APPENDIX D

LAKE BARCROFT REPORT

Report on the Response of Lake Barcroft Dam to Heavy Rains during the Period June 23 through June 29, 2006

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Lake Barcroft Watershed Improvement District

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I. Overview

During the period from Friday, June 23 to Thursday, June 29, 2006, a stationary weather system sent a series of rainstorms up the East Coast in what has variously been reported as a “major” or even “300-year” storm. Total rainfall for our general area in the period was reported to be 12.10 inches. The Washington Post reported a 24-hour total of more than seven inches of rain on the 26th with more arriving overnight on the 27th.

As a result of this rain, flooding was experienced in Holmes Run downstream of Lake Barcroft and in the Huntington area of Fairfax, just south of the City of Alexandria, also downstream. Fairfax County engineers are exploring the dynamics of the heavy flow and trying to understand the functioning of the Lake Barcroft dam as one piece of the puzzle.

This report first describes the Lake Barcroft dam and the operation of its large hydraulic gate, designed to maintain a nearly constant lake level. Second, it uses data from the computer control system that operates the gate to show exactly how the gate functioned over the storm period.

The recorded minute-by-minute data on rainfall, lake level, gate position and flow over the dam demonstrate that the Lake Barcroft dam did not contribute to downstream flooding, performing flawlessly throughout the storm to maintain a nearly constant water level in the lake. Water flowing downstream from the dam consisted entirely of water flowing into the lake from its feeder inlets (primarily Holmes Run and Tripps Run) and a much smaller amount of direct rainfall into the lake. The unfortunate flooding downstream would have been comparable if the lake and dam did not exist.

II. Lake Barcroft Dam Background

THE DAM

Lake Barcroft was created by constructing a masonry dam with earthen embankments at the sides in the early 1900’s just below the confluence of Tripp’s Run and Holmes Run. The dam was originally built as a reservoir for the City of Alexandria. By the 1940’s the city’s population had outgrown the watershed’s capacity to supply water. Of little use after the construction of a large county reservoir and water system, the lake was sold and its adjoining land subdivided for residential development breaking ground in the 1950’s.

The original dam continued in service until 1972 when rains from Hurricane Agnes caused exceptionally high water to erode the earthen embankment at the western end of the masonry portion of the dam. The erosion scoured out the embankment and drained the lake.

The dam was rebuilt with protection against rising lake levels in the form of a 151 ft wide by 12 ft high bascule gate set into the top of the masonry. Four huge hydraulic rams (like arms) open and close the gate in response to a computer-operated monitoring and control system. The combination is designed to maintain the lake level and essentially remove the risk of the dam failing in the manner it did during Hurricane Agnes. The picture, below, is the dam and its hydraulic rams seen from downstream.

LAKE BARCROFT DAM AND GATE

DAM OPERATOR

The dam is operated and managed by the Lake Barcroft Watershed Improvement District (LBWID), a government entity with taxing authority to raise capital and operating funds.[1] LBWID is governed by the state via the Northern Virginia Soil and Water Conservation District, and its annual budget is reviewed and approved at state level by the Virginia Soil and Water Conservation Board. The Lake Barcroft dam, as all dams in the state, is regulated and monitored and inspected by the Virginia Dam Safety Board.

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[1] The Lake Barcroft Watershed Improvement District is organized under Virginia Law § 10.1-614, which authorizes the creation of watershed improvement districts. To raise funds, LBWID is empowered to levy property taxes and to issue municipal debt. It also may exercise eminent domain within its boundaries. It is managed by three pro-bono trustees appointed by the State and has a permanent full-time staff of four plus seasonal workers.

The dam structure is licensed under Virginia Department of Conservation and Recreation's Dam Safety Division, which issues a Class 1 Operations and Maintenance Certificate. The authorization for reconstructing the Lake Barcroft Dam and the Lake Barcroft impoundment (post Hurricane Agnes) was granted by the Circuit Court in Fairfax, Virginia, on January 12, 1973. The court ordered that the dam be operated in accordance with recommendations of Whitman, Requardt and Associates, the engineering firm that managed the reconstruction. One specific requirement of that ruling is that the dam cannot be used as a flood control device.

LAKE BARCROFT'S WATERSHED

A 14.5 square miles watershed drains into Lake Barcroft. It includes parts of Fairfax County and most of the City of Falls Church, bounded roughly by Route 7 on the east and north, Gallows Road on the west and Columbia Pike on the south. A short stretch of Route 66 forms a northwest piece of the boundary.

The area of Lake Barcroft itself is about 135 acres, about 1.5% of its watershed. This is an important ratio because it indicates that in watershed rain events, the water added to Lake Barcroft, and subsequently flowing downstream, is overwhelmingly drainage from the watershed, not rainfall directly into the lake. This effect is intensified when additional rain falls upon an already saturated watershed.

Downstream of Lake Barcroft, water flows into lower Holmes Run, which crosses into Alexandria and joins Cameron Run alongside the Beltway between Van Dorn Street and Telegraph Road. Cameron Run becomes Hunting Creek south of Alexandria, where it empties into the Potomac just below the Wilson Bridge.

DAM GATE OPERATION

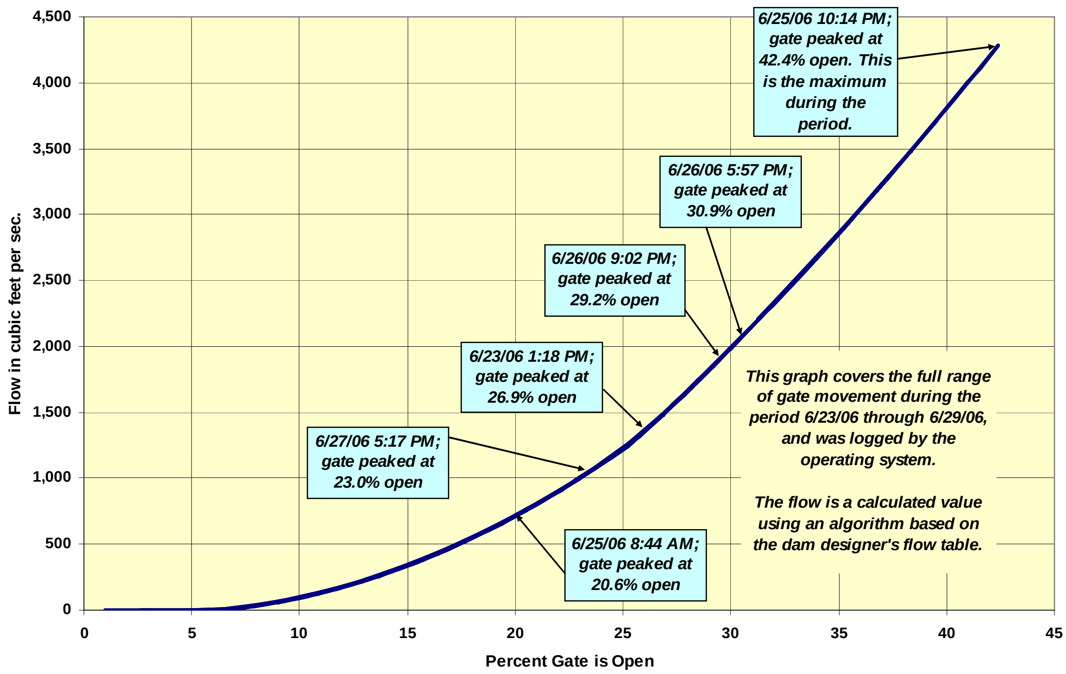
The Virginia state operating license for the dam requires the water level in the lake to be maintained at an elevation above sea level between 208.5 feet and 209.0 feet. The maximum depth of the lake is approximately 45 feet.

The control system for the gate includes sensors that measure the water level accurately to the nearest 0.01 ft. The control system updates its readings every second, so literally, the second that inflowing rain water begins to raise the water level above 208.50 feet, the control computer begins the process of sending instructions to a powerful electro-hydraulic system to open the gate a specific amount and allow the incoming water to flow downstream. The computer carefully matches the gate position to the water level, opening the gate to the degree needed as the water level rises, and closing it as the water level recedes.

Even when the gate is 100% closed, small amounts of water pass through the end seals of the gate and over a secondary fixed spillway at the 208.5 baseline water level. This nearly constant flow prevents the downstream channel from drying out in periods of low rainfall and allows the normal small inflows to the lake to pass without lowering the gate.

Moved by four huge hydraulic rams, the gate opens by tilting around hinges along its lower edge. For the first third of its travel, the top lip moves in a fairly flat arc and changes height slowly. That motion, plus the normal position of the lip six inches above water level when the gate is fully closed, creates a small delay in releasing water as the lake's water level begins to rise. Thus, as water enters the lake, the dam stores two or three inches (20 or 30 acre-feet) of it before significant flow is released downstream. This is a moderation of flow downstream, which becomes less significant as the gate opens. In the final two-thirds of its travel, the lip of the gate descends more quickly, and the rate of flow over the gate increases more rapidly.

Chart 1: Relationship of Gate Opening to Flow over Dam



Notice in Chart 1, which relates the percent of gate opening (bottom scale) to the flow over the dam (right scale), how the first 10% passes only a minor amount of water. As the gate opens wider, flow increases less than proportionately with only about 20% of flow capacity passing over the dam at 40% of gate opening. Only above 40% does the flow increase become roughly linear.

The maximum flow over the dam in Hurricane Agnes, with the primitive old gate in service, was estimated to be 14,500 cubic feet per minute. The new gate has the capacity to pass 21,500 cubic feet per second. In an extreme rainfall event, the dam could pass up to 29,000 cubic feet per second without endangering the earthen embankments.

Chart 1 also dates the significant peak openings of the gate during the June storm event. The greatest opening, at 42.4% was well below the full capacity of the gate to discharge water flowing into Lake Barcroft. The greatest flow over the dam at the peak discharge occurring at 10:14 PM on 6/25 was approximately 4,300 cubic feet per second, compared to a maximum possible 21,500 at a 100% gate opening. The latter would only occur during an almost unimaginable storm, even more severe than Hurricane Agnes. (Subsequent charts and discussion will examine rainfall, lake level, gate operation and flow during the storm).

III. Gate Performance During the June 2006 Rain Event

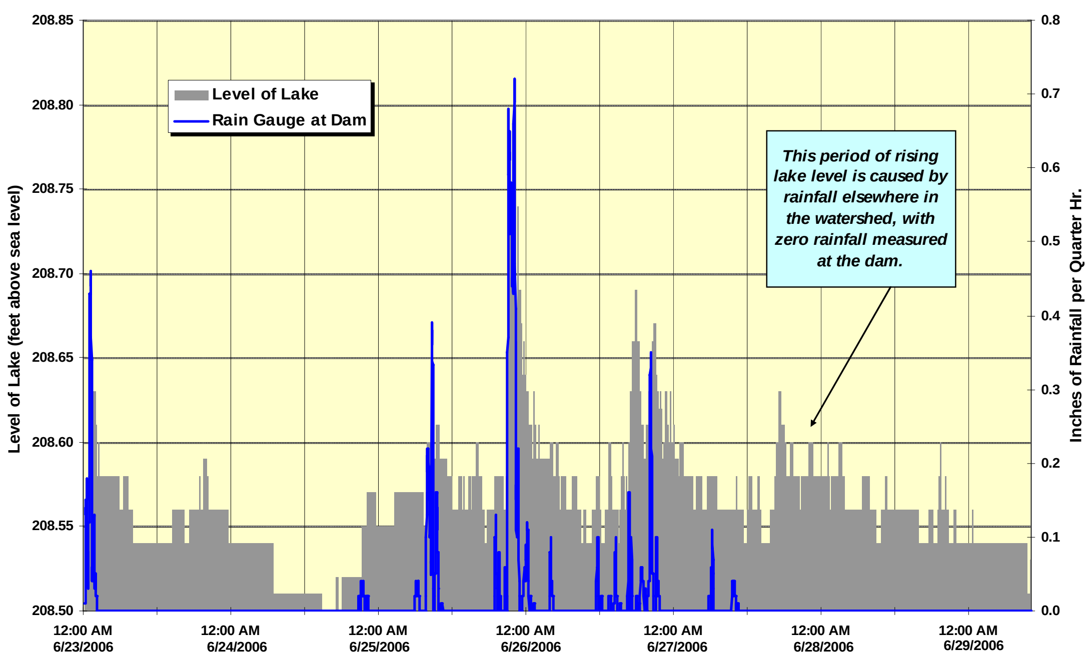
The gate control system, which has been completely renewed and upgraded during the past three years, automatically logs lake level and limited weather data, along with the performance of the dam gate. Extracted minute-by-minute data covering the time period 6/23/2006 through 6/29/2006 is displayed in a series of charts, below.

The charts unequivocally demonstrate that the gate performed as designed when torrents of storm water swept down Tripps Run and Holmes Run into the lake. The small change in lake level during the entire period is evidence that what flowed in, flowed out, nothing more, nothing less, except for a small moderation in flow each time the gate first opened (as discussed earlier).

LAKE LEVEL AND RAINFALL COMPARED

The control process is driven by sensors that measure the water level of the lake, with changes caused by rainfall (or lack thereof) throughout the lake's watershed. Chart 2, comparing rainfall and lake level, shows how quickly water flushes down the watershed into the lake. The left scale, corresponding to lake level and represented by the solid grey areas of the chart, is contrasted with rainfall at the dam, shown on the right scale and represented by the thin (blue, if color) line.

Chart 2: Rainfall Measured at Dam versus Lake Level



Note:Depending on location of rain in watershed, the time for watershed flow to reach the dam varies.

Rainfall is measured in small increments, reported by the minute, and aggregated into blocks of time. The data presented here are rainfall in rolling 15-minute aggregations. That interval most clearly shows the extreme variation in the rate of rainfall over the period. Rainfall aggregated into longer one-hour or several-hour blocks averages out and hides the surprising short-term intensity of individual storm cells.

The peaks in both rainfall and lake level that occurred around midnight on the 23rd, both late morning and again at midnight on the 25th, and a double peak on the 26th show very little time lag between the rainfall peak and the lake level peak. The storm cells that passed over our watershed had quite sharply defined, intense and often violent leading edges.

It is important to note that the rainfall data shown was gathered from a gauge located at the dam. This is at the southeastern edge of the lake watershed. Because storm cells can be relatively small in area, it frequently happens that rain may fall heavily in one part of the watershed and lightly or not at all in other parts. So there is only imperfect correlation between rainfall at the dam and the indication, by rising water level in the lake, of heavy rain elsewhere in the watershed.

The Lake Barcroft watershed is extremely responsive in moving storm water down the network of streams. Two factors contribute to this:

- Large areas of impervious surfaces in Fairfax and Falls Church, consequent to development of buildings, parking lots, and roads; and

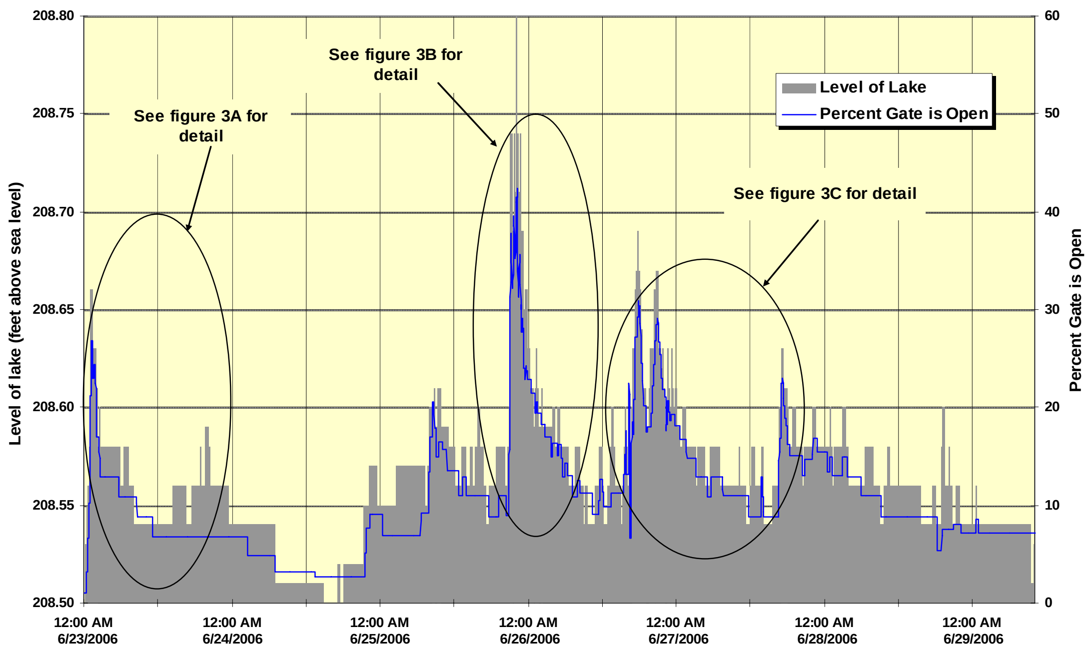
- The high-velocity concrete-lined drainage channel for Tripps Run in the City of Falls Church.

In June, the situation was worsened by ground saturation from earlier rain that encouraged new rainfall to run immediately into the streams. It takes varying amounts of time for the watershed to drain into its streams and then into the lake. Depending on the rain’s location, the permeability and saturation of the ground upon which it falls, the grey area of the chart may extend in diminishing steps for many hours after the rain ceases. Rain elsewhere in the watershed may cause the lake to rise even with a zero measurement of rain at the dam.

LAKE LEVEL AND DAM GATE OPENING COMPARED

As rain falls and storm water runoff arrives in Lake Barcroft, the water level begins to rise. In response, the gate control system begins to open the gate, the computer control responding to the change in lake level sensors to determine the degree of gate opening.

Chart 3: Percent of Gate Opening versus Level of Lake



Lake level is compared to the percent of gate opening in Chart 3 to illustrate how closely the gate opening is linked to changes in water level. The left scale, corresponding to lake level and represented by the solid grey areas of the chart, is contrasted with the percent of gate opening, shown on the right scale and represented by the thin (blue, if color) line.

By design and in accordance with the license under which the dam operates, water coming into the lake is passed downstream almost immediately. Notice in the chart how an increase in lake level is matched by a greater gate opening. Notice also, particularly with large gate openings, how lake level reduces as the open gate spills more water downstream, decreasing the lake towards its target of 208.5 feet above sea level.

In order to see the detail of operations during the particularly high peaks of water inflow to the lake, segments of Chart 3 are enlarged for three intense storm periods (Chart 3A 12:00 AM 6/23 to 12:00 AM 6/24, Chart 3B 4:43 PM 6/25 to 10:43 AM 6/26, and Chart 3C 12:00 PM 6/26 to 6:00 PM 6/27).

Chart 3A: Percent of Gate Opening versus Level of Lake

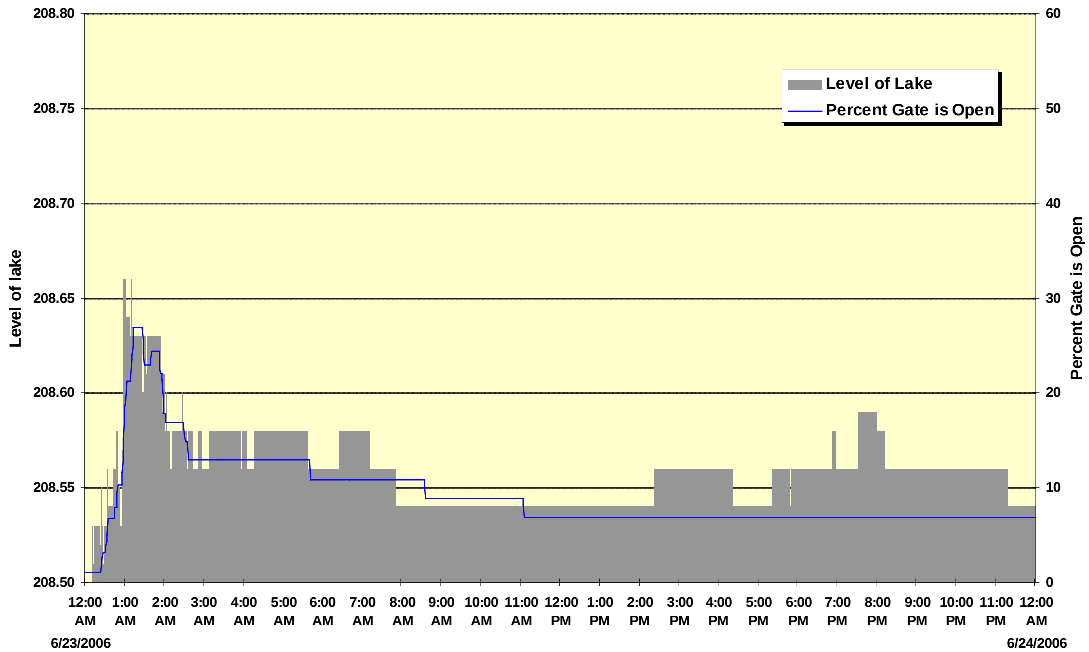


Chart 3B: Percent of Gate Opening versus Level of Lake

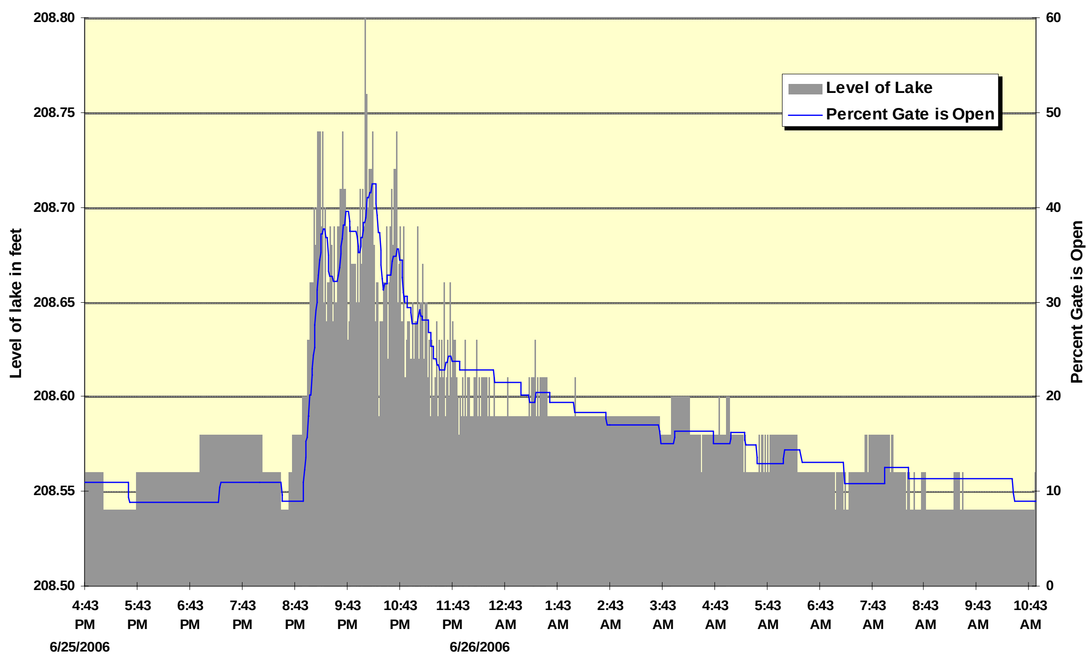
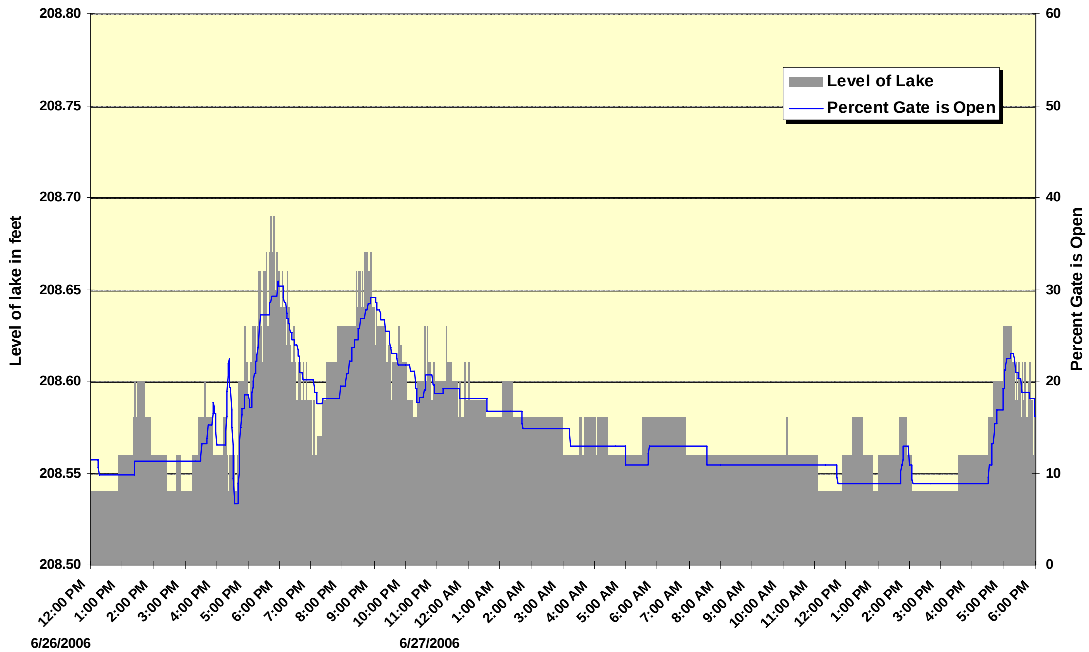


Chart 3C: Percent of Gate Opening versus Level of Lake



Each of the Charts, 3A, 3B, and 3C, shows an interesting phenomenon that occurs during periods of peak water level. It is best seen in Chart 3B, which documents the peak that occurred just after 10:00 PM on 6/25. At this time, the peak water level very briefly touched 208.8 feet, the maximum for the entire storm period.

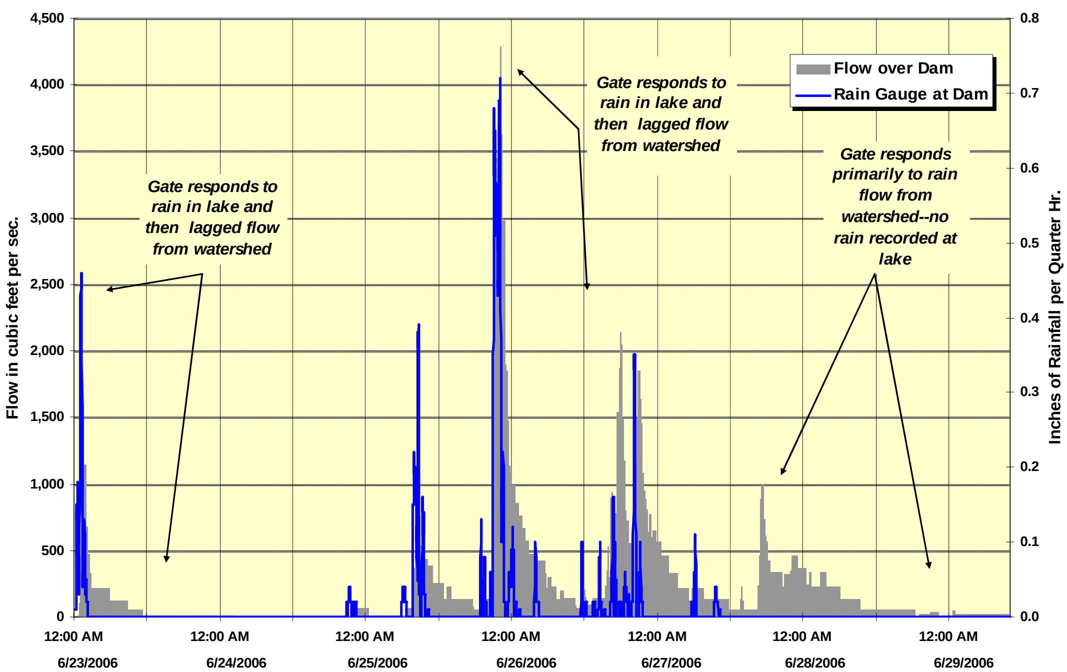
At this water level, the operating rule calls for the gate to open as much as 60%. However, the peak gate opening was only about 43%. The time lags built into the computer software controlling gate openings allows a brief water level peak to pass before opening the gate to the rule value. This moderating influence prevented a surge over the dam and downstream. Similar lags and gradual peak reductions are also shown on Charts 3A and 3C.

FLOW OVER DAM AND RAINFALL COMPARED

The relationship between gate opening and flow over the dam (from Chart 1) is used to convert gate openings to flow in Chart 4. The left scale, corresponding to flow over the dam and represented by the solid grey areas of the chart, is contrasted with the amount of rainfall, shown on the right scale and represented by the thin (blue, if color) line.

Despite the moderation in flow that may be inferred from Chart 3, the passage of storm cells over the watershed did create sharp spikes in flow down the streams feeding into the lake, and consequently, over the dam and downstream into Holmes Run. Similar spikes very likely were experienced throughout all the branches of Cameron Run. It is simply water flowing into the lake from the watershed and then flowing over the dam into the lower reaches of Holmes Run.

Chart 4: Flow over Dam versus Rainfall Measured at Dam



Note:Depending on location of rain in watershed, the time for watershed flow to reach the dam varies.

These spikes in flow probably were the cause of the surges and abrupt high water experienced at the foot of Chambliss Street, about a mile below the Lake Barcroft Dam on lower Holmes Run. The spikes may have exacerbated the flooding in Huntington. It is clear they were not caused by the Lake Barcroft Dam, but rather were the consequence of water quickly draining through a saturated and largely impervious watershed into the lake and subsequently discharged according to the dam's design and its operating license.

IV. Closing Observations

FUTURE HEAVY STORMS MAY INEVITABLY LEAD TO FLOODING

As damaging as they were, the June, 2006 rain events were characterized by distinct storm cells of intense rain in transit through the watershed. They often impacted relatively small areas at a given time and quickly passed elsewhere. Future high intensity storms of longer duration may cause greater flooding downstream from Lake Barcroft. This is one consequence of swift drainage throughout a highly impervious watershed into the lake. Speeding water away from upstream roads and streets into sewers, culverts and other devices that empty into Holmes Run and Tripps Run may have solved some problems, but inevitably causes others.

It is troublesome that in recent years weather seems to be more unpredictable and severe. Our area may well experience even worse rain and flooding than the June storm. The response of the watershed to the June, 2006, rain events should be looked at as part of a broader set of possibilities.

Hurricanes in particular carry with them the inherent threat of greater potential for flooding and destruction in Northern Virginia's watersheds. Unlike storm cells that produce spikes of rainfall and runoff that peak and quickly dissipate, hurricanes can produce long-duration downpours that result in flows of very destructive high-energy water.

In a hurricane, erosion and flooding may build up to extreme levels and persist for many hours. Trees and debris carried downstream by the raging flow will jam up at choke points to create dams that exacerbate local flooding. The Lake Barcroft community and its dam do what can be done within their physical and operational limitations to moderate flow and trap debris to keep it from adding to problems downstream.

However, even in a hurricane flow, the lake and dam cannot do more than pass the storm water into the downstream watercourses as soon as it flows through the lake. It is a simple equation: what flows into the lake flows out.

LIMITATIONS IN THE ABILITY OF THE WATERSHED TO HANDLE LARGE RAINFALLS

The June, 2006, rain events exposed limitations in the ability of the Holmes Run and Cameron Run channels to handle high runoff. This is a warning that worse may be in store unless changes are made to the channels, the flood plains, and the choke points such as culverts.

The impact of Lake Barcroft and its dam on the downstream water is the same as if the dam and lake did not exist. The design and operating rules of the gate control system <u>do not</u> add to the natural flow over the dam gate. If anything, they introduce a small time lag in passing storm water over the gate that marginally moderates flow in the downstream channels.

Large volumes of water flowing through the lake from Tripps Run and upper Holmes Run are likely to contribute to flooding in some areas of lower Holmes Run and Cameron Run. However, Lake Barcroft does not have the capacity to store storm water. The dam was designed to create a reservoir, not to impound storm water. There is only a 6-inch working freeboard and an additional 2-1/2 feet of <u>emergency</u> freeboard beyond that before we risk Agnes-like erosion of the earthen embankments on either side of the dam. Weather predictions are too unreliable to risk either delayed or premature gate opening, and it is not possible to lower the lake significantly because hydrostatic pressure would collapse seawalls and cause immense damage.

Lake Barcroft occupies 1.5% of its watershed. If one half-inch of rain falls in the entire watershed, and if the lake could somehow retain all that water (which it cannot), its water level would rise nearly six feet. The experience of Lake Needwood near Rockville, MD, during the June, 2006, rain events shows what a storm water impoundment dam does in response to high rainfall. Their water level rose 25 feet and nearly caused the dam to fail!

Lake Barcroft performs a valuable service for downstream areas by traping all the trash, debris and heavy sediments carried with the storm water from 14.5 square miles of Fairfax County and Falls Church. The result is cleaner water downstream to the Potomac River and, ultimately, the Chesapeake Bay.

<u>It is unfortunate that some properties downstream were flooded by the June storm. However, the flow of water down Holmes Run and into Cameron Run and the watershed was a direct result of the amount of rain and the speed of watershed drainage. The Lake Barcroft dam did nothing to increase the flow, and had no capacity to decrease it. What flowed into the lake flowed out.</u>