ArcGIS Spatial Analyst Helps Model Water Availability During the August 14th Blackout

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Abstract

The Cleveland (Ohio) Division of Water has four main pump stations that deliver treated Lake Erie water to approximately 1.5 million customers. At 4:11 pm on August 14, 2003, these pumps were knocked out by the blackout that hit most of the Northeast United States. ArcInfo 8.3 (Spatial Analyst extension), elevation data, and hydraulic grade information taken at Cleveland Water facilities were utilized to produce hour-by-hour raster plots of water pressure and estimates of the number of customers without water from the time of the blackout until service was restored. With these plots, the impact of the outage could be realized on a detailed level, both spatially and temporally.

Introduction

Over the last 20 years, Geographic Information Systems (GIS) have become commonplace tools for both public and private utilities. To have a map of the exact location of an asset only a few mouse clicks away saves time spent looking up indexed paper-based maps. GIS also gives engineers and technicians more flexibility in developing ad hoc maps as well as being an efficient robust analytical tool. After the blackout of August 14, 2003, the Cleveland Division of Water (CWD) realized the value of modeling in GIS to recreate the events in the water system during the crisis.

The Blackout

At 4:11 p.m. on August 14, 2003, power went out across a large portion of the Northeastern United States and Canada, leaving 50 million people without power. In the greater Cleveland area it took nearly 30 hours to fully restore power to all customers. The Blackout dramatically affected the lives of Cleveland area residents as well as the Cleveland Water System.

The Cleveland Division of Water (CWD) is the provider of drinking water to 1.5 million people in the greater Cleveland area. Every drop of water treated and distributed by CWD must be pumped to customers resulting in a heavy dependence on electricity.

This is a result of utilizing Lake Erie as CWD's source of water. Lake Erie is the lowest elevation in the region and CWD's service area increases in elevation as you travel south from the lake. Consequently, without electricity, CWD lost the ability to produce and distribute drinking water (Halperin and Haddad, i).

Over the years CWD has engaged in various planning efforts in order to assure its customers a reliable supply of safe drinking water. Planning has focused on a number of areas including the redundancy and reliability of the electrical supply. CWD is prepared to deal with localized, short-term power outages as CWD operates a highly redundant and reliable water system that can accommodate any one station being down for a limited period of time. During the planning process, CWD considered the possibility of a total power failure, but deemed it unlikely due to the reassurances received from its power suppliers. CWD now recognizes that its dependence on the national power grid is a vulnerability that must be addressed (Halperin and Haddad, ii).

The Blackout severely impacted CWD's ability to provide water service to its customers. Approximately 80% of CWD's distribution system experienced partial water outages. The worst hour of impact varied among service districts, overall, the most critical period was at 4:00 AM August 15, 2003, when 14% of CWD's customer accounts were without water and another 23% experienced pressure less than 20 psi. CWD's Low Service District, for the most part, was able to maintain water service and pressure as a result of available gravity fed storage. Consequently the lack of water and compromised water quality in the remainder of the distribution system caused CWD to issue a boil advisory that affected approximately 80% of its customers (Halperin and Haddad, i).

In addition to heavy dependence on electricity for operations, CWD realized its reliance on important tools including: the computer network, the Hydraulic Model, Geographic Information System (GIS), Supervisory Control and Data Acquisition (SCADA) system, desktop computers, internet access, and email for crisis management. CWD was forced to manage the Blackout event without these essential tools due to the fact that CWD's local area computer network and servers had to be powered down for danger of overheating. These tools would have provided CWD with state of the art capabilities to analyze, control and perform projections about the Cleveland Water System (Halperin and Haddad, iii).

By Friday evening, water service was restored to all CWD customers with 21 hours being the longest period any customer was without water service. Restoration of the water system was completed and the system was returned to normal operation by August 16, 2003 at 12:00 PM.

The Cleveland Water System

The Cleveland Division of Water (CWD) provides drinking water service to approximately 1.5 million people in the greater Cleveland, Ohio area. Its service area covers 640 square miles in Cuyahoga County and portions of Medina, Summit and Geauga Counties. CWD provides direct water service to approximately 440,000 customer accounts in the City of Cleveland and sixty-five suburban communities. In addition, CWD provides wholesale water service on a continuous basis to six suburban communities and on an emergency back-up basis to eight suburban communities.

The CWD water system is a complex network of water treatment plants, pump stations, ground-level storage tanks, elevated towers, transmission mains, local distribution mains, pumping districts, and pressure regulated zones. The CWD water system is composed of four water treatment plants. Each treatment plant has its own intake 2-5 miles out in the lake in addition to a primary pumping station and raw water pump station. The rest of the water system is made up of 11 secondary pump stations, 3 reservoirs, 11 elevated towers, 7 ground-level storage tanks, 420 miles of transmission mains, 4900 miles of distribution mains in the direct service communities, 350 miles of distribution mains in the master meter communities, 9 pumping districts, 83 regulated hydraulic zones, and 4 surge protection towers (Halperin and Haddad, 2-1).

The capacity of a water system can be measured in a number of ways. When describing system capacity, CWD typically refers to treatment, pumping, and storage capacities. The total water treatment capacity of the four water plants combined is 537 million gallons a day (MGD). The total pumping capacity of the CWD system is 500 MGD with daily average pumping at 250 MGD (Halperin and Haddad, 2-2).

The topography of an area will generally dictate the hydraulics of any water system. In the Cleveland metropolitan area, Lake Erie is the lowest elevation at approximately 574 feet above sea level. In general, the elevation of the Cleveland area increases the farther south one travels from the lake. Since CWD's source of drinking water is Lake Erie, treating and distributing drinking water depends entirely on pumping.

As a result of the topography of the area, the CWD water distribution system evolved into nine distinct pumping districts, whose boundaries are generally governed by elevations. It is also important to note that the greater Cleveland area has two major rivers that impact the geography of CWD's distribution system: the Cuyahoga River and the Rocky River. These rivers create natural physical divides that have had a significant impact on how CWD's pumping districts were developed (Halperin and Haddad, 2-2).

The Cleveland Division of Water has invested heavily in its infrastructure during the last 20 years. This investment reflects the Division's concern for system redundancy and reliability. CWD maintains more than one feed to each service district with adequate transmission mains to deliver the water. This reflects CWD's philosophy that no single point of failure should disrupt service for a significant period of time during a normal non-summer day operation.

GIS Blackout Analysis with Spatial Analyst

Once the distribution system returned to a normal operating state, engineers began analyzing what happened in the system. GIS played a major role in this task. It was decided that it would be helpful to attempt to reconstruct the system condition hour-by-hour from 4:11p.m. Thursday the 14^{th} until the system was back under control approximately 24 hours later. The goal was to create a system timeline indication the number of customers affected by system pressure for each pumping district. CWD engineers and analysts utilized Environmental Systems Research Institute’s (ESRI) ArcGIS 8.3 (with the spatial analyst extension) software, hydraulic formulae, a digital elevation model (DEM), mini-GIS data, electronically and manually logged operational data, and hourly pressure estimates for every location in the CWD distribution system to accomplish the task.

The first step was to organize the operation data. Tank levels, pumpage reports, and valve states were taken from all reservoirs, pump stations, and elevated storage tanks. Some data was collected from the Supervisory Control and Data Acquisition (SCADA) system. This system typically allows engineers to examine operational information in real-time from electronic sensors at hydraulically significant locations in the treatment plants, pump stations, storage tanks, and in the distribution system. During the blackout, not all SCADA sensors continued to report due to the power failure. Operators also log data manually as part of their normal routine. They continued monitoring their stations while SCADA was down and the power was out.

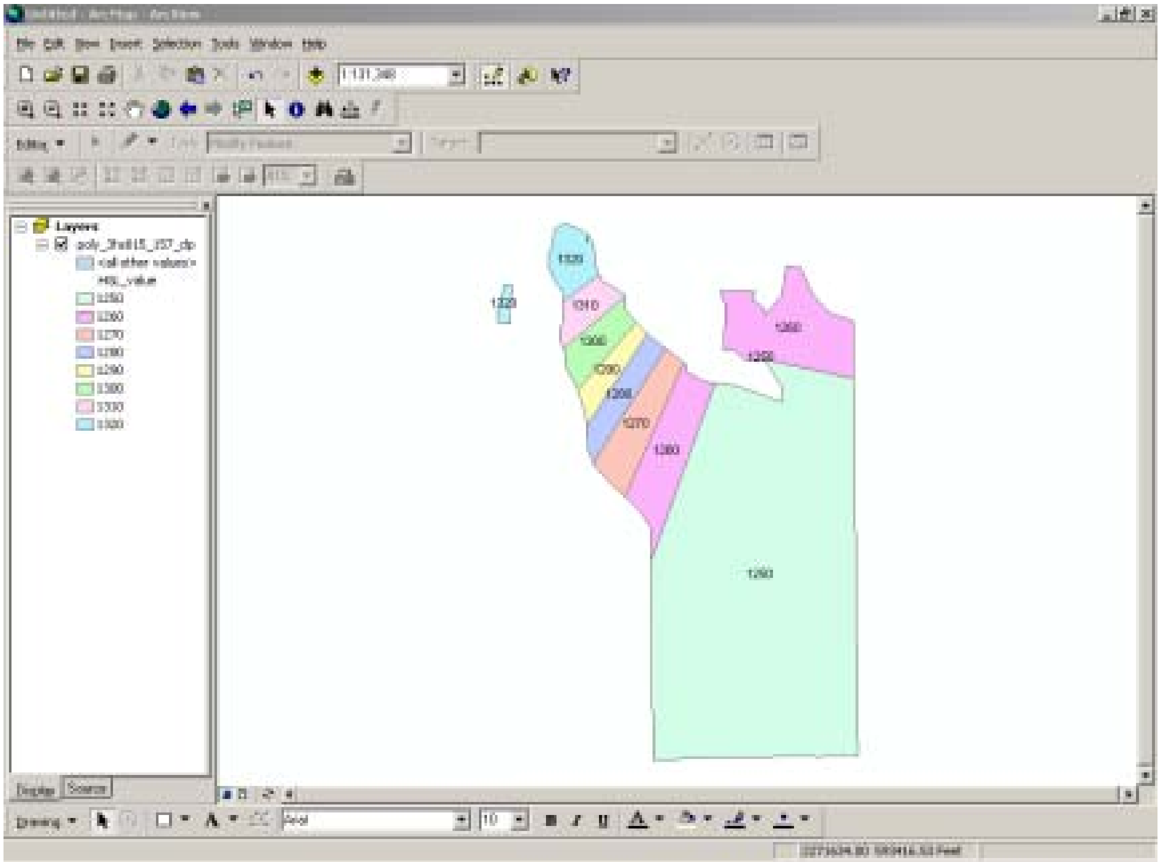


Figure 1. Hydraulic Grade Polygons Based on SCADA and Field Measurements

Using this information, the head hydraulic engineer generated contour maps of constant water elevation, or hydraulic grade. GIS analysts created blank maps of each pumping district for the engineer to manually draw the contour lines on. The engineer took the known hydraulic grades at the stations and used his experience and engineering judgment to estimate the shape and direction of the contour lines. The contour interval used was typically 10 feet. Using this, a GIS analyst created polygon layers for each hand-drawn hydraulic grade contour map (Figure 1). A map was created for each of the nine pumping districts for each hour and for any specific occurrence that would instantaneously change the system hydraulics, such a pump turning on or off. The total number of maps was approximately 250.

The hydraulic grade polygons were then converted to a raster grid dataset with a cell size of 100 feet using the Features to Raster function in Spatial Analyst. The hydraulic grade grid was then combined with the USGS DEM utilizing the following formula, [(Hydraulic Grade, (ft)) – (Water main elevation, (ft))] / 2.31 = Pressure (in psi), within Spatial Analyst's raster calculator to derive the estimated pressure at any location. The pressure raster grid was then reclassified into ranges representing a graduation of 10-psi for map production (Figure 2).

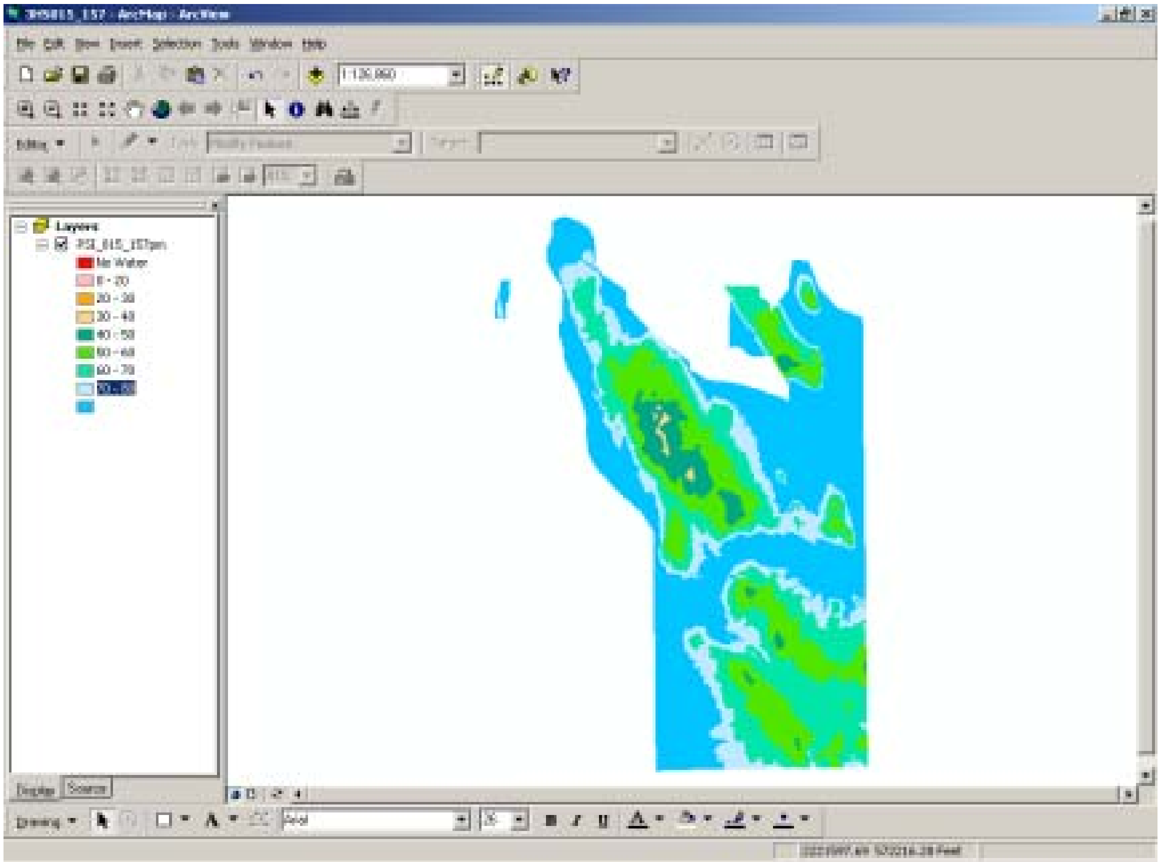


Figure 2. Pressure Raster Grid Generated from DEM and Figure 1

The final step was to use the address matching tools within ArcGIS to geocode the customer database, built from 2002 billing records, to estimate the number of customers with low pressure or no pressure for the hour being analyzed. Once the customers were represented in the GIS the raster pressure data was converted to polygons so that the 'Select By Location' tool within ArcGIS could be used to query how many customer points fell within the low pressure range (<20 psi), or the no pressure range (<0 psi) (Figure 3). This analysis was repeated for each of the maps drawn by the hydraulic engineer.

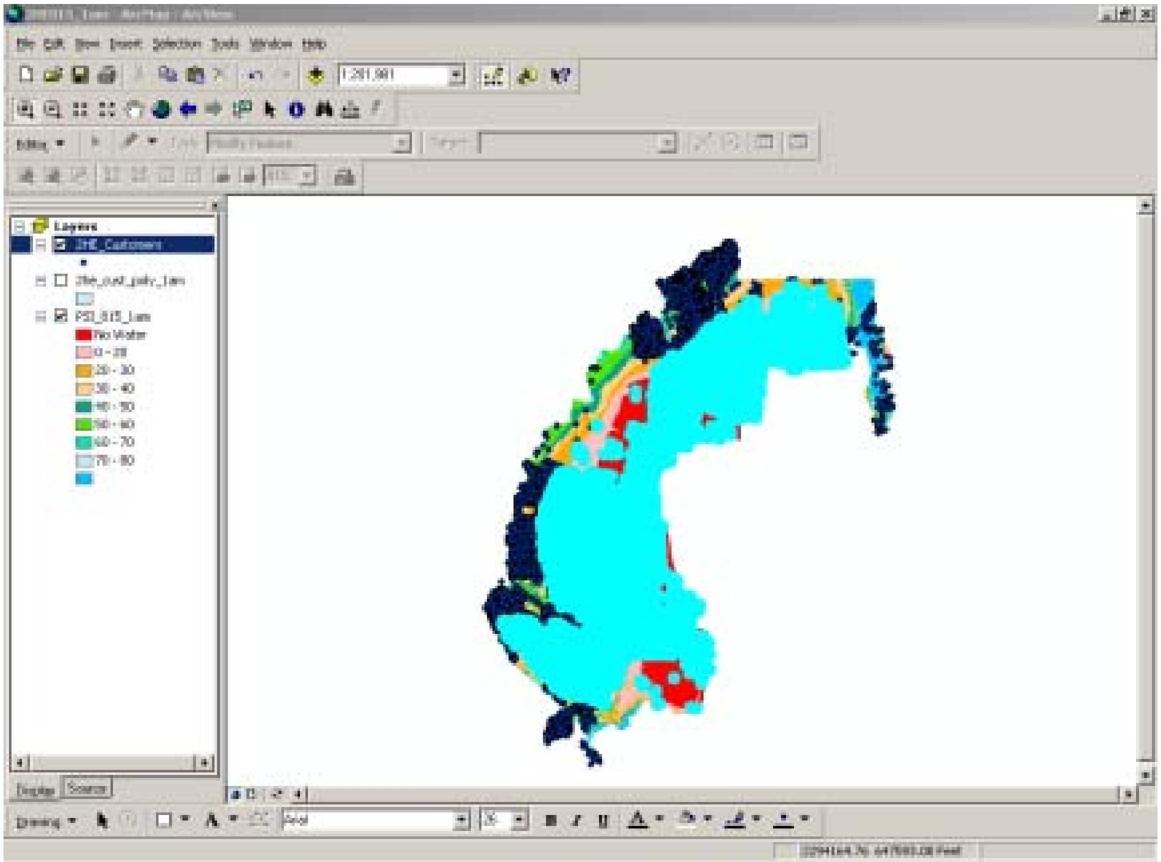


Figure 3. Selected Customer Account Points in Second High East District where Pressure is <20 psi

Once this was complete, composite maps showing all pumping districts for each hour were developed to visualize the hydraulics system-wide (Figure 4). Figures 5 and 6 show the conditions in the distribution system prior to the outage and the pressure conditions at the 4:00 AM hour on August 15, where the largest number of customers were affected.

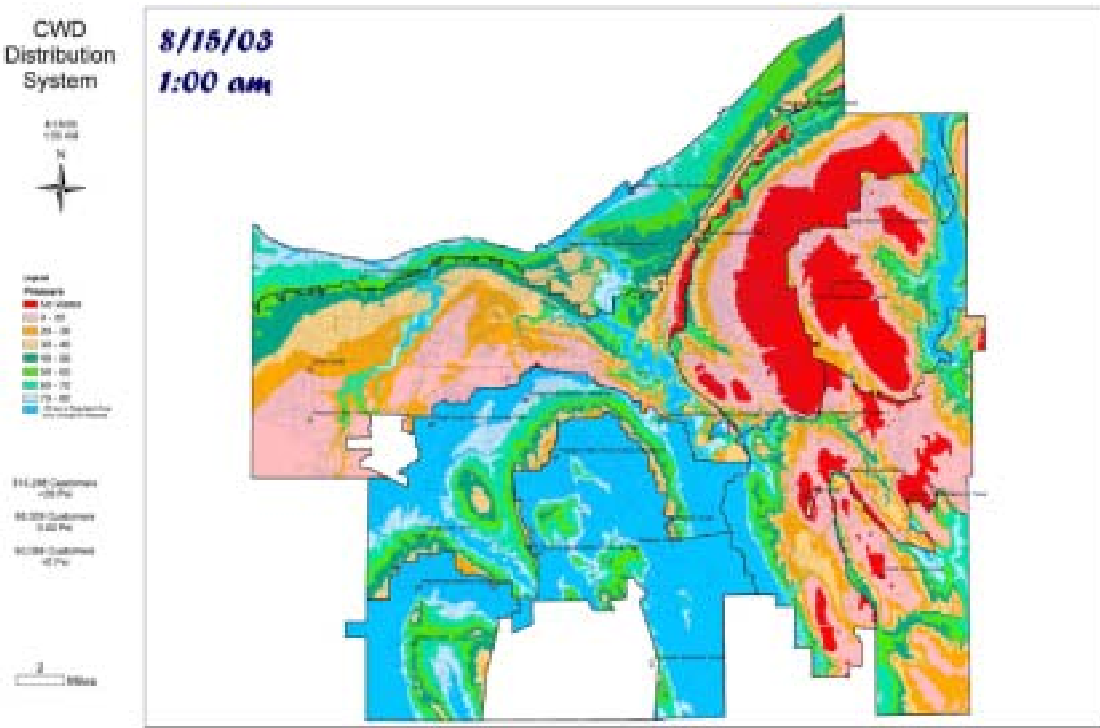


Figure 4. Systemwide Composite Pressure Grid Map with Customer Counts

Conclusions

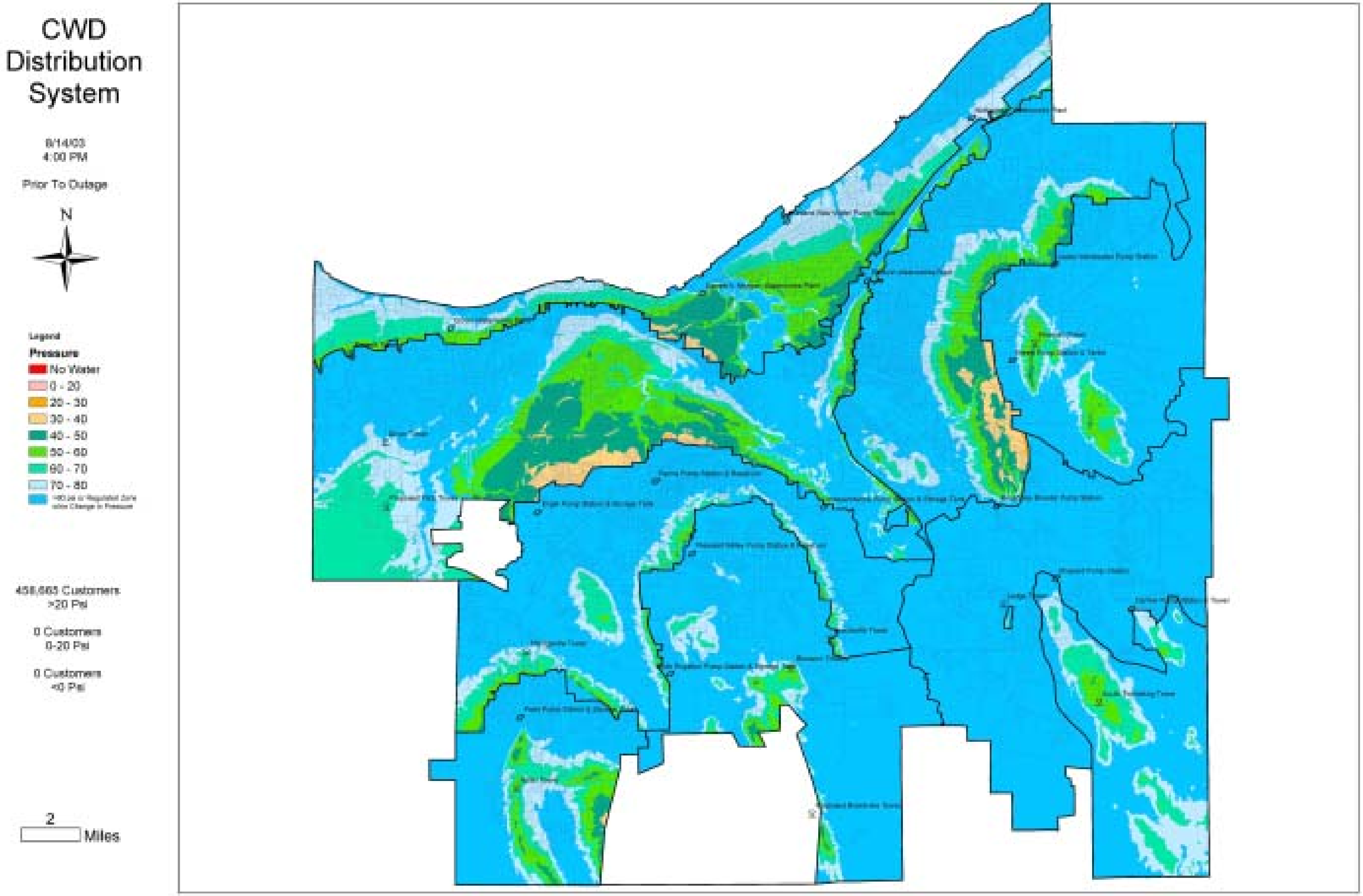
The sequence of composite maps created from the GIS analysis gave decision-makers a good idea about the amount of existing storage capacity in the distribution system and estimates of what additional storage would be needed. The customer counts helped decide which stations critically needed backup power sources in case of the reoccurrence of such a power outage. Without the GIS, this information would have taken much more time to develop. The spatial analysis capability of the GIS may have also led to more accurate results than those that would come from similar calculations done by hand. With confidence in the results of the study, the Division of Water was able to deliver a specific plan to the Mayor for improvements to the distribution system that would reduce the chance for customers to be out of water if another blackout fell upon the city.

Works Cited

Halperin, Robin and Haddad, Pierre. Blackout 2003: The Cleveland Division of Water's Experience. 2003. Cleveland Division of Water. Cleveland, Oh: [n.p.], 2003.

MAPS

Maps:


CWD
Distribution
System
8/14/03
4:00 PM
Prior To Outage
N
Legend
Pressure
No Water
0 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
458,665 Customers
>20 Psi
0 Customers
0-20 Psi
0 Customers
<0 Psi
2
Miles

CWD Distribution System

8/15/03
4:00 AM

N

Legend

Pressure

- No Water
- 0 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80

290,617 Customers
>20 Psi

102,906 Customers
0-20 Psi

65,142 Customers
<0 Psi

2
Miles