BOSWELL MCCLAVE ENGINEERING ENGINEERS ■ SURVEYORS ■ PLANNERS ■ SCIENTISTS
EST. 1924
330 Phillips Avenue • P.O. Box 3152 • South Hackensack, N.J. 07606-1722 • (201) 641-0770 • Fax (201) 641-1831

December 6, 2011

The Honorable Mayor and Council
Borough of Westwood
101 Washington Avenue
Westwood, New Jersey 07675

Re: Pascack Brook Flood Study
Woodcliff Lake and Oradell Reservoirs
Borough of Westwood
Bergen County, New Jersey
Our File No. WW-532

Dear Mayor Birkner and Members of the Council:

Boswell McClave Engineering is pleased to submit this report regarding the above referenced matter. The study, which was approved under your Resolution #11-213, consisted of:

- Meeting with United Water and their engineer, Buck, Seifert & Jost, Inc. (BS&J), and obtaining hydrologic and hydraulic analyses of the Woodcliff Lake Reservoir.

- Review of Hydrologic Engineering Center-River Analysis System (HEC-RAS) Analysis of Pascack Brook performed by BS&J.

- Review of United Water operational procedures for both the Woodcliff Lake and Oradell Reservoirs.

- Review of New Jersey Department of Environmental Protection (NJDEP) Operating Permit for Woodcliff Lake Reservoir.

It is to be noted, in addition to the above services, we have reviewed Federal Emergency Management Agency (FEMA) flood maps of the Pascack Brook and a 1977 study by the Army Corps of Engineers (ACOE), and have performed an independent analysis of the Pascack Brook flooding. The analysis included a review of the United States Geological Survey (USGS) flood data. We also performed routing computations for recent floods through the Woodcliff Lake

Reservoir and analyzed options to improve the attenuation effect of the Woodcliff Lake Reservoir.

EXECUTIVE SUMMARY

1. The flood data for Westwood from 1935 to 1999 displays there were four floods greater than 1,500 cfs. From 2000 to 2010 there were also four floods greater than 1,500 cfs. This year alone, there have been four significant rainfall events which led to major flooding.

2. The Woodcliff Lake Reservoir has not caused downstream flooding and, in many cases, it has mitigated the impact of flooding by providing flood storage capacity.

3. The Woodcliff Lake Reservoir is operated by United Water in either a summer mode or winter mode. In summer mode, which extends from May 1st through August 31st, the discharge gates of the reservoir are set at elevation 95.0′. During a rainfall event, when the water level in the reservoir rises above 95.0′, the gates are lowered automatically in one-foot increments to relieve the stormwater inflow into the reservoir. The water level is maintained above elevation 95.0 until the rain ceases.

   In winter mode, which is September 1st to April 30th, the discharge gates of the reservoir are adjusted to elevation 91.0′. During a rainfall event, if the water elevation increases to approximately 92.5′, the gates are raised automatically until the water level reaches elevation 95.0′ while maintaining a water elevation over the gates at a maximum of 1.5′. Maintaining 1.5′ of water over the gates limits the discharge from the reservoir to approximately 1,400 cfs or 628,320 gallons per minute.

4. The volume of water in the Woodcliff Lake Reservoir between elevation 91′ and 95′ is approximately 218 million gallons or 1.6% of United Water's reservoir system storage capacity comprised of Lake Deforest, Lake Tappan, the Oradell Reservoir and the Woodcliff Lake Reservoir, according to the NJDEP Water Allocation Permit.

5. It is recommended that for maximum flood mitigation United Water operate the Woodcliff Lake Reservoir year round in winter mode or, in the alternate, lower the Woodcliff Lake Reservoir to elevation 91.0′ in the summer period when storms of large and moderate magnitude are forecasted and then proceed with winter mode operation.

This report presents a description of the engineering performed and findings of the study.

1. Meeting

We held two (2) presentation meetings with United Water and BS&J. These presentation meetings took place at the United Water office in Haworth on September 6, 2011; and September 22, 2011. The September 6, 2011 meeting was scheduled by this office, and the September 22, 2011 meeting was arranged by the Borough of New Milford.

Appendix "A" includes documents given to us at these meetings. These documents provide pertinent information on the storage capacity of the Oradell, Lake Tappan and Woodcliff Lake Reservoirs owned and operated by United Water, and flood discharges during Tropical Storm Floyd on September 16, 1999; a nor'easter on April 16, 2007; and Hurricane Irene on August 28, 2011.

The storage data for the reservoirs indicates the Woodcliff Lake Reservoir provides 10%± of the overall capacity of these three (3) reservoirs. The documents also include information on the Woodcliff Lake and Oradell Reservoir Dams, the USGS stream flow graphs at the Park Ridge and Westwood gauging stations, and flow routing hydrographs for flooding that occurred in March and April 2011, prepared by BS&J. The inflow-outflow hydrographs indicate the Woodcliff Lake Reservoir attenuated the peak flow of the Pascack Brook during the March and April 2011 storm events when the reservoir was in winter mode operation.[1]

Also included in Appendix "A" are graphs showing changes in the relation of rainfall and runoff, and a trend showing an increase in precipitation since the 1960's.

2. HEC – RAS Analysis

BS&J provided HEC-RAS computations for the Pascack Brook on a CD-Rom. The computations include water surface elevations of the Pascack Brook from the Woodcliff Lake Reservoir to the Westwood municipal boundary for floods of 500 cfs, 1,000 cfs, 1,500 cfs and 2,000 cfs. These discharges represent small to moderate floods in the Pascack Brook. In comparison, the 10-Year and 100-Year Flood discharges of the Pascack Brook at Westwood (at the location of the USGS gauging station) are 1,780 cfs and 4,400 cfs, respectively.

A comparison of the HEC-RAS data with FEMA flood panels indicates the BS&J water surface computations are based on different Manning's Roughness Coefficients than those of the FEMA study. Also, the cross sections are not at the same locations as those

[1] The water level in the reservoir is maintained at 91.0' during the winter mode operation (September 1st through April 30th)

of the FEMA study. Therefore, these computations are excluded from this report. However, we have included the FEMA flood profiles of the Pascack Brook from the Woodcliff Lake Reservoir to the Oradell Reservoir in Appendix "B." An overall Flood Map of the Pascack Brook is included in this report. This map was prepared using the current FEMA Flood Panels 93, 94, 181, and 182 of the County of Bergen, dated September 30, 2005. As the Flood Map indicates, the flooding extends over 2,000' wide in parts of the Borough of Westwood.

The extensive flooding of the Pascack Brook has been known for decades. Nearly 35 years ago, the ACOE conducted a feasibility study to control flooding in the Pascack Brook. The results of the study were published in a report titled, "Hackensack River Basin, New York and New Jersey, Pascack Brook Flood Control Feasibility Study," dated September 1977. The study included non-structural measures, channel excavation, levees and floodwalls, a diversion pipe along Muddy Creek, and the removal of the Woodcliff Lake Reservoir Dam. The flood control measures that were proposed in the study consisted of lowering the stream bed four (4) to five (5) feet and providing a channel top width of 70' to 90' for a 19,000'± reach of the Pascack Brook extending from the Woodcliff Lake Reservoir Dam to Cedar Avenue. The study also concluded that four (4) bridges, including those at Hillsdale Avenue, Paterson Street, the Erie Lackawanna Railroad and Broadway within this reach of the Pascack Brook and Brookside Avenue downstream thereof, would have to be replaced. In addition, floodwalls up to 9' high and levees up to 10' high would have to be constructed within this reach of the brook. An excerpt of the 1977 ACOE report is enclosed as Appendix "C."

We have examined the option of piping the Pascack Brook from the Woodcliff Lake Reservoir to the Oradell Reservoir. A preliminary engineering assessment indicates in order to contain the 100-Year Flood, a flood channel consisting of three (3) cells approximately 17' wide by 10' high would be required. In order to develop a preliminary cost estimate, we secured a cost estimate for the structure from a precast concrete supplier and developed installation and construction cost estimates from discussions with experienced contractors and prior experience. The construction cost of such an installation alone would amount to over $250 million dollars. This construction cost estimate does not include the cost of easement acquisition, and engineering and permitting fees.

3. United Water Operation Procedures for the Woodcliff Lake and Oradell Reservoirs

The Woodcliff Lake Reservoir operation consists of a summer mode and a winter mode. In the summer mode, which extends from May 1st through August 31st, the gates (two gates each 65' long) are set at elevation 95'. The dry weather flow is discharged through two 24" gated outlets at elevation 65.0'. During a storm event, the gates are automatically lowered gradually from elevation 95.0' in one (1) foot increments in an effort to relieve the stormwater inflow to the reservoir. In the completely open position at elevation 89.0', the gates can discharge nearly 9,000 cfs through the spillways when the water level builds up to elevation 96.0'.

We understand that during Hurricane Irene on August 28, 2011, the water surface level was initially at 90.5' and the gates were lowered to elevation 91.0' (winter mode operation) before the storm to partially store the runoff volume in the reservoir in order to alleviate peak discharge. Notwithstanding these operational procedures, Hurricane Irene caused flooding to occur downstream of the reservoir.

During winter mode operation which extends from September 1st to April 30th, the top of the gates are lowered to elevation 91.0'. When a storm occurs, the water is allowed to rise by 1.5' (to elevation 92.5'±) before the gates are operated. This limits the discharge from the reservoir to approximately 1,400 cfs, which is found to be the passage capacity of the Paterson Street Bridge. When the water rises, the gates are automatically raised to maintain a 1.5' head. This continues until the water level reaches elevation 95.0' where the gates go to summer mode operation. This procedure increases the attenuation effect of the reservoir and reduces downstream flooding. We understand that United Water used to set the automatic operation level of gates to 1.75' above elevation 91.0'; however, with growth in development, they lowered it to 1.5' to reduce discharge from the reservoir.

The Oradell Reservoir Dam, built in 1923 and modified in 1955, has a 331' long spillway and seven (7) manually operated sluice gates, each 7' wide by 9.0' high. The spillway crest is at elevation 23.16', the invert of the sluice gates is at elevation 2.67', and the tailwater is at elevation 7.0'. The normal water level of the Oradell Reservoir is at elevation 17', and the top of its dam is at elevation 25.9'. Photographs of the Woodcliff Lake Reservoir and Oradell Reservoir Dams are also enclosed in Appendix "A."

The stage-storage table and the summer operation stage-discharge graph for the Woodcliff Lake Reservoir are included in Appendix "D." Also included in this Appendix is relevant engineering data for the Woodcliff Lake Reservoir Dam.

4. NJDEP Operating Permits for the Woodcliff Lake Reservoir

Appendix "E" provides the NJDEP Water Allocation Permit for the Woodcliff Lake Reservoir issued on March 3, 2011. The permit, which is valid for twenty (20) years, beginning April 1, 2011, and expiring on March 31, 2031, gives permission to United Water to divert water from their reservoirs and wells in seven (7) municipalities in Bergen County. These municipalities include Emerson, Haworth, Hillsdale, New Milford, Old Tappan, Oradell and River Vale, with a total population of approximately 800,000 and an average monthly consumption of 91 gpcd.

The Water Allocation Permit does not specify any water level requirement for the Woodcliff Lake Reservoir. However, we have been advised by BS&J that based on water budget and safe yield analysis, it has been determined that the water level at the reservoir has to be maintained at 95.0' elevation in order to meet the summer demands of their customers.

5. INDEPENDENT ANALYSIS

To determine whether or not the Woodcliff Lake Reservoir has any adverse downstream impact on the Pascack Brook flooding, we performed an independent investigation. The investigation consisted of the following:

I. Review of the USGS annual flood data at their gauging stations in Park Ridge, Hillsdale and Westwood.

II. Develop a flood discharge–drainage area relation for the Pascack Brook and compare calculated vs. observed flood discharges in Westwood.

III. Perform routing computations of flood hydrographs through the Woodcliff Lake Reservoir.

IV. Evaluate operational procedure modifications to lessen downstream flooding.

These engineering analyses which were not included in our scope of services approved by the Borough are described in the following sections of this report.

I. REVIEW USGS FLOOD DATA

Appendix "F" includes peak flood data of the USGS gauging stations of the Pascack Brook at Park Ridge, Hillsdale and Westwood. The drainage area of the Pascack Brook at these stations are 13.4, 20.7 and 29.6 square miles, respectively. The data indicates floods exceeding 1,500 cfs which occurred five (5) times in Park Ridge; however, only three (3) times in Hillsdale since Tropical Storm Floyd in 1999. This flooding information is worth noting, considering that the drainage area of the Pascack Brook is over 1.5 times larger in Hillsdale than in Park Ridge. The explanation of this unusual behavior is the attenuation effect of the Woodcliff Lake Reservoir.

The flood data for Westwood indicates floods greater than 1,500 cfs occurred four (4) times from 1935 to September 16, 1999 (Tropical Storm Floyd); and four (4) times from 1999 to 2010. However, during this year alone there have been four (4) major floods, including those on March 6th, 7th, April 12th, June 23rd and Hurricane Irene on August 28th.

II. DEVELOP DISCHARGE - DRAINAGE AREA RELATION

Using the annual flood data in Appendix "F," we have prepared a graph of flood discharges at the Westwood gauging station vs. those at Hillsdale. This graph, also included in Appendix "F," shows a straight line relation on a log to log paper. Since both of these stations are located downstream of the Woodcliff Lake Reservoir, this relationship is independent of any effect of the reservoir. Also, since the land between the Hillsdale and Westwood gauging stations is, to a great extent, residential and fully developed, it is fair to assume the discharge is solely related to drainage area. Based on this assumption, we developed the following equation between the flood discharges at these locations:

$$(Q_{Westwood}/Q_{Hillsdale}) = (29.6/20.7)^{0.67}$$

In the above equation, 29.6 and 20.7 represent the drainage areas of the Pascack Brook at the Westwood and Hillsdale stations, respectively. The above relation may be expressed as:

$$Q \sim A^{0.67}$$

Based on the above relation, we then calculated discharges at Westwood using those at Park Ridge station (13.4 mi^2 drainage area)

$$Q_w = Q_{pr}\,(29.6/13.4)^{0.67}$$

where Q_w and Q_{pr} represent flood discharges at Westwood and Park Ridge, respectively. The above equation simplifies as:

$$Q_w = 1.7\,Q_{pr}$$

Table 1 lists measured discharges at the USGS Park Ridge and Westwood gauging stations for annual floods since Tropical Storm Floyd in 1999. Also listed on this table are the flood discharges at Westwood calculated using the above equation.[1] This table indicates that the measured flood discharges at

---

[1] Note that the DEP's 1997 Technical Manual for Land Use Regulation Program has a similar formula, however, with a 0.75 exponent which is less conservative than ours.

Westwood are far smaller than the calculated values, except for Tropical Storm Floyd. During this immense storm, the calculated and measured floods are practically equal. The table also shows that measured floods at Westwood for all floods except for Floyd in 1999 and the nor'easter in 2007 are smaller than those of Park Ridge with a drainage area of 45% as that of Westwood. Thus, this table clearly indicates that the Woodcliff Lake Reservoir has not been a reason for flooding at Westwood. Rather, it has had a damping effect on flood peaks.

III. FLOOD ROUTING THROUGH THE WOODCLIFF LAKE RESERVOIR

To evaluate the impact of the Woodcliff Lake Reservoir on flood hydrographs, we obtained real time stream flow data at Park Ridge and Westwood from the USGS. Appendix "G" includes flood stage and flood discharge hydrographs for a 120-day period prior to October 13th when the data was received. Using these hydrographs, we focused on the June 23, 2011 and July 8, 2011 flood hydrographs at Park Ridge and Westwood. These hydrographs, also included in Appendix "G," show peak discharges of 2,580 cfs at Park Ridge and 2,280 cfs at Westwood during the June 23rd storm. Likewise, the July 8, 2011 hydrographs indicate peak discharges of 1,230 cfs and 353 cfs at Park Ridge and Westwood, respectively.

Based on the discharge – drainage area relation described in a previous section, we generated the flood hydrograph at the Woodcliff Lake Reservoir. Then we routed these floods through the reservoir using the United Water stage-storage-discharge relations for the reservoir. Routing computations for the June 23rd storm, included in Appendix "H," show peak inflow and outflow discharges of 3,354 cfs and 3,136 cfs, respectively. Thus, our computations demonstrate that the Woodcliff Lake Reservoir did not aggravate flooding downstream. Rather, it created a 6.5±% attenuation in the flood peak during the June 23rd storm. The computations for the July 8th flood also show peak inflow–outflow discharges of 1,599 cfs and 1,580 cfs, respectively.

IV. SUGGESTED OPERATIONAL MODIFICATIONS OF FLOOD GATES

To determine if further flow attenuation can be achieved through operational modification of the gates, we examined the following options:

A. Operating one (1) gate at a time.

B. Lowering the water surface elevation to 93.0' before a storm, and storing water to elevation 95' before operating the gates.

C. Lowering water surface elevation to 91.0' and storing water to elevation 95' before operating the gates.

The computation results for these options are described below:

A. Operating (opening) one (1) gate during a storm.

This option reduces discharge from the reservoir by approximately one-half (assuming a constant weir flow coefficient) for a given water surface elevation thereby storing more water during the storm. The stage-storage table, stage-discharge chart and the routing computations for this modified procedure are included in Appendix "I." Table 2 presents the routing computation results. A review of this table indicates this operational modification would further reduce the discharge by 17 cfs to 3,119 cfs while raising the water level behind the dam by 0.18' (2"±) during the June 23rd storm. The incremental reduction for the July 8th flood is 12 cfs, which is also small. Thus, it can be deducted that operating one or both gates in summer mode has an insignificant effect on the peak discharge for large floods.

B. Lowering water level to 93.0' before a storm.

This option provides an additional 342± acre-feet of retention storage from elevation 93.0' to elevation 95.0' before the gates are opened to relieve the storm. Routing computations for this case indicate a peak discharge of 3,116± cfs and 513 cfs during the June 23rd and July 8th storms, respectively. Thus, the computations reveal that lowering the reservoir by 2' before a storm and opening one (1) gate above elevation 95.0' produces an insignificant incremental attenuation in the peak discharge from the reservoir during very large floods; however, a marked reduction during moderate floods. Table 2 also summarizes the computation results for this case.

C. Lowering the water level to 91.0'.

This option basically entails operating the Woodcliff Lake Reservoir year round in winter mode or lowering the water level to 91.0' before a storm arrives and retaining the water elevation to 95.0' before the gates are operated. In this option, approximately 671 acre-feet of water is stored before any discharge occurs. According to our calculations, this storage amounts to the runoff volume from approximately 1.6" of rainfall, which is nearly equal to one-half of the 2-Year, 24-Hour Storm.

Computations for the storms of June 23rd and July 8th, also included in Appendix "I," indicate that operating one (1) gate at a time produces a significantly greater attenuation in flood discharge than option "B." Using this option would retain storms in their entirety of similar magnitude to that of July 8th which had an approximate 5-year± frequency. As such, the discharge in Pascack Brook in Westwood would be due to the runoff from the uncontrolled 10+ square miles of drainage area downstream of the Woodcliff Lake Reservoir.

In view of the above, it is our recommendation that in order to provide some amelioration of flood events, United Water consider modifications to the operations of the Woodcliff Lake Reservoir.

Very truly yours,

BOSWELL McCLAVE ENGINEERING

Hormoz Pazwash

Hormoz Pazwash, Ph.D., P.E., D.WRE

HP/jmp
Attachments

TABLE 1

CALCULATED VS. OBSERVED FLOOD DISCHARGES (IN CFS)[1] OF PASCACK BROOK AT PARK RIDGE AND WOODCLIFF LAKE

DATE	PARK RIDGE (Q_{pr}) MEASURED	WESTWOOD (Q_w)	
		MEASURED	CALCULATED*
9/16/99 (FLOYD)	5660	9630	9625
7/18/05	2190	1170	3723
4/16/07	2450	3260	4165
9/06/08	2160	1320	3672
8/22/10	1880	1330	3196
6/23/11	2580	2280	4386
8/28/11 (IRENE)	>2700**	4630	-
9/18/11	1700	963	2890

* $Q_W = (29.6/13.4)^{0.67} \times Q_P = 1.70 \times Q_P$
Q_W = PEAK FLOW AT WESTWOOD (D.A. = 29.6 MI^2)
Q_{PR} = PEAK FLOW AT PARK RIDGE (D.A. = 13.4 MI^2)
** PEAK FLOW WAS NOT RECORDED
(1) SEE APPENDIX F FOR USGS FLOOD DATA

TABLE 2

COMPUTED INFLOW – OUTFLOW DISCHARGES
WOODCLIFF LAKE RESERVOIR

JUNE 23RD AND JULY 8TH STORMS

RESERVOIR OPERATION	PEAK OUTFLOW(CFS) / W.S. ELEVATION (FT)	
	JUNE 23RD STORM PEAK INFLOW = 3354.0 CFS	JULY 8TH STORM PEAK INFLOW = 1599 CFS
STARTING W.S. El = 95'		
BOTH GATES OPEN AT 95' ONE (1) GATE OPEN AT 95'	3136 CFS / 95.68' 3119 CFS / 95.86'	1580 CFS / 95.56' 1568 CFS / 95.68'
STARTING W.S. El = 93'		
BOTH GATES OPEN AT 95'	3116 CFS / 95.86	513 CFS / 95.50'
STARTING W.S. El = 91'		
BOTH GATES OPEN ONE (1) GATE OPEN	2863 CFS / 95.66' 2628 CFS / 95.81'	0.0 CFS / 93.89'