CHAPTER 8: HYDROLOGY AND OPERATING PARAMETERS OF THE MILLS

In order to understand the significance of the waste gates uncovered beneath Bridge 238, it is necessary to understand the hydrology of the system as a whole. The mills' hydraulic components (the dam, the pond, the wheels, and the waste gates) were interdependent. Mills worked by harnessing the energy released by falling water using a water wheel that transferred that energy to shafts and gears. In some mill systems, water was conveyed to the wheel by diverting water from a stream through head races. There were a variety of wheel types of varying efficiency. Overshot wheels were struck by water at the top of the wheel. In other mills where there may not have been sufficient change in elevation for this (fall, or head loss), water may have come to the wheel in the middle (breast wheel), or low on the wheel (undershot). These wheels were sometime easier to build, but were less efficient than overshot wheels. A breast wheel might capture 40% of the water's energy compared to 65 to 75% for an overshot wheel (Colley n.d.; Knepper 1992). Turbines were 19th-century improvements to much older horizontal wheel designs (Garrett et al. 1994). Turbines were more efficient than breast or overshot wheels, achieving efficiencies of over 80% (Lowell National Historical Park n.d.) Once through the wheel, tail races then conveyed the water away from the wheel. In Delware with its relatively low relief, millwrights created the fall of water needed to power mills by constructing dams across streams, and placing the mills on top of the dam.

The power available to such mills was a function of the height of the pond, which was in turn a function of the height of the dam (the greater the fall of water, or "head loss", the more energy was transferred from the water to the water wheel). How close to the top of the dam the pond elevation could be kept depended the inflow of water from the surrounding watershed and on the discharge capacity of the mills and waste gates. The quantity of water flowing into the pond varied with rainfall. In periods of heavy rain, the volume of water flowing into the pond could exceed the total discharge capacity of the mills and gates. If this happened, the level of the pond could rise until the pond overflowed the dam. Since this could have catastrophic consequences, it was important to ensure that either there was enough capacity in the mills and waste gates to discharge excess water, or the level of the pond was kept low enough to ensure there was enough extra capacity in the pond to contain a flood. The greater the capacity of the mills and waste gates, the higher the level of the millpond could be maintained without risking a flood. If the capacity of the pond was low, and the water supply from the river unreliable during dry months, there might not be sufficient water to keep the mills running at the desired capacity.

To understand the relationship between the Middleford Mill complex and the hydrology of the area, it is necessary to reconstruct the quantity of water flowing into the pond, the elevation of the pond surface, the volume of water in the pond, and the discharge capacity of the mills and waste gates.

The historical details of the Middleford pond were reconstructed using historical documents and GIS analysis of the local topography. Based on the elevation of likely 18th-century mill features, the original dam was probably not much higher than 5 feet amsl, and was approximately 600 feet long. This pond was reconstructed in ArcView using the 5-foot contour line (Figure 62). The resulting pond would have covered 159 acres and held 67 million gallons of water.

Based on historical documents and the USGS 7.5 minute topographic map, the height of the 19th-century milldam appears to have been more than 10 feet amsl. This dam was approximately 1,200 feet long. The industrial census for 1880 describes the fall in feet for the Grist and Carding mills as 6 feet, and 7 feet for the Saw and Planing mills. The water below the dam would have ranged in elevation from 2.52 feet amsl at high tide, to -0.48 feet amsl at low tide, with the normal water level being 1.02 ft amsl (DelDot 1998). Since the average elevation of the stream below the mills is approximately 1 foot, this means the top of the pond was 7 to 8 feet above sea level. Using ArcView GIS software, a mill pond was reconstructed following the 10-foot contour line upstream from the dam, as well as following an 8-foot line extrapolated from the other data (Figure 63). The shape of a pond at 8 to 10 feet amsl agrees well with 19th-century maps depicting the pond (Figures 8 and 9). The millpond up to 8 feet amsl would have covered approximately 215 acres, and would have held approximately 388 million gallons of water. Thus, moving the dam downstream, lengthening it, and raising it by 5 to 6 feet produced a pond with nearly 6 times as much water as the earlier pond. Although the larger dam would have been more expensive to build and maintain, it would have allowed a higher head, and thus more power for the wheels. Moreover, the larger pond would have allowed the mills the run longer during dry months.

The rate of water flowing into the historic mill pond can be estimated using daily mean discharge data collected by the US Geological Survey from a gauging station (Station number: 01487000) located upstream from the mill on the Nanticoke River, near Bridgeville, DE. Data are not available for other tributaries flowing into the pond (Hurley Drain, Gravelly Branch above Fisher's Mill Bridge, Ake Ditch, or Turkey Branch). To derive an estimate of the total flow into the millpond, the watershed for the Middleford mills was constructed from a digital elevation model of Sussex County using the hydrologic functions of the Spatial Analyst extension in ArcView (Figure 64). This was compared to the size of the watershed for the gauging station, and the ratio was used to estimate the average daily stream flow past Middleford Mills. Daily data are available for this station from April 1, 1943 through March 12, 1984.

Using the estimates described above, the average daily flow past the mill area between 1943 and 1984, was 149 cubic feet per second, with a low of 11 c.f./sec, and a high of 4781 c.f./sec. (on Feb. 26, 1979). September and October averaged the least amount of flow with 80 c.f./sec. And 77 c.f./sec. respectively. March averaged the most flow at 264 c.f./sec. The slowest month in the data was September 1943, when the flow was only 17 c.f./sec. The month with the greatest flow was August 1967, with an average of 684 c.f./sec.

Estimating the water consumption of the mills involves a formula using the height of head, the efficiency of the water wheels, and the horsepower produced. The 1860 industrial census shows that Lot Rawlins was operating a sawmill, gristmill, and carding machines. All were water powered, but the size and horsepower of the wheels is not given. The 1870 industrial census for Seaford Hundred lists a gristmill, sawmill, planing mill, and carding mill. Each was powered by an iron wheel; the gristmill wheel produced 20 horsepower, the lumber mill 20 hp, the planing mill 18 hp, and the carding mill wheel 10 hp. In 1880, the industrial census describes the gristmill as having 2 wheels with 6 feet of head, one with 25 hp, and another with 15 hp. It also lists a sawmill with one wheel of 48 feet in diameter, 7 feet of head, and 18 hp. There is no mention of a planing mill or carding mill; perhaps the second wheel listed for the gristmill had previously been used for the carding mill. These data are summarized in Table 8.

The type of wheels used is unknown. The 1880 industrial census describes the wheels as ranging in size from 30 to 48 feet in breadth. The breadth likely refers to diameter, but a 48 foot diameter wheel for a fall of 6 feet makes no sense. However, given that the wheels are iron, it is more likely that the wheels were turbines, in which case the power produced for a fall of 6 or 7 feet would be consistent with turbines 30 to 48 inches in diameter. Such wheels might have been expected to have an efficiency of between 70 and 80%. Assuming a 70% efficiency, the mills would have used 122.4 cfs of water in 1870 and 104.4 in 1880. Assuming a 30% efficiency in an undershot wheel, the mills would have used 285.3 cfs in 1870 and 243.4 cfs in 1880.

Table 8: Mills of Middleford Mills

Mill	**Wheel Type**	**Horsepower**	**Diameter**	**Months in Operation**	**Water Consumption**
			1870		
Gristmill	Iron	20		12	36 cfs (turbine) 83.9 cfs (undershot)
Sawmill	Iron	20		10	36 cfs (turbine) 83.9 cfs (undershot)
Planing Mill	Iron	18		6	32.4 cfs 75.5 cfs (undershot)
Carding	Iron	10		3	18 cfs (turbine) 42 cfs (undershot)
			1880		
Gristmill 1		25	36	12	45 cfs (turbine) 104.9 cfs (undershot)
Gristmill 2		15	30	12	27 cfs (turbine) 63 cfs (undershot)
Sawmill		18	48	12	32.4 cfs (turbine) 75.5 cfs (undershot)

The final element needed to reconstruct the operating parameters of the mill complex is the discharge capacity of the waste gates. This figure is based on a combination of archaeology and GIS analysis. The discharge capacity of the gates is largely a function of their dimensions. The waste gates excavated under Bridge 238 may have been as much as 40 to 45 feet wide, and about 10.5 feet high (from the top of the wooden sill, Feature 2, located approximately at sea level, to the top of the dam). The dimensions of the middle gates can only be estimated based on the width of the present channel, and the assumption that it would have had a design, and therefore a height similar to the other gates. The present channel is approximately 100 feet wide. Using the formula 0.98*width*height*SQRT(2*32.2*height) (Urbonas and Stahre 1993), the discharge capacity of the gates at Bridge 238 would have been approximately 24 cfs.

Using all of the data estimating discharge capacities and stream flow, a simulation of water levels was written using Excel. The simulation was intended to show whether the discharge capacity of the system was sufficient to prevent floods during periods of high rainfall, and whether there was sufficient water flowing into the pond to keep the mills running consistently during dry months. The simulation estimates the level of water in the 19th-century mill pond from the historical stream flow data, and adjusts the volume of water flowing through the waste gates to keep the estimated level of the pond between 6 and 8 feet amsl. The simulation was designed to shut off water to the mills if the water in the pond dropped below 7.5 feet amsl. This simulation showed that there was sufficient water to power the mills 98% of the time, assuming the mills did not run more than 12 hour per day. According to the Industrial Census, only the gristmill was in operation 12 months of the year, the sawmill was in operation 10 months of the year, the planing mill 6 months, and the carding mill only 3 months. The combined water use to generate the horsepower described in the 1870 census (122.4 cfs assuming a turbine) was less than the average stream flow for the Nanticoke (149 cfs), but substantially more than the flow during dry months (the average for October was 76.3 cfs, and the average minimum month flow as 54 cfs). That meant that all the mills could not operate during dry months without the dam to create a reservoir. However, the stream flow data and computer simulation suggest that there was more than enough water to supply the power needs for this level of production. In fact, there was considerable unused water capacity.

The computer simulation suggests that if the two waste gates together were able to discharge 130 cfs (the average daily flow is 149 cfs), then the pond would not have risen above the dam given conditions similar to the historical stream flow data. This assumes that the wheels in the mills are either undershot wheels, or if they are turbines, that they are able to discharge excess water around the turbine in addition to what the turbine used. Whether or not the middle gates could have accommodated more than 100 cfs will not be clear without excavating the foundations of the gates there.

In order to protect the mills from flooding, the portion of the dam containing the structures may have been slightly higher than the portion with the waste gates. The east side of the dam (where the two sets of waste gates were located) appears to have been lower than the portion containing the mills. The elevation near Bridge 238 is now just short of 10 feet amsl. The portion of the dam where the mills were was above the 10-foot contour line, but how much higher is unknown. The portion of the dam that was lower than the rest was approximately 700 feet long (the dam as a whole was approximately 1,200 feet long).

In addition to heavy rain, the mill operators had to contend with the tidal nature of the Nanticoke. With high tide backing up to the dam, the discharge capacity of the dam would have been reduced. That this was of concern is illustrated by a letter from John Rawlins to James Rawlins from Georgetown in September 1878:

> *James,*
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> *You doubtless have noticed the long continuance of this Easterly Wind, and thought of the Effect it has and will have to make full tides. If it passes off without the heavy fall of rain we sometimes have at the Equinoxeal, it would not effect as much; but a heavy rain storm might fill the ponds so full that we could not get clear of it with so much back water. I have no doubt you will commence running the water off in time and have the pond down, if there is a necessity to it. With best wishes, yours,*
>
> *JM Rawlins.*