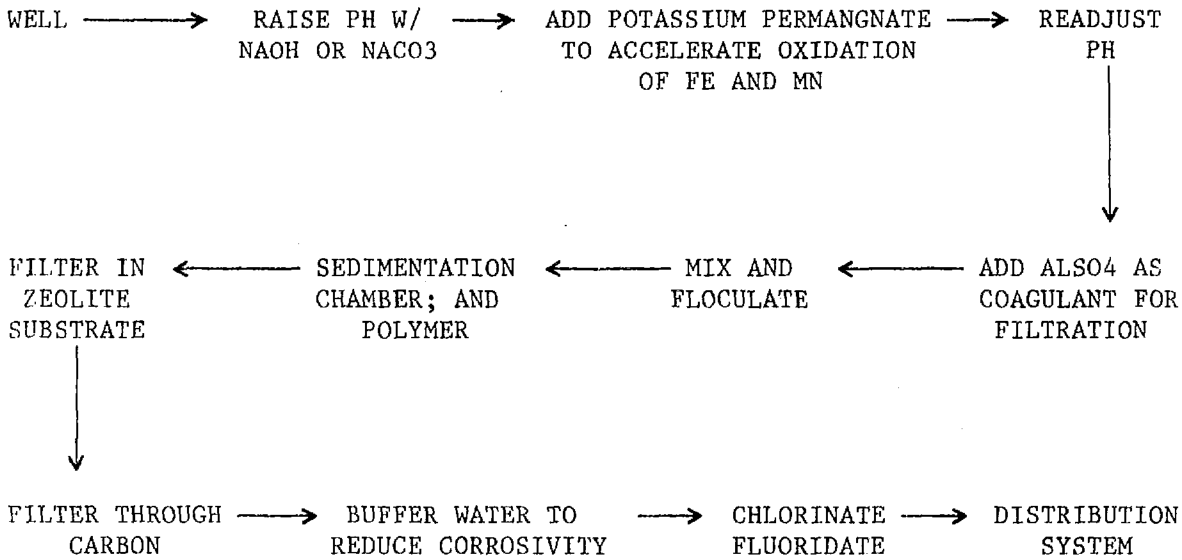

FIGURE 4

CONVENTIONAL FILTRATION OPERATIONAL FLOW CHART

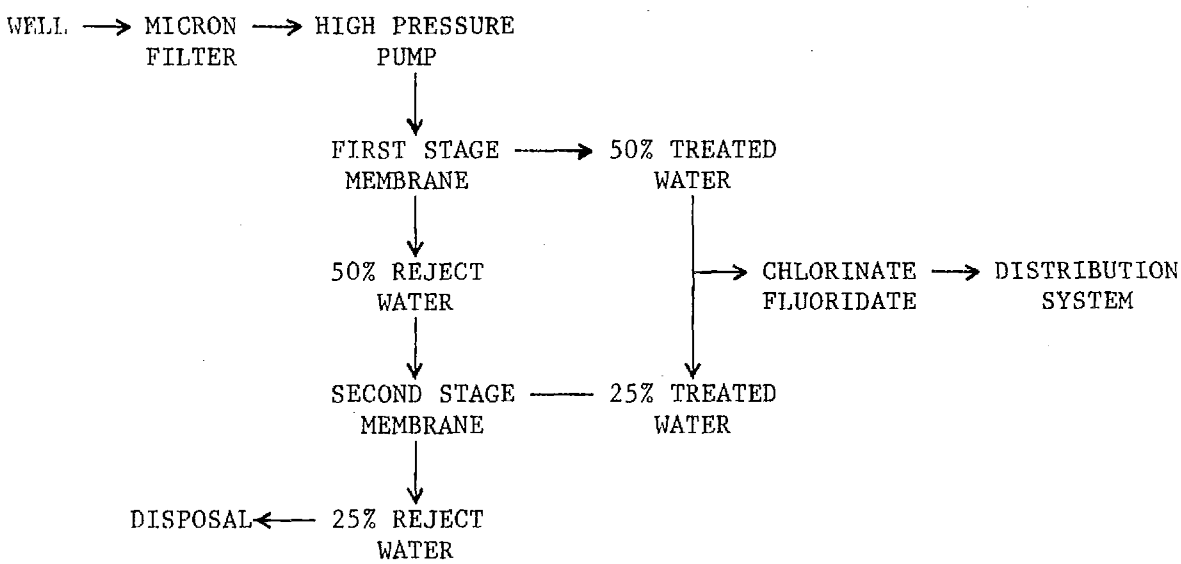

FIGURE 5

REVERSE OSMOSIS OPERATIONAL FLOW CHART

iron casing and grouted. Drilling continued for an additional 70 feet, until the void representing the Skidmore vein was encountered. The workings of this vein provided an opening of about seven feet in height. The total depth of the second well was 165 feet. Eight inch casing was set to a depth of 152 feet and the anulus was pressure grouted to seat the casing.

In October of 1984, a 72 hour pumping test was conducted in accordance with the PA DER requirements. The test began at a rate of 780 gpm, but decreased to 635 gpm due to an equipment malfunction. The maximum drawdown for the test was 3 feet. At the end of this 72 hour test, samples were taken and analyzed for the Safe Drinking Water Act parameters, primary and secondary drinking water standards, along with analyses for petroleum distillates and volatile organic compounds.

The water quality analysis showed high levels of iron (9.01 mg/l); manganese (5.75 mg/l); sulfates (380 mg/l); total solids (634 mg/l); turbidity (2.9 ntu); sodium (11.4 mg/l) and a borderline level for lead (0.045 mg/l). A second 72 hour pumping test was performed in April of 1985 at 890 gpm. A total drawdown of one foot was recorded during the test. Water quality results generally improved compared to the first test. (Iron - 1.41 mg/l; Manganese - 3.39 mg/l; Sulfates - 183 mg/l; Total Solids - 313 mg/l; Turbidity - 7.0 ntu; Sodium - 12.6 mg/l and Lead - less than 0.005 mg/l.) This increase in quality could be due to the purging of stagnate waters during the first test. Although the well pumped at 890 gpm (1.28 mgd), PA DER sets a "permitted yield" at 1.5% above the anticipated yield. This would allow the well to be pumped at a rate of approximately 596 gpm or 0.86 mgd.

With the test well completed and all the water quality data compiled, the next step was to determine the best treatment process for this source. The laboratory results for the second 72 hour pumping test indicated that only the parameters of iron, manganese and turbidity would need treatment. This could be accomplished by conventional filtration methods. A simple flow chart showing this process is presented in Figure 4.

The total installation costs of a conventional filtration system was estimated to be approximately $2 million, with a yearly chemical and operational cost of $43,000 per year.

As stated earlier, the nature of this source lends itself to the possibility of considerable changes in quality. In light of this factor, it was recommended that a reverse osmosis (ultrafiltration) system be implemented. This would provide maximum protection to the public in the event of a change in the water quality.

This process first involves passing the raw water through a 10 micron filter to remove any turbidity or particulate matter. Then the filtered, raw water (considered to be the concentrate solution in the process) is pressurized and forced through a semi-permeable membrane into a dilute solution. This results in a superconcentrated solution of dissolved solids and treated water which is ready for chlorination and eventual consumption. (Refer to Figure 5.) The process is capable of removing 95% of the dissolved solids in the range of 200 ppm to 10,000 ppm. Twenty-five percent of the raw water entering the system is lost as superconcentrate. The

Borough of Mt. Carmel would, therefore, need a reverse osmosis treatment plant capable of handling 750,000 gallons of water per day to maintain their daily water usage. Depending on the compounds being treated, the reject water should be able to be disposed of in a sewage treatment plant capable of accepting industrial effluent. Such treatment is available to the Borough.

The estimated 1985 cost for the installation of a reverse osmosis system was 2.72 million dollars. It was estimated that a loan for that amount could be obtained at 6.5% interest to be paid back over 25 years. This would result in an annual loan payment of $223,000. The estimated operational costs (electric and process chemicals) were $102,000. In order to finance the replacement of the filter membranes (every 3-5 years), an interest bearing account (7%) would be established. This would amount to $12,600 per year. The final cost consideration would be the salary of a certified plant operator ($23,000 per year). (These costs do not reflect the treatment costs for the superconcentrate.)

The total yearly costs to the Borough for implementation of a reverse osmosis treatment system to be used to provide a potable water supply from the abandoned mine workings beneath the town would be $361,000. This would also provide total independence from the local water company and could provide the opportunity to gain additional revenue through sale of surplus water to neighboring communities. The individual residential consumers would pay an average of $81.61/year and the industrial/commercial users $249.00/year or only 52% of what they have been paying to have the Authority purchase water and maintain the storage and distribution system.

Conclusions:

The utilization of abandoned underground mine pools as a potable water source should not be thought of as a panacea to the water problems being faced by communities in the coal regions of the eastern United States. There are drawbacks and problems which must be addressed. However, given the proper hydrogeologic and economic circumstances, the use of these vast underground reservoirs does provide a viable alternative which should be considered.

The well drilled for the Borough of Mt. Carmel, Northumberland County, Pennsylvania, which intercepted an underground anthracite mine pool did prove to be treatable for use as a potable water source. The well was pump tested at 890 gpm and treatment parameters could be handled by a reverse osmosis treatment system. Even with the substantial costs of treatment, it was calculated that the Borough's customers could save approximately 48% on their annual water bills by developing and treating water from the mine pool.

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BIOGRAPHICAL SKETCH

Edward A. Dobson, P.G.

EDWARD A. DOBSON received his Bachelors of Science degree in geology from the University of Pittsburgh-Johnstown in 1980. While an undergraduate, Mr. Dobson worked as Soil Mechanics Technician for a Harrisburg, Pennsylvania engineering firm.

In October of 1980, he was hired as a staff geologist for Benatec Associates, an engineering/architectural firm located in Camp Hill, Pennsylvania, and in February of 1985, was promoted to the title of Engineering Geologist. Mr. Dobson has been pursuing graduate studies in engineering geology and hydrogeology at Millersville (Pennsylvania) University.

While with Benatec Associates Mr. Dobson has gained varied experience in the fields of engineering geology and hydrogeology. His primary responsibilities include the determination of adverse geotechnical and hydrogeologic consequences resulting from highway and building construction, water supply and flood control dam installation, coal mine permitting and reclamation and hydrogeologic investigations for industrial and municipal water supplies.