USE OF MODELING IN DECISION MAKING
FOR WATER DISTRIBUTION MASTER PLANNING

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Abstract. One of the primary uses of water distribution system models is to identify problems and evaluate alternative solutions to existing or anticipated problems in water distribution planning. While numerous papers have been written on use of optimization for design, optimization techniques rarely fit real problems. Rather than discuss the generalities of modeling, this paper uses the Comprehensive Planning Study (CPS) (i.e. "master plan") of the water distribution system for the Pennsylvania American Water Company's (PAWC) Wilkes-Barre/Scranton system to illustrate the kinds of issues that drive modeling efforts in a master planning study.

Background

Master planning studies for water distribution system are one of the mot common uses of hydraulic pipe network models. Given some range of estimates of future demands, the models can be used to test different pipe, tank and pump sizes and locations to determine which projects can meet projected needs with the greatest net benefits.

In examining the literature, the conclusion that could be drawn is that the use of optimization is widespread. In reality most water distribution planning studies do not use optimization because optimization algorithms do not completely address the problems. This has been pointed out a few times by the first author (Walski, 1995; Walski, in-review) and discussed by deNeufville, Schaake and Stafford (1971). Rather than discuss generalities, this paper focuses on the details of a particular master planning study—the Comprehensive Planning Study for the PAWC's Wilkes-Barre/Scranton System.

System and Model Description

PAWC's Wilkes-Barre/Scranton system is served by 10 water treatment plants treating water for 133,000 customers with deliveries on the order of 50 MGD to 50+ municipalities in four counties. The plants receive water from reservoirs located in the surrounding mountains while most of the customers are located in the Susquehanna and Lackawanna River valleys in northeastern Pennsylvania. Most of the water is delivered to customers, not by pumping, but through a series of pressure regulators (pressure reducing valves), which cut the pressure to customers in the valleys. There are 63 pump stations, 84 pressure regulators, 42 tanks and 110 pressure zones in the system.

There has been very little population growth in the area and water production has decreased in recent years due to a program to reduce unaccounted-for water. A great deal of the piping in the system was laid during the early 1900s and therefore most of the issues in this system are focused on reliability and rehabilitation rather than growth, although growth is the issue in several areas. This study provided a good sampling of the range of problems a water utility can face in a master planning study.

Over 40 water distribution system projects were identified in this study. Roughly half were projects that did not need modeling (e.g. conducting a pump efficiency study, replacing specific plastic service lines). The remainder required some hydraulic analysis, which was performed using the WaterCAD program by Haestad Methods, Inc.

Because of the way the system evolved, there are really seven distinct service areas, which in general, can be modeled individually. Models with somewhat less than 1000 pipes were constructed for each of these service areas. A larger model of the entire Wilkes-Barre/Scranton system, with just under 2000 pipes, was constructed to study water transfers between the service areas.

Use of Modeling in Distribution Planning

One might think that water distribution system planning would be a fertile area to apply some type of optimization. However, this study illustrate the wide breadth of problems that are faced in just one planning study and highlight the difficulty in developing generalized optimization approaches to planning. Most of the optimization methods presented in the literature are based some of the following assumptions:

1. Future demands are accurately known in terms of quantity, location and timing,
2. There are a large number of alternatives which are fairly similar except for different pipe sizes,
3. Any hydraulic capacity in excess of the minimum required to meet design criteria is to be eliminated,
4. Problems cannot be isolated (i.e. all pipes must be sized simultaneously),
5. Costs are known with precision,
6. No budgetary constraints exist,
7. No one understands where the weaknesses in the system are located.

As the examples given below will demonstrate, very seldom are any of these assumptions valid. What is needed in modeling is the ability to simulate a very wide range of demand loadings and make accurate assessment of the costs and benefits of alternatives.

The planning process in this study (and most others) did not consist of an engineer receiving a set of known demands, deciding where problems exist (or may occur in the future) in the distribution system and then solving those problems. Instead, the process consisted of the engineers formulating a list of problem areas and meeting with operations personnel for a series of brainstorming sessions in which problems were discussed and alternatives were formulated. The engineers then developed solutions, tested them using the models for a wide range of conditions and prepared cost estimates. They then meet with operations and management personnel to discuss the desirability of the alternatives. In most cases, the decisions boiled down to a comparison of two or three promising alternatives, and pipe size was almost never the key issue. For example, how many customers should be in a pressure zone before a tank is needed, or should a line that is difficult to repair be replaced? The discussions generally focused, not on which alternative was least costly, but on the level of benefits from each alternative.

A good way to understand the use of modeling in planning studies is to take some examples of problems solved using models. A few examples are presented in the following sections to illustrate how models were used.

Lake Scranton Second Feed. The Scranton Area (Lake Scranton) water treatment plant serves Scranton and surrounding municipalities through a single, old, cast-iron 48 in. pipe laid in a tunnel through a mountain (Figure 1) . If this line should fail, tens of thousands of people would be without water immediately with several thousand more losing water within hours as tanks drained. A second feed from Lake Scranton to the City of Scranton was the logical way to provide this reliability. The logical route for this pipeline was along a stream, Stafford Meadow Brook. This pipeline route would pass near and serve a fast growing portion of the system, called Glenmaura.

Using a set of extended period simulations, it was determined that the second feed line did not need to be 48 in. but could be 36 in. with a 16 in. spur off to Glenmaura. However, in spite of the benefits of the pipeline, the cost of this proposed pipeline (approximately $7 million) made it unlikely that it would survive the budget process.

The driving force behind this project is the potential outage that could be caused by a failure of the 48 in. pipe in the tunnel. In reviewing the condition of the tunnel, the proposal was made that the second feed line could be eliminated based on improving the reliability of the tunnel carrying the 48 in. pipe. The possibility of installing a 36 in. pipe alongside the 48 in. in the tunnel was investigated but there was not sufficient room. The engineers determined that there was space for two 24 in. pipes in the tunnel and these two pipes could carry the needed flow if the 48 in. was out of service. (The old 48 in. was oversized for current and projected flow.) Once the two 24 in. pipes were placed in the tunnel, the tunnel void space would be filled with flowable fill to protect the pipes from collapse and provide a passive environment for the old cast iron pipe.

While the tunnel work cost roughly $2 million compared with the $7 million Stafford Meadow Brook route, additional capacity had to be provided to the Glenmaura area. This would need to be provided by a 16 in. pipe from the outlet side of the tunnel to Glenmaura at a cost of $1.

The discussions regarding this project focused on the issues of: 1) whether the two 24 in. pipes could meet peak day demand if the 48 in. was out of service and 2) whether there was a significant risk that construction workers would accidentally knock the 48 in. pipe out of service while installing the 24 in. pipes and flowable fill.

Brownell – Forest City Interconnect. The Brownell and Forest City service areas are two independent service areas separated by roughly two miles of undeveloped land along a state road. Because the Forest City treatment plant only has a single filter and clarifier, the lack of redundancy made the water company uncomfortable about the reliability of the system. An interconnection with the larger Brownell system would increase the reliability of the Forest City service area (Figure 2). Conversely, the Forest City system has a very large source reservoir such that in time of drought, it could provide water for the Brownell service area.

The Forest City hydraulic grade line (HGL = 1820 ft) is 240 ft higher than the Brownell gradient (HGL = 1580 ft). Pumping and pressure reduction would be required at the interconnection. The first issue was whether to cut the pressure between the two zones in one step or two (i.e. should there be a 1700 ft zone). It was decided to connect the two zones through a single pump/PRV station, which meant relatively high pressures at the Brownell end of the pipeline. The size of the pipeline would be 12 in. even though this would result in fairly low water velocity. It was anticipated that growth would occur along the pipeline and demands would increase once the pipeline was installed.

Model runs indicated that pressures would be poor on the suction side of the Brownell/Forest City pump station. To correct this problem the 12 in. suction line needed to be extended back to a 10 in. pipe in the Brownell system. The accuracy of model calibration on the Brownell side of the pump station was still in question, so additional fire hydrant flow tests were conducted in the Brownell system to better identify any bottlenecks in that part of the system. The flow tests indicated that all the flow into the Brownell high service pressure zone (the zone connected to the pump station) passed through a single old 12 in. line. The first reaction was to parallel or replace this old line. However, later discussions identified another pipeline route, which takes the load off this pipe and delivers water to the main portion of the pressure gradient more effectively. While this route takes much of the load off the bottleneck section it is longer. The cost of the longer route was somewhat offset by the fact that it will be laid in an abandoned railroad bed which should reduce laying cost.

White Oak Pressure Zone Feed. The White Oak pressure zone has a hydraulic grade line of 1264 ft (Figure 3) and is fed from three pump stations:
Sturgis – suction from Dunmore No. 7 zone (HGL = 1074 ft)
Riverside – suction from Dunmore No. 1 cut one (HGL = 1110 ft)
Powder Mill - suction from Gordon Ave. zone (HGL = 1230 ft)

The Powder Mill zone does not have as strong a source of supply behind it so it can only be a backup source. The Sturgis source has the strongest supply so it is the preferred use even though in terms of energy cost it is the lest desirable. Attempts to draw more water from Sturgis to serve projected growth showed that extensive work would be needed back in the suction side to reinforce the system. A similar problem existed with the Riverside pump station.

The solution came from realizing that there is another pressure zone Dunmore #1 uncut (HGL = 1240 ft) which has plenty of capacity and a head that would require very little energy for pumping. This alternative involves additional pipe installation but this pipe laying will be laid through undeveloped land that appears ready for industrial development. The key questions in this analysis were: 1. the timing of the Dunmore No. 1 pipeline, and 2. whether there would be a significant drop in pressure near the discharge side of the Sturgis pump station if it was no longer operated.

Hanover Crossing. The Flat Road pressure regulator (PRV) serves several pipelines, in particular one, which crosses to the east side of the Susquehanna River to Wilkes-Barre, and another which crosses the river a few miles to the south to serve Nanticoke (Figure 4). On the east side of the river, the Nanticoke and Wilkes-Barre portions of this pressure zone do not interconnect. The gap between the two parts of the system is primarily abandoned strip mine land that is being developed into a large industrial park, Hanover Crossings, including a new exit off the state limited access highway.

The largest pipes to both the Wilkes-Barre and Nanticoke sides of Hanover Crossing are 10 in. pipes, yet the industrial park has the potential for attracting large water using industries. The main issue was how to size the piping in the industrial park in a way that would be flexible without making major investments in the distribution grid until a large water using industry actually arrived.

While an 8 in. backbone of pipes through the industrial park would meet minimum needs and a 12 in. had good capacity, the decision was made to install a 16 in. pipe so that the industrial park could meet the most optimistic of future demands. The 16 in. pipe is now being laid from the Wilkes-Barre side of Hanover Crossing to the first tenants. If a large water user arrives it will need to be looped into piping on the Nanticoke side to provide better capacity. If the most optimistic plans for growth materialize, the distribution grid feeding the new 16 in. pipe will need to be reinforced.

If the industrial park has a large number of warehouse customers or industries with high peak demands, the normal demands can easily be met from the existing system while meeting peak demands for fire or industrial peaking would be problematic. A storage tank in the industrial park was considered, however, it was decided that it would be better to run a third feed, this one from a nearby higher pressure zone with a storage tank (Sugar Notch) to provide this water during peak demands through a PRV.

Gordon Ave. Zone. The Gordon Ave pressure zone is fed by the Gordon Ave regulator. It has some high pressures along the Lackawanna River and some low pressures in nearby high elevations. It serves two pump stations, the lower Rushbrook station, which runs continuously and the Powder Mill station, which is a backup feed to the White Oak zone mentioned earlier. The challenge here was to raise the pressure in the high areas without adversely affecting the low areas, while proving more reliability to both the Gordon Ave and lower Rushbrook service areas.

The key to solving the problem was to take high-pressure water from the inlet side of the Gordon Ave regulator (along Brooklyn Ave.) and deliver it to the high areas through a new main. This shift in the pressure zone boundary makes it possible to eliminate the lower Rushbrook pump station. Installing a PRV near the lower Rushbrook pump station provides a backup feed to the Gordon Ave zone. A final step to improve reliability is to install a PRV at the Powder Mill pump station to deliver water from the White Oak pressure zone to the Gordon Ave. zone. The only pipe sizing decision involved is that of the Brooklyn Ave. pipe which could have been an 8 in. given current demands but will be a 12 in. to allow for growth and improve fire flows.

Summary

The examples given above are typical of nearly all of the dozens of distribution system hydraulic design issues found in the Wilkes-Barre/Scranton CPS. In each case some or all of the assumptions made in typical pipe sizing optimization problem described above are violated. In each case finding the most desirable solution did not involve exhaustively enumerating huge numbers of alternatives, but rather applying teamwork and creativity to solve the problems. Decisions often hung on tradeoffs between capacity, cost, reliability, fire demands and water quality.

The research needs identified include better tools for estimating the costs and benefits of water distribution improvement decisions made with a high degree of uncertainty in future conditions. The concept that distribution design is a problem of minimizing costs subject to known constraints doesn't compare well to real studies as water distribution design actually involves tradeoffs between multiple objectives.

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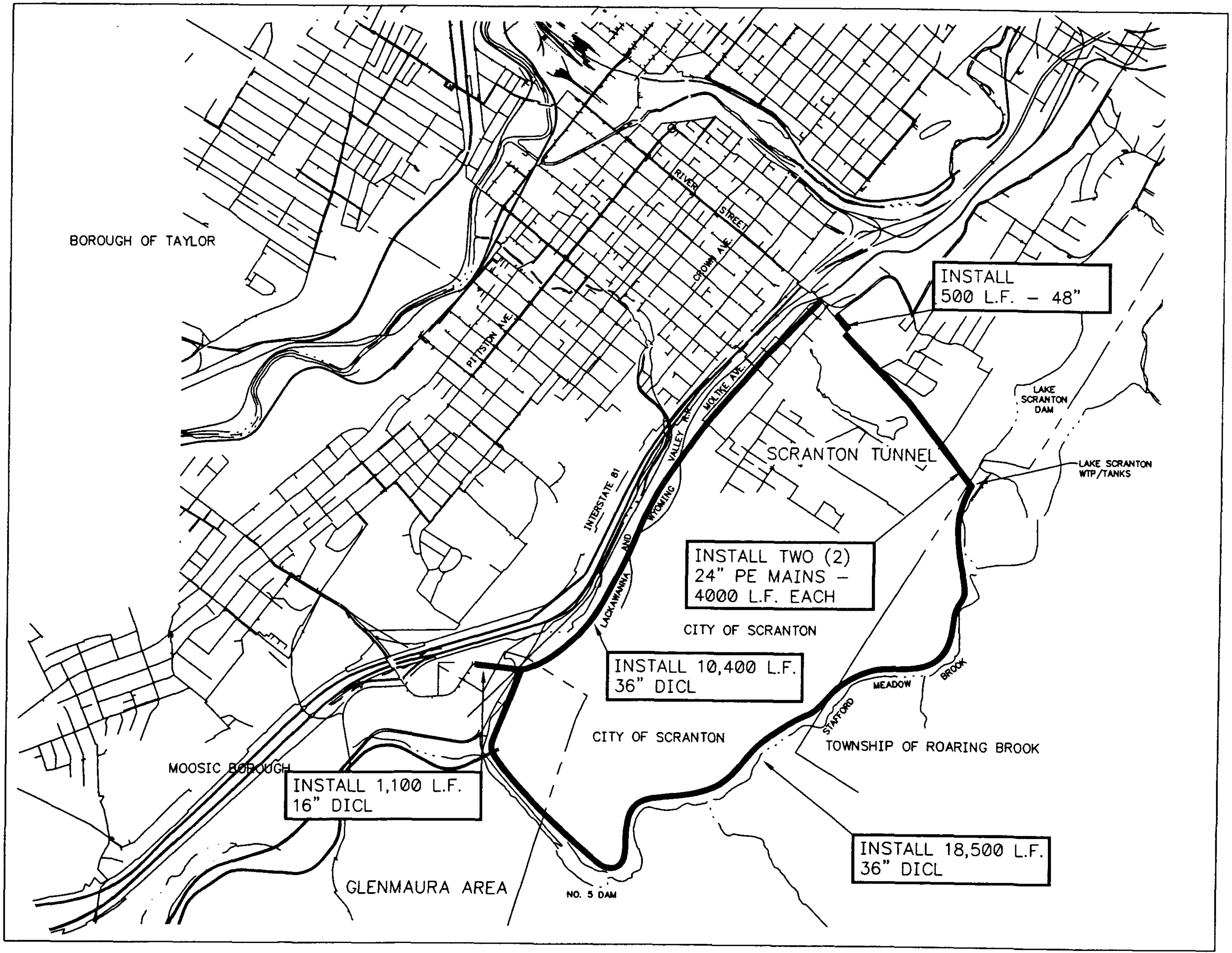

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FIGURE 1 - LAKE SCRANTON FEED

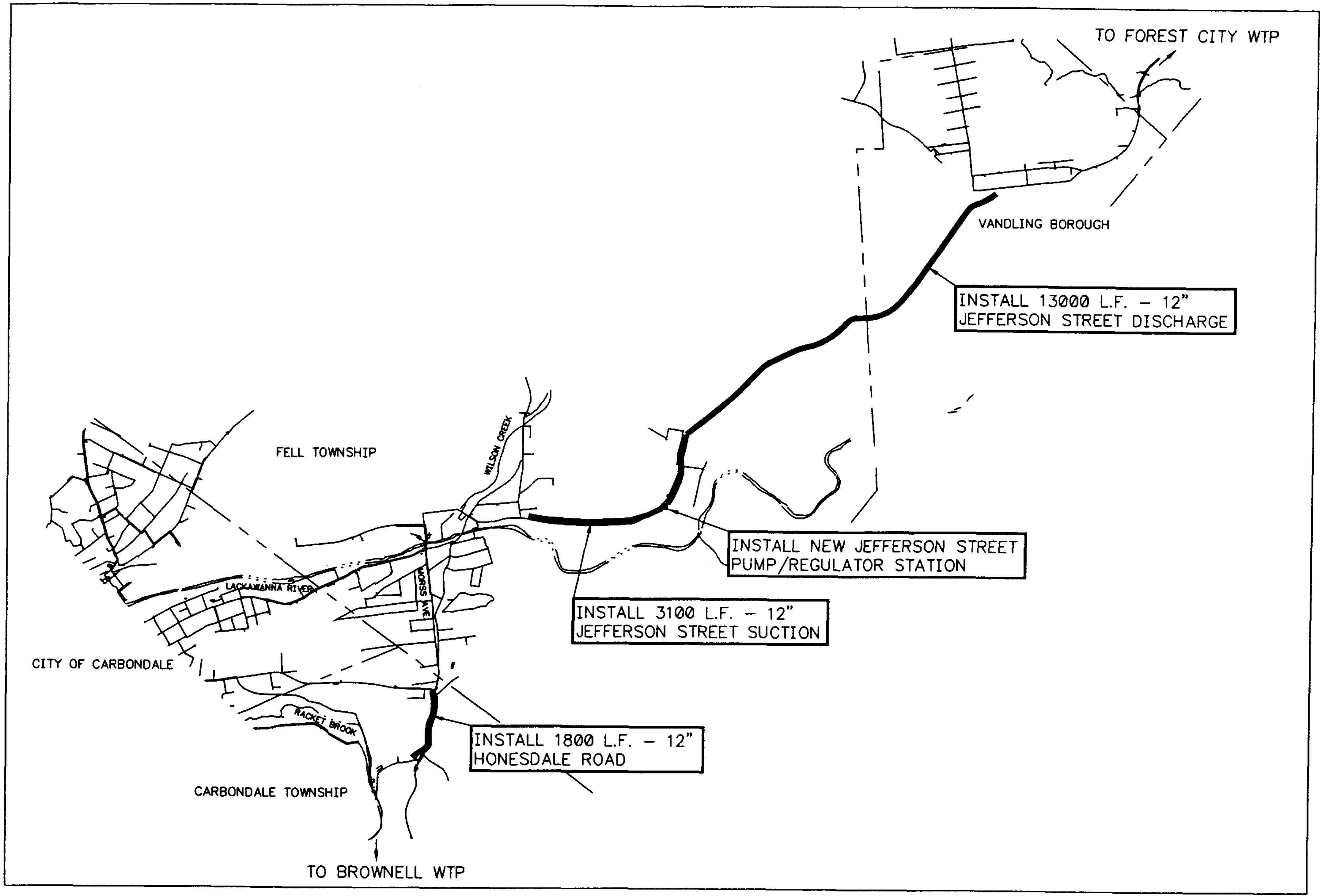

FIGURE 2 - BROWNELL-FOREST CITY INTERCONNECT

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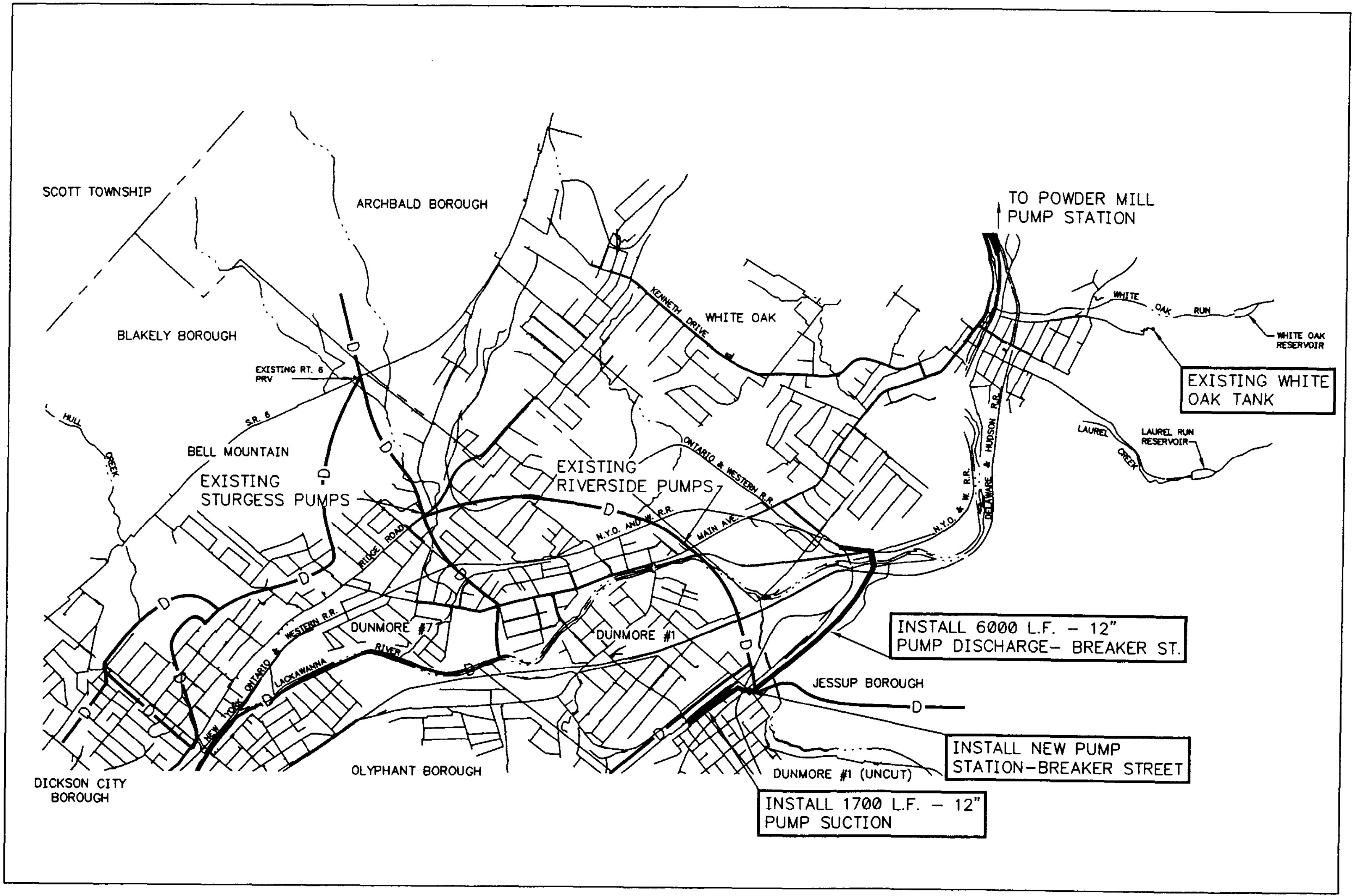

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FIGURE 3 - WHITE OAK PRESSURE ZONE FEED

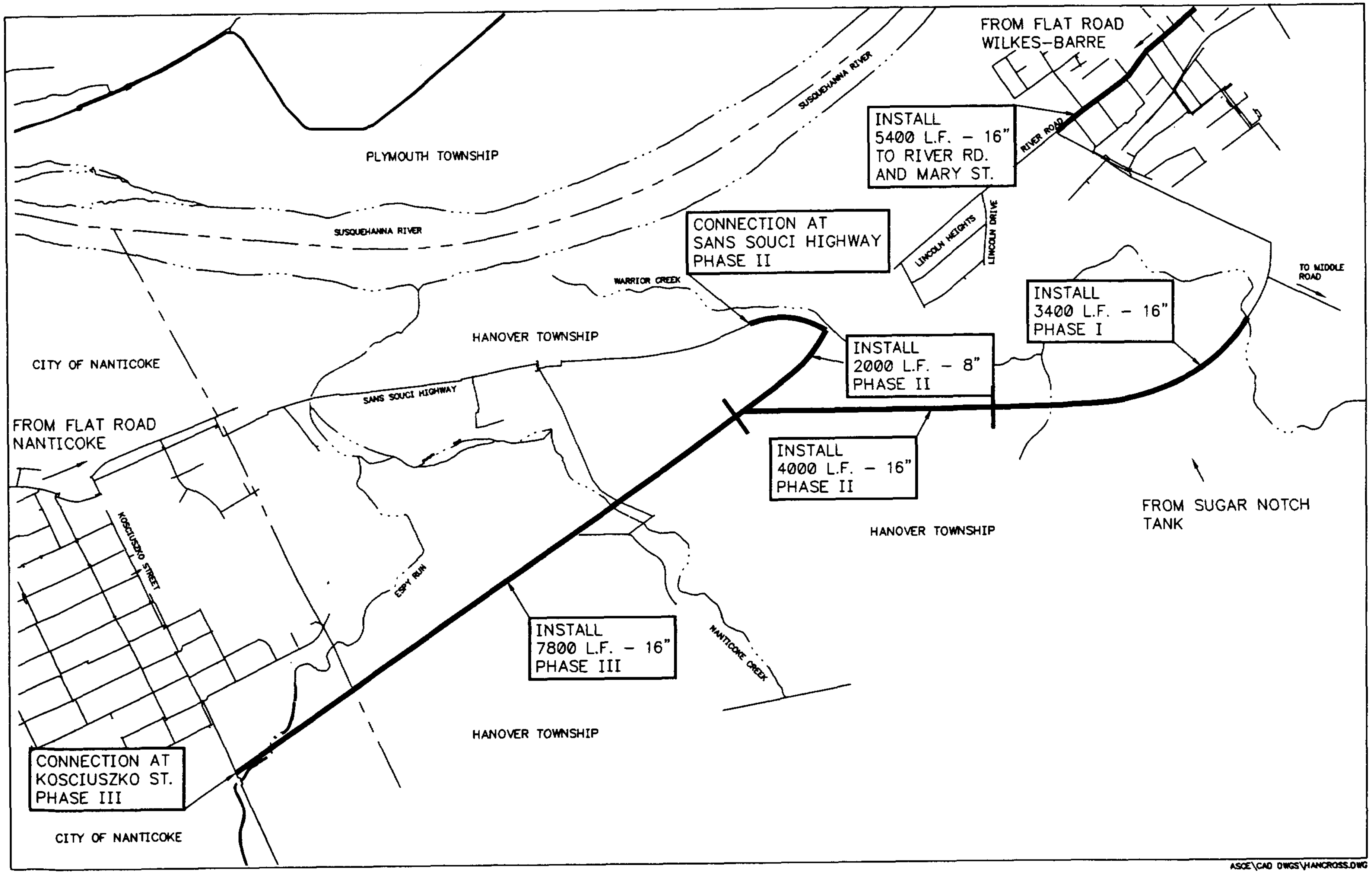
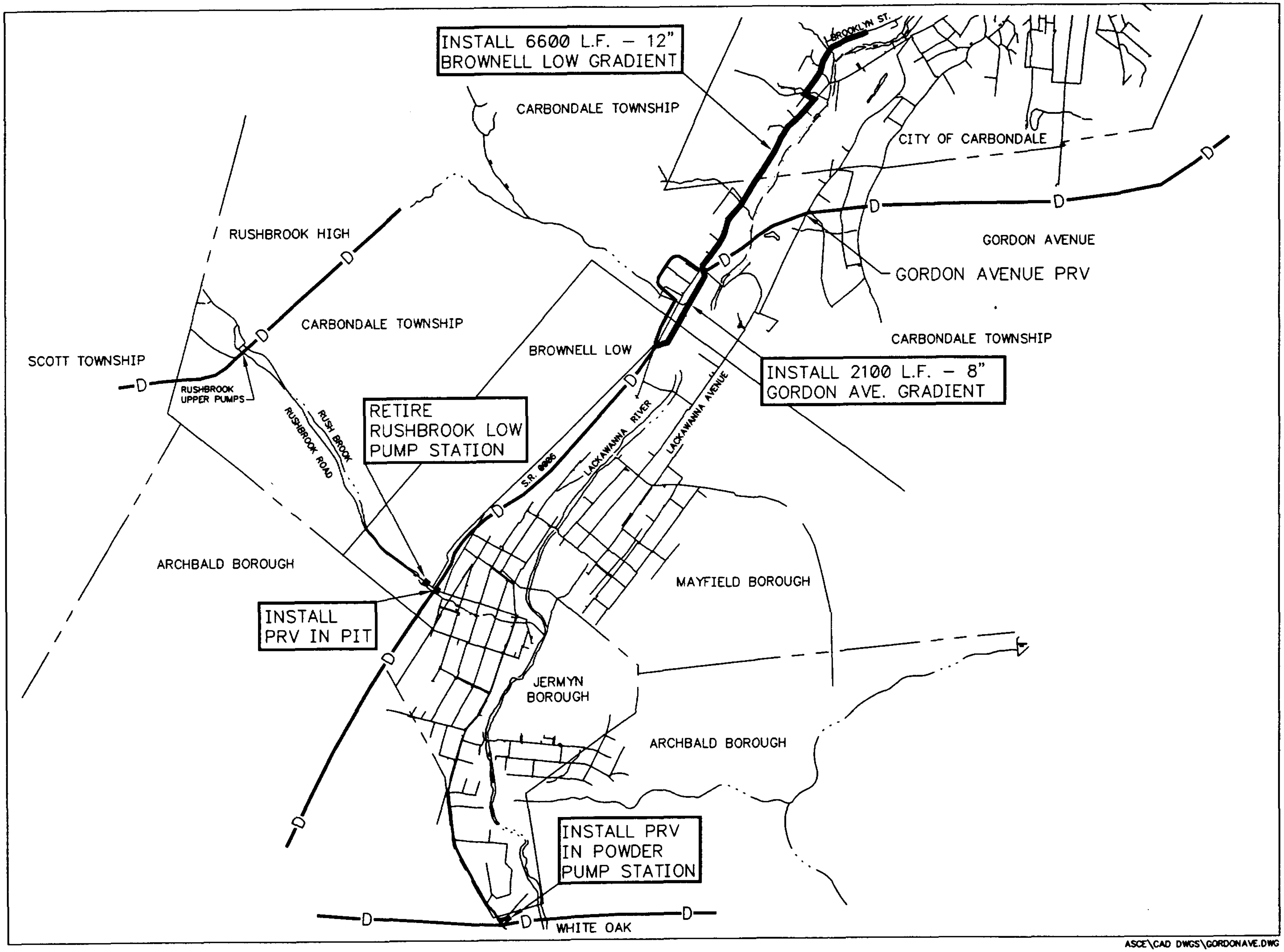


FIGURE 4 - HANOVER CROSSING



INSTALL 6600 L.F. – 12"
BROWNELL LOW GRADIENT

GORDON AVENUE PRV

INSTALL 2100 L.F. – 8"
GORDON AVE. GRADIENT

RETIRE
RUSHBROOK LOW
PUMP STATION

INSTALL
PRV IN PIT

INSTALL PRV
IN POWDER
PUMP STATION

FIGURE 5 - GORDON AVE. ZONE