JENNINGS RANDOLPH RESERVOIR

"NATURAL" DAILY INFLOWS

Prepared by

Erik R. Hagen
Roland C. Steiner
Jan L. Ducnuigeen

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6110 Executive Boulevard, Suite 300
Rockville, Maryland 20852

The Interstate Commission on the Potomac River Basin

Section for Cooperative Water Supply Operations on the Potomac

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Abstract

The prior ICPRB set of daily inflows to Jennings Randolph Reservoir was examined and revised to account for local variation in sub-watershed precipitation and runoff rates. Jennings Randolph Reservoir is located on the North Branch of the Potomac River in the mountains of the upper Potomac River basin on the border between West Virginia and Maryland.

The prior ICPRB set of daily inflows to Jennings Randolph Reservoir was developed in three sections. Each section of the inflow data set was based on flow measurements from different gages in the watershed. These inflows were examined and discrepancies were noted during periods when gages used to develop the inflows overlapped. Three reasons for the differences were investigated: errors in reported gage drainage areas, inaccuracies in gage flow measurements, and differences in annual precipitation and runoff patters within gaged subwatersheds.

Subsequent investigation verified the gage drainage areas as well as the measured flow rates for the gages. Investigation of watershed precipitation records and gaged flow rates showed that local areas within the watershed had markedly different patterns of precipitation and runoff, a characteristic not uncommon in mountainous watersheds. The differences in annual precipitation correlated with the observed differences in watershed runoff, which in turn accounted for discrepancies in synthetic reservoir inflows.

Reference inflows were developed that represented the best available estimate of inflow to the reservoir. Reference inflows were developed based on gages that were located close to the site of the existing dam, and thus incorporated measured flow information from the widest possible portion of the reservoir watershed. Reference flows were used as a yardstick against which the reservoir inflows could be compared during overlapping gage periods. The comparisons suggested the following changes in the inflow data record:

1. The prior inflow record from October 1, 1929 through September 30, 1949 was **increased by 2.1 percent**.

2. The prior ICPRB inflow record from October 1, 1949 through September 30, 1985 was **decreased by 5.3 percent**.

3. The prior ICPRB inflow record from October 1, 1985 through September 30, 1996 was **decreased by 19.3 percent**.

RESERVOIR DA = 263 sq. mi.

1. Introduction

Jennings Randolph Reservoir, a multi-purpose reservoir on the North Branch of the Potomac River, is located in the mountains of the upper Potomac River basin between West Virginia and Maryland (Figure 1). Jennings Randolph Reservoir began regulating flow in July of 1981. There are currently 13.36 billion gallons (BG) of conservation storage space allocated for water supply. The water supply storage is owned by the Washington metropolitan area water utilities, and managed by the U.S. Army Corps of Engineers at the direction of the Co-op Section of the Interstate Commission on the Potomac River Basin (ICPRB).

Throughout the historical gage-record there were no gages directly measuring the inflow to the Jennings Randolph Reservoir. However, a synthetic record of "natural" daily inflows was constructed for the period from October 1, 1929 through September 30, 1996 using the area-adjustment method. ("Natural" daily inflows are those flows unaffected by upstream regulation, withdrawals, or return flows.) The area-adjustment method is used to convert gaged flows to reservoir inflows by multiplying the gaged flow by an amount equal to the area of the reservoir watershed divided by the area of the gaged drainage area. An underlying assumption implicit to the area-adjustment procedure is that each part of the reservoir watershed is equally productive.

A caveat: the area-adjustment method was selected for its ability to predict the volume of inflow to the reservoir. This technique is not appropriate for estimating the timing and magnitude of peak flows into the reservoir. Therefore, the inflow record created using this method should not be used to analyze the magnitude or frequency of peak daily flow events (e.g., as for flood risk analysis). This inflow record was instead developed and validated for use in simulation models that perform volumetric accounting of reservoir contents, for water supply planning purposes.

2. Examination of prior inflow data set

The prior ICPRB inflow data set for Jennings Randolph Reservoir was developed in three sections for water years 1929-1949, 1949-1985, and 1985-1996 using the area adjustment method. The gage records used to develop the three sections overlapped. Comparisons revealed that the inflows did not match as well as expected for overlapping periods. This portion of the report details these comparisons.

The inflow for 1929-1949 was compared with the inflow for 1949-1985. The 1929-1949 inflow was based on area-adjustment applied to the North Branch Potomac River at Bloomington gage (Bloomington gage), downstream of the site of the current reservoir. The 1949-1985 inflow was based on area-adjustment applied to the North Branch Potomac River at Kitzmiller gage (Kitzmiller gage), upstream of the site of the current reservoir. The Kitzmiller and Bloomington gages overlapped from October 1, 1949 through September 30, 1950. The average Bloomington-based inflow was 14.7 percent less than the average Kitzmiller-based inflow. Figure 2 shows that the Kitzmiller-based inflow was consistently higher than the Bloomington-based inflow.

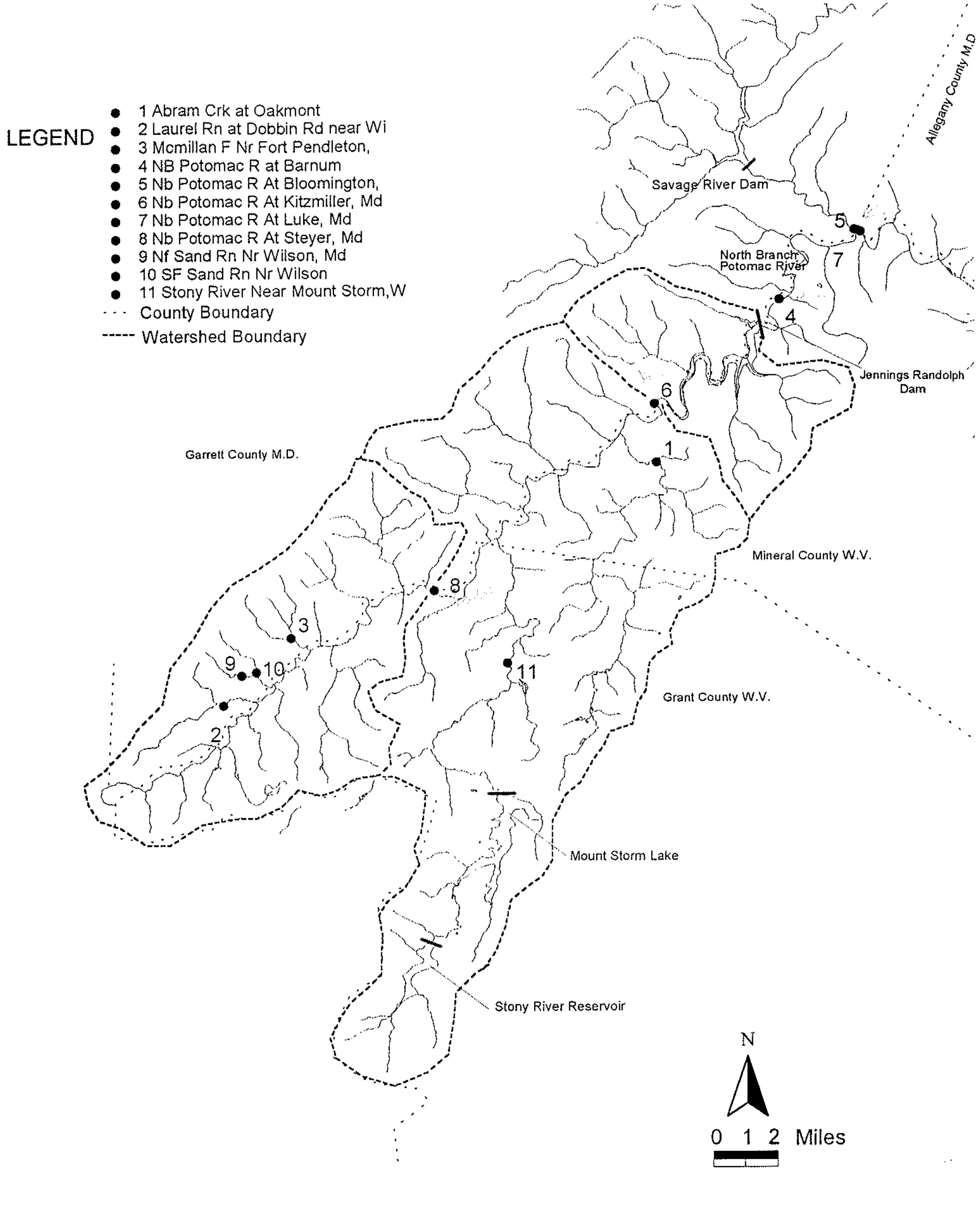


Figure 1: Jennings Randolph Reservoir watershed and neighboring Savage River, USGS gaging stations, county boundaries, and sub-watersheds.

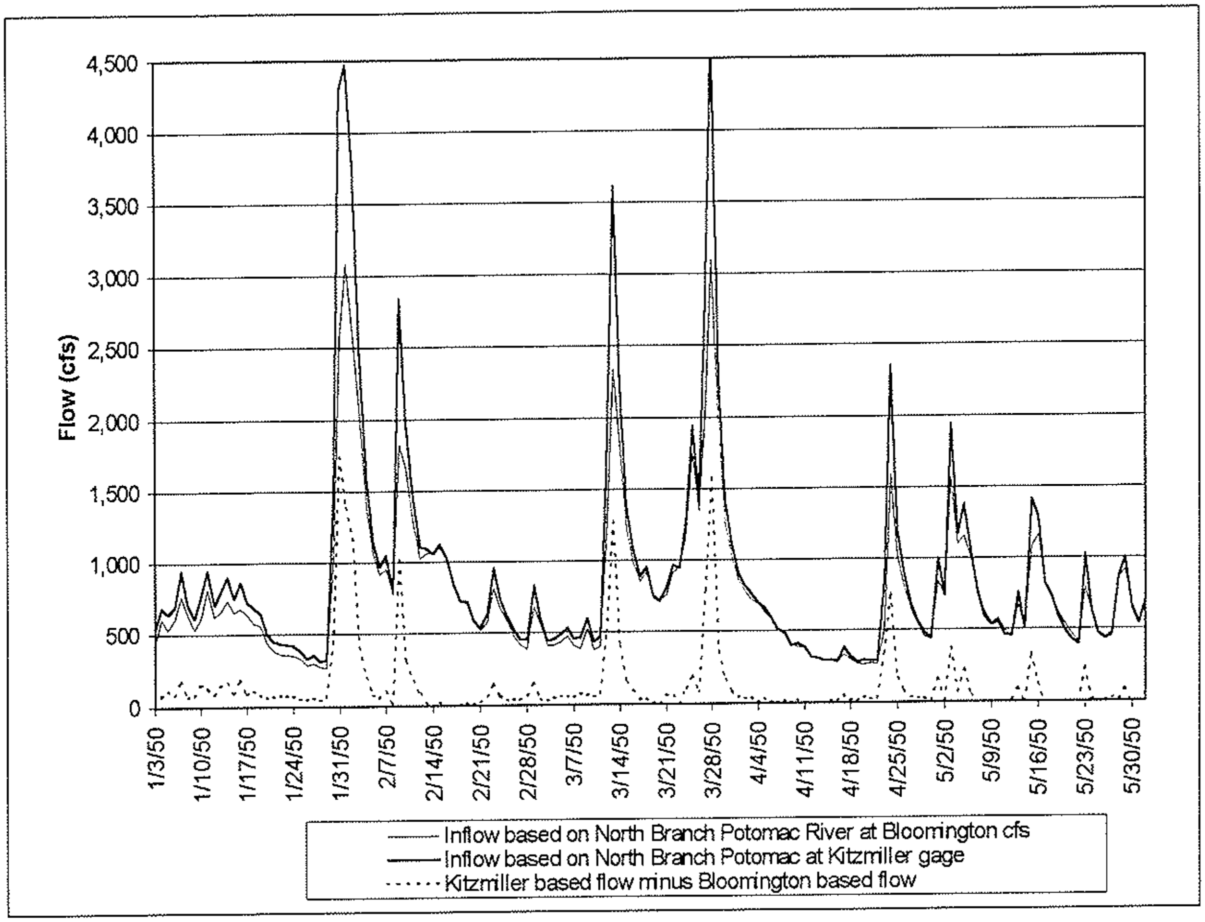


Figure 2: Example hydrograph comparing area-adjusted reservoir inflows based on the North Branch Potomac at Kitzmiller and North Branch Potomac at Bloomington gages.

The inflow for 1985-1996 was compared to the 1949-1985 Kitzmiller-based inflow. The 1985-1996 inflow was based on area-adjustment applied to the North Branch Potomac River at Steyer gage (Steyer gage). The Steyer and Kitzmiller gages overlapped from July 1, 1956 through September 30, 1985. The average Kitzmiller-based inflow was 15.3 percent less than the average Steyer-based estimate of inflow during the period of overlap. Figure 3 shows an example hydrograph of inflows calculated from the two methods. As was the case for Figure 2, inflows do not match very well.

Note that the Kitzmiller based inflow rate is 15.3 percent lower than the Steyer based flow rate, and that the Bloomington based flow rate is 14.7 percent lower than the Kitzmiller based flow rate. This comparison suggests that on average, the Bloomington based inflow rate is 32.2 percent lower than the Steyer calculated flow rate (equals 1.147 * 1.153 * 100 - 100).

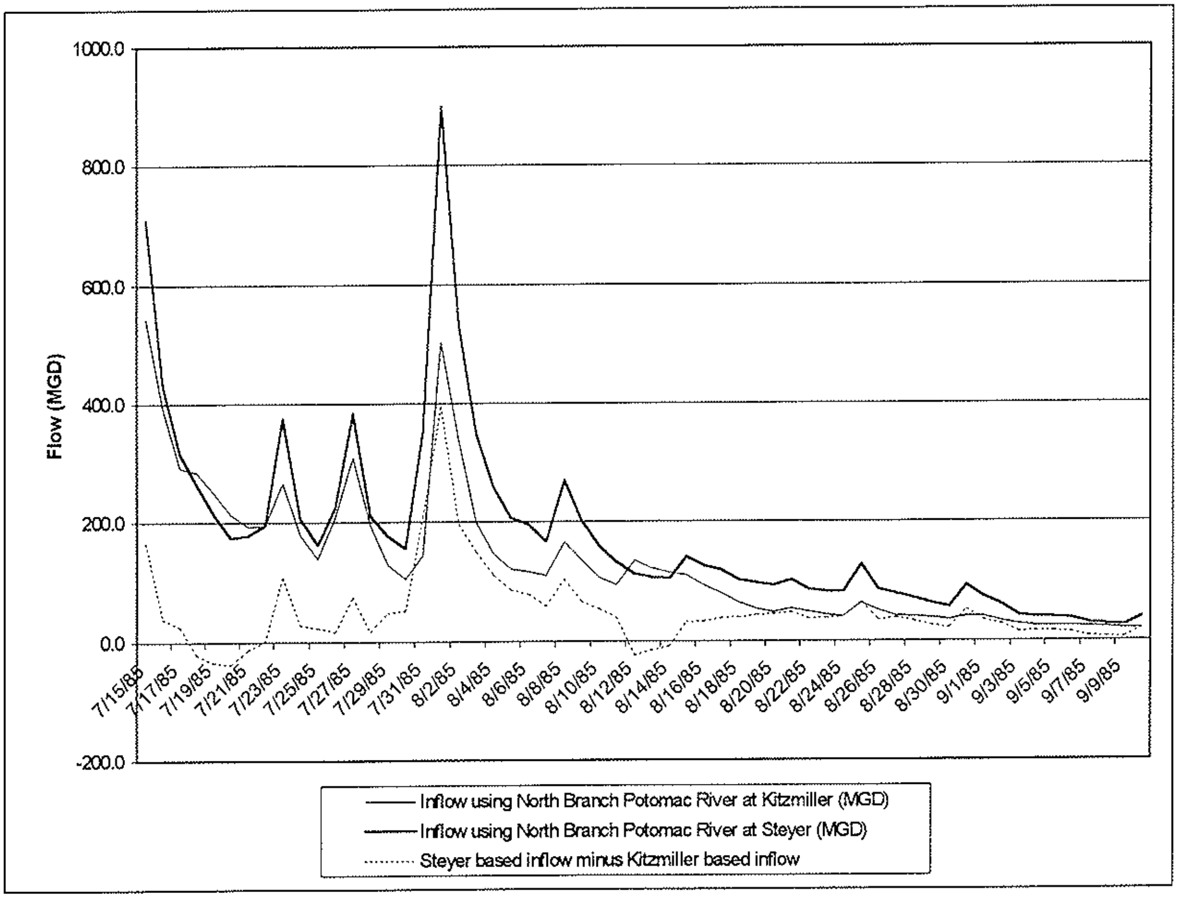


Figure 3: Example hydrograph comparing area-adjusted reservoir inflows based on the North Branch Potomac at Kitzmiller and North Branch Potomac at Steyer gages

Figure 2 and Figure 3 show a consistent difference between the compared inflows. The difference could be due to inaccuracies in the reported drainage areas, consistent errors in flow measurement, or different levels of flow productivity (runoff) for different regions within the reservoir watershed. Each of these potential causes was examined in more detail.

3. Verification of gage drainage areas

A verification of active-gage drainage areas in the Potomac was conducted by the USGS in the Charleston, West Virginia office in 1998 using planimetric analysis. Table 1 shows those gage areas that were verified in the Jennings Randolph watershed.

The report findings suggest that the original estimates of drainage area reported by the USGS are quite accurate. Only minor revisions were necessary for gaging stations in the Jennings Randolph watershed. Therefore, the discrepancies in the reservoir inflow data sets are probably not due to errors in gage drainage area.

Table 1: Original and revised drainage areas for the Jennings Randolph Reservoir watershed. (Source: USGS, 1996)

Gage	Original USGS estimates of drainage area (square miles)	Revised USGS estimates of drainage area (square miles)	Percentage change (percent)
North Branch Potomac at Luke	404	405.81	0.45
North Branch Potomac River at Steyer	73.0	73.14	0.19
Stony River	48.8	48.7	-0.21
Abram Creek	42.6	42.55	0.18

4. Verification of gage flow measurements

Fortunately, the Jennings Randolph Reservoir watershed has had many gaging stations in the upper watershed throughout the period of record. These upper-watershed stations allow for an independent verification of measured flow rates at downstream stations via area-adjustment methods. When synthetic flow rates developed from the upstream stations closely match flow rates measured at the downstream gaging station, then an independent check of the measured flow at the downstream station is obtained. (This verification of flow rates assumes that the measured drainage areas reported by the USGS are accurate.) Flow rates were verified for the gages located at Kitzmiller, Steyer, and Bloomington.

Kitzmiller Gage

Three upstream gaging stations were used to verify the flow measurements at Kitzmiller gage. These stations are the North Branch Potomac River at Steyer, the Stony River near Mount Storm, and the Abram Creek at Oakmont gages. Flows from these stations were combined and converted into a synthetic Kitzmiller flow using an area-adjustment factor of 1.369 [= 225/(42.6+73+48.7)]. The flow rates were compared from October 1, 1961 through September 30, 1982. The overall synthetic Kitzmiller flow-rate was 2.9 percent higher than the gaged Kitzmiller flow rate. That the flow rates were so close, independently verifies the Kitzmiller gage flow measurements. Figure 4 shows an example hydrograph of the synthetic Kitzmiller flow compared to the gaged Kitzmiller flow. The flows track together very closely.

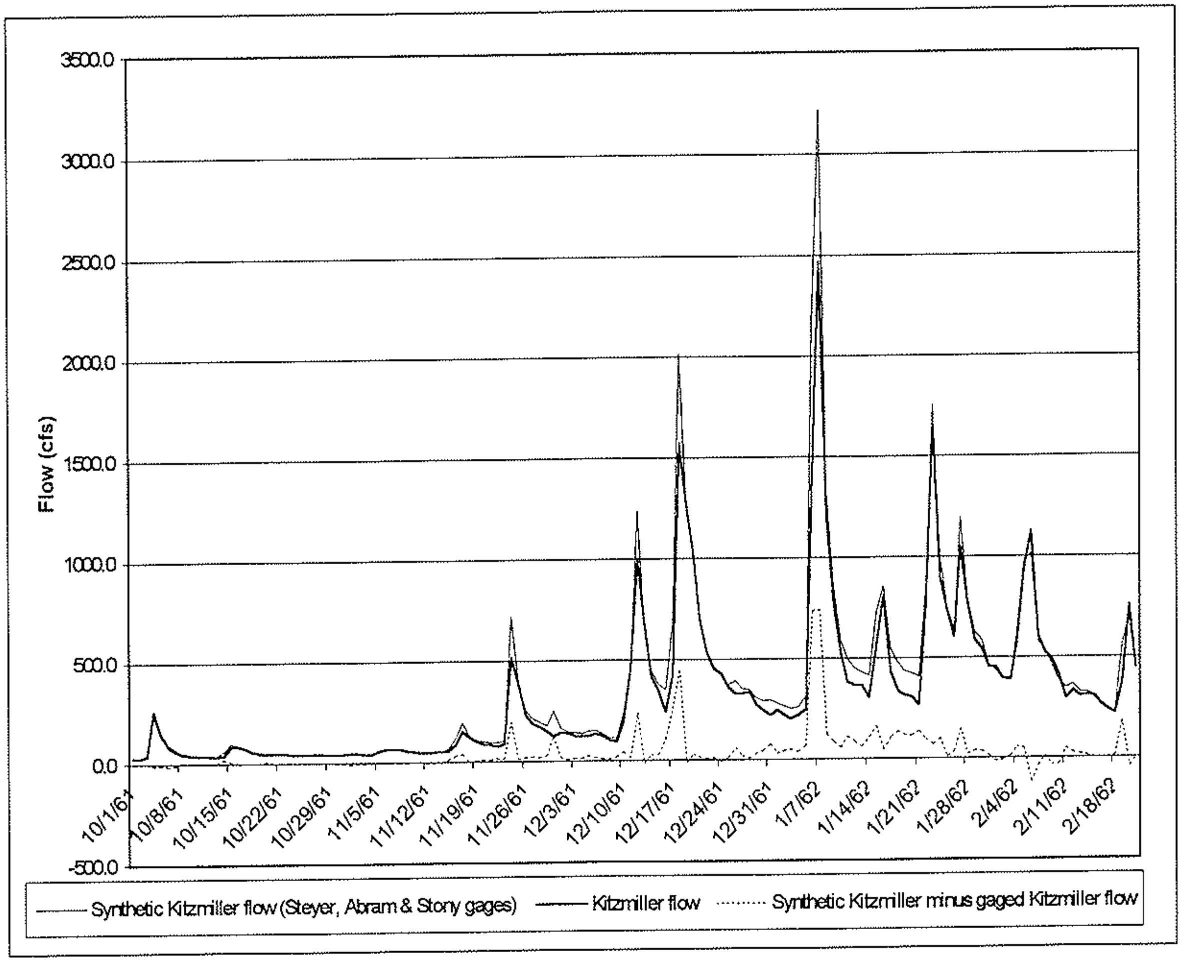


Figure 4: Example hydrograph comparing synthetic Kitzmiller flow with gaged Kitzmiller flow.

Steyer Gage

Four upstream tributary gaging stations were used to verify the flow measurements at Steyer gage. These stations measure flow from minor tributary flows to the North Branch Potomac. These stations are the North Fork Sand Run near Wilson, the South Fork Sand Run near Wilson, Laurel Run at Dobbin Road near Wilson, and Mcmillan Fork near Fort Pendleton gages. Flow from these stations was combined and converted into a synthetic Steyer flow using an area-adjustment factor of 5.868 [=73/(8.23+1.91+2.3). The flow rates were compared from October 1, 1986 through September 30, 1996. The overall synthetic Steyer flow-rate was 5.3 percent higher than the gaged Steyer flow rate, which indicates that the Steyer gage is probably not over-registering. Figure 5 shows an example hydrograph of the synthetic Steyer flow compared to the gaged Steyer flow.

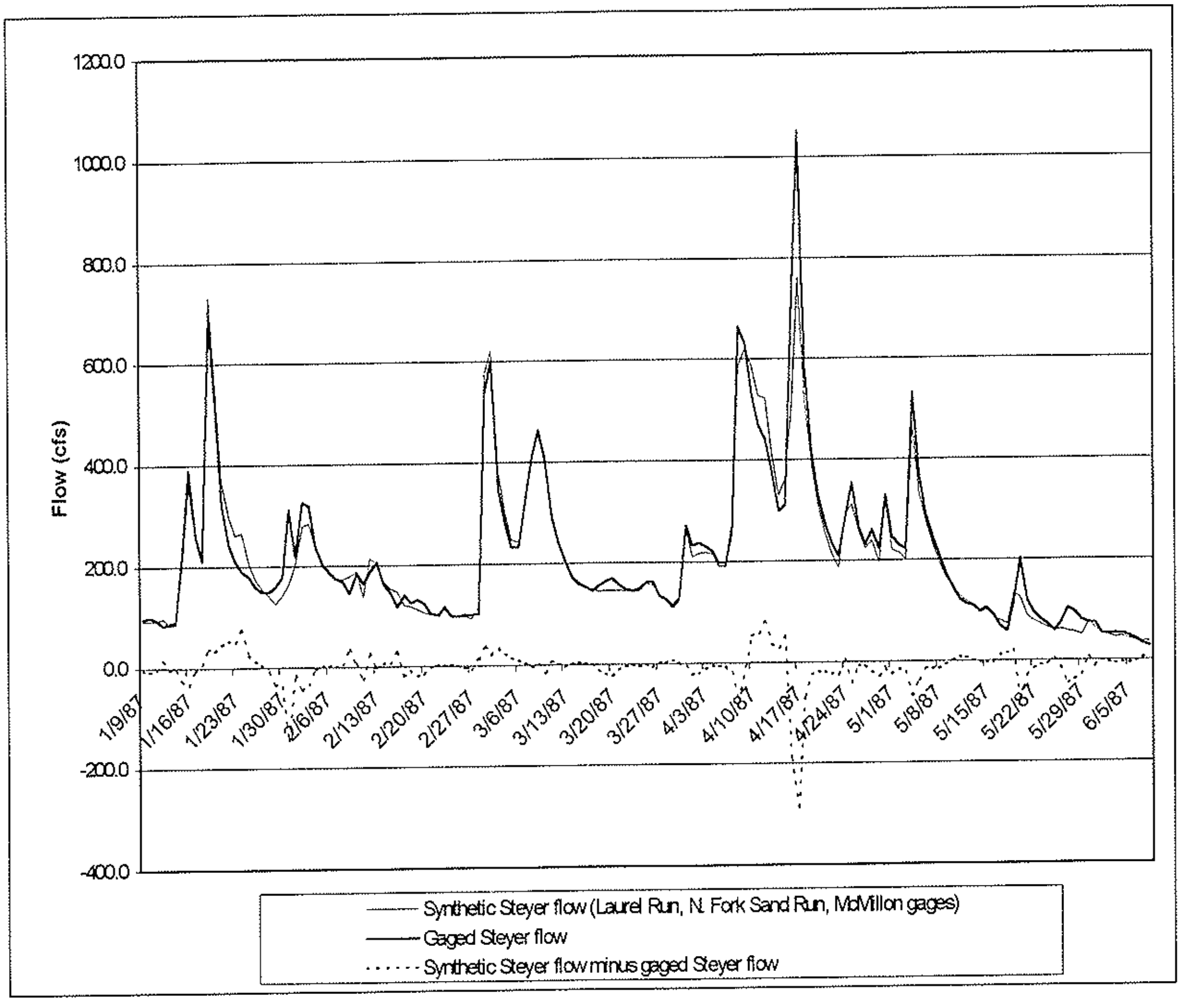


Figure 5: Example hydrograph comparing synthetic Steyer flow with gaged Steyer flow

Bloomington gage

Two nearby gages were used to verify the flow measurements at Bloomington gage, the North Branch of the Potomac River at Luke (Luke gage), and the Savage River below Savage Dam near Bloomington gage (Savage gage). The Bloomington gage site is located on the Savage River upstream of the Luke gage. The Bloomington gage site is also upstream of the North Branch Potomac's confluence with Savage River, but the Luke gage site is located just downstream of the confluence with the Savage River. Overlapping flow measurements were made from October 1, 1949 through September 30, 1950, so flow comparisons were possible. Gaged flow from the Savage gage was subtracted from the Luke gage, and converted to a synthetic flow at Bloomington using an area-adjustment factor of 0.963 [equals 287/(404-106)].

The overall synthetic Bloomington flow-rate was 0.9 percent higher than the gaged Bloomington flow-rate, which verifies the Bloomington gage record of daily flows. Figure 6 shows an example hydrograph of the synthetic Bloomington flow compared to the gaged Bloomington flow.

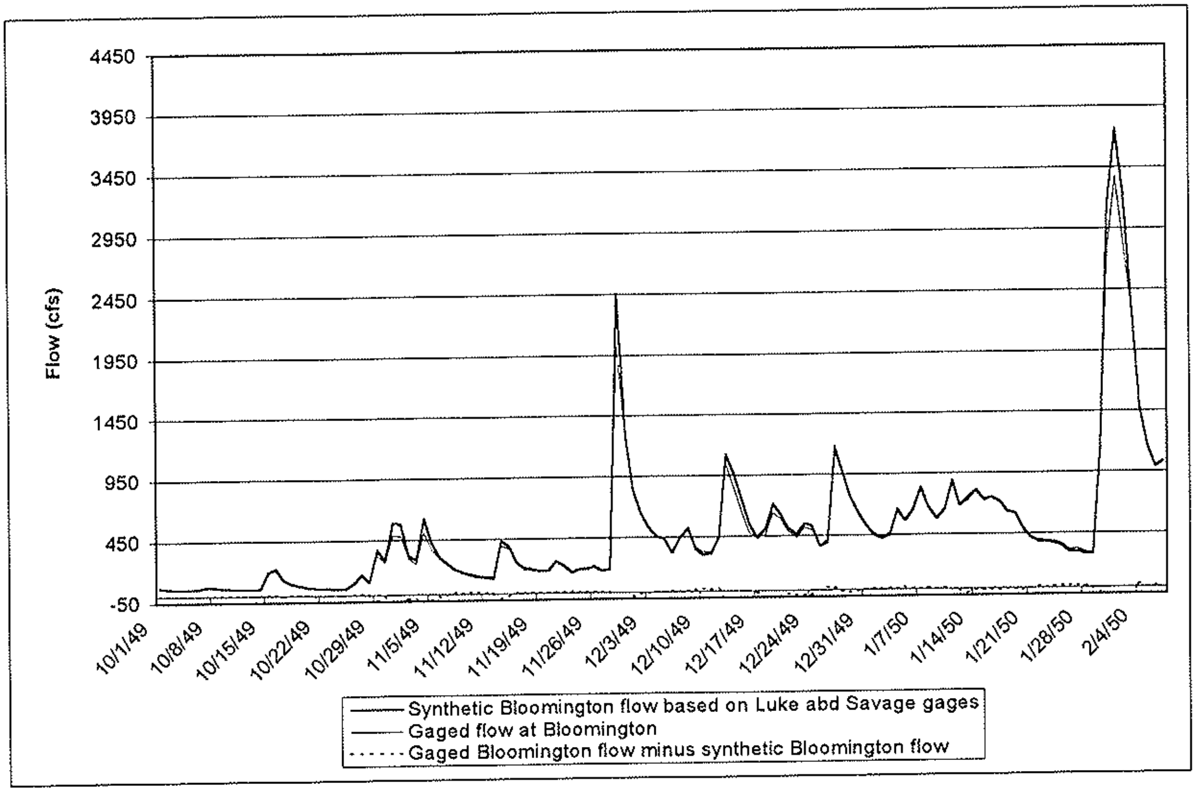


Figure 6: Example hydrograph comparing synthetic Bloomington flow with gaged Bloomington flow.

The measured flow rates at Kitzmiller, Steyer, and Bloomington gages were between 0.9 and 5.3 percent of synthetic flow rates developed using area-adjustment methods applied to nearby gages in the watershed. These relatively close percentages suggest that the 14.7 to 15.3 percent discrepancies in the prior inflow data set are probably not due to errors in measured flow rates at these gages.

5. Investigation of subwatershed runoff and precipitation

An underlying assumption implicit to the area-adjustment procedure is that runoff per square mile is the same throughout the watershed. Because gage-drainage areas and measured flow rates were independently verified, the likely remaining factor that could cause discrepancies in the prior inflow data set was different levels of runoff for different regions within the watershed.

Average runoff (productivity) was examined by dividing each sub-watershed's average flow rate by its contributing drainage area. To determine the flow specific to each sub-watershed, daily gaged flow going out of the watershed was subtracted from daily gaged flow going into the watershed. Productivity was computed over two intervals, from October 1, 1961 through September 30, 1979 and from October 1, 1980 through September 30, 1996. Productivity values are shown in Figure 7. Generally, watershed productivity increases towards the headwaters of the watershed. During the period 1961-1979, runoff was lowest downstream from Kitzmiller gage (1.6 in/month), and highest upstream from Steyer gage (2.7 in/month).

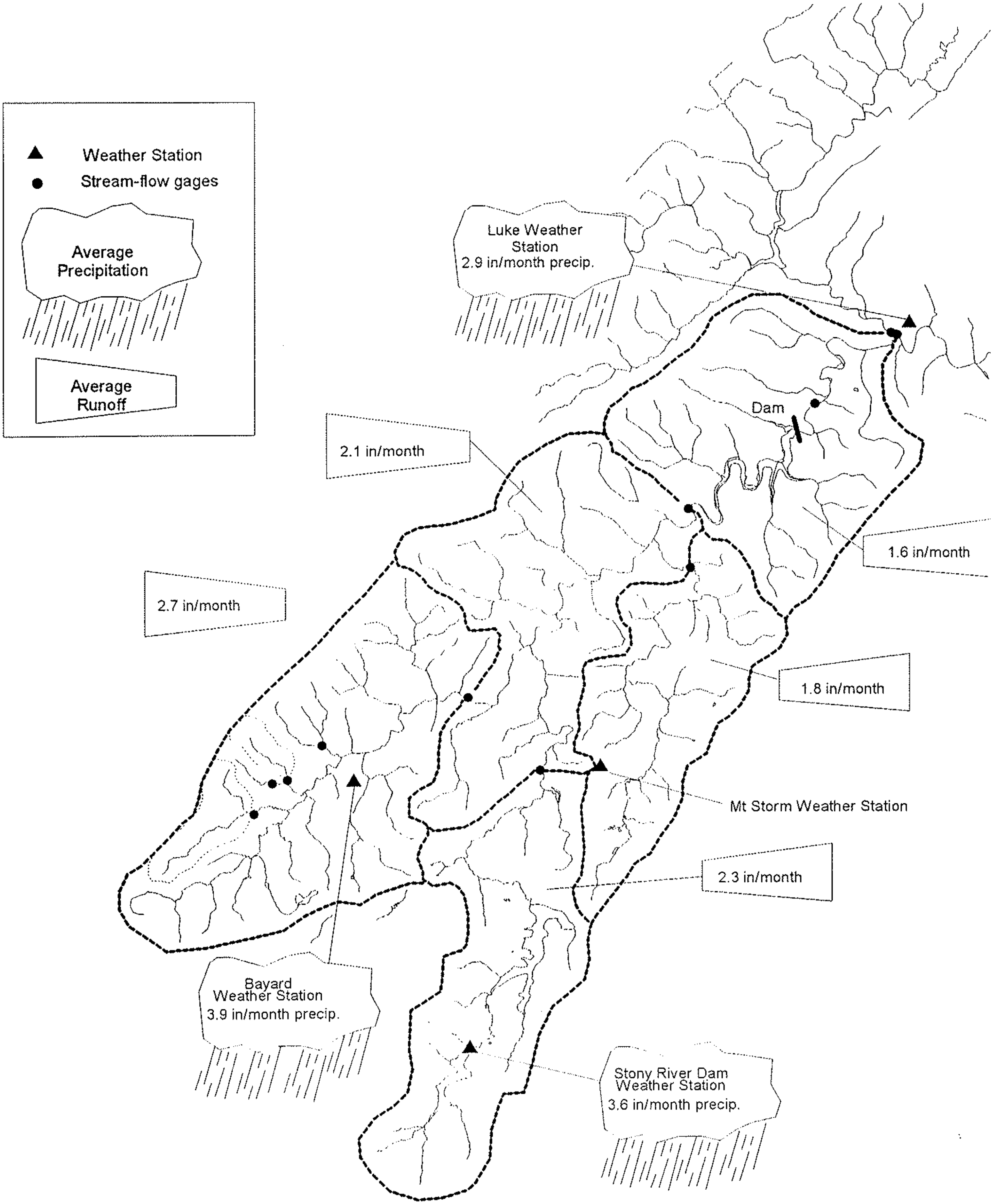


Figure 7: Average monthly runoff and precipitation rates for selected sub-watersheds

Annual precipitation records within the watershed were investigated to see if differences in rainfall amounts might account for the variation in watershed runoff. Precipitation data were obtained from the National Climate Data Center, for stations located within the Jennings Randolph watershed (U.S. Department of Commerce, 1998). A comparison of the total average annual precipitation for these stations revealed significant differences. Figure 8 shows several precipitation gage records in the reservoir watershed from 1931 through 1974, and reveals that annual rainfall at Luke was consistently lowest.

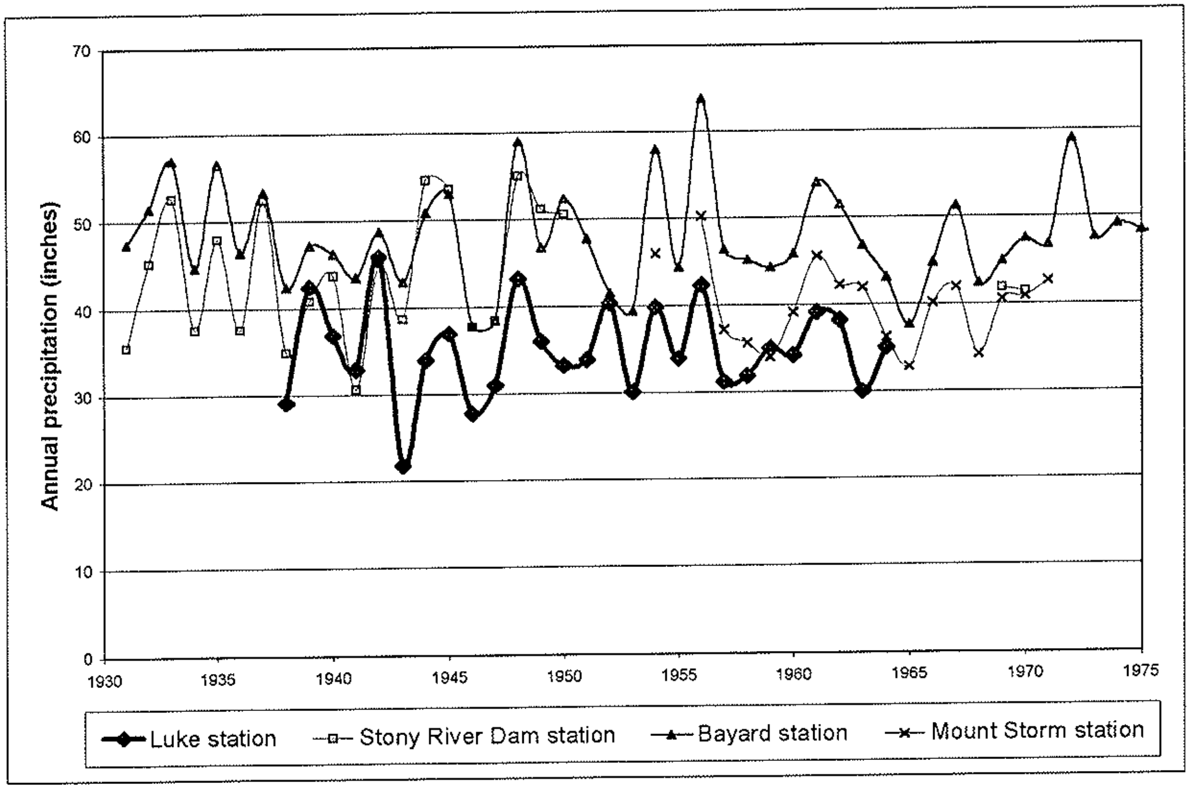


Figure 8: Average annual precipitation for Luke, Stony River Dam, Bayard, and Mount Storm weather stations.

A recent USGS report provides a map of average annual precipitation in the Potomac River Basin (USGS, 1996 b), verifying that average precipitation in the lower portion of the reservoir watershed is significantly lower than in the higher portion (Figure 9). The decrease in average annual precipitation from the high western mountains to the South Branch Potomac and Shenandoah River areas is probably caused by orographic effects of the western Appalachian Mountains (USGS, 1996 b).

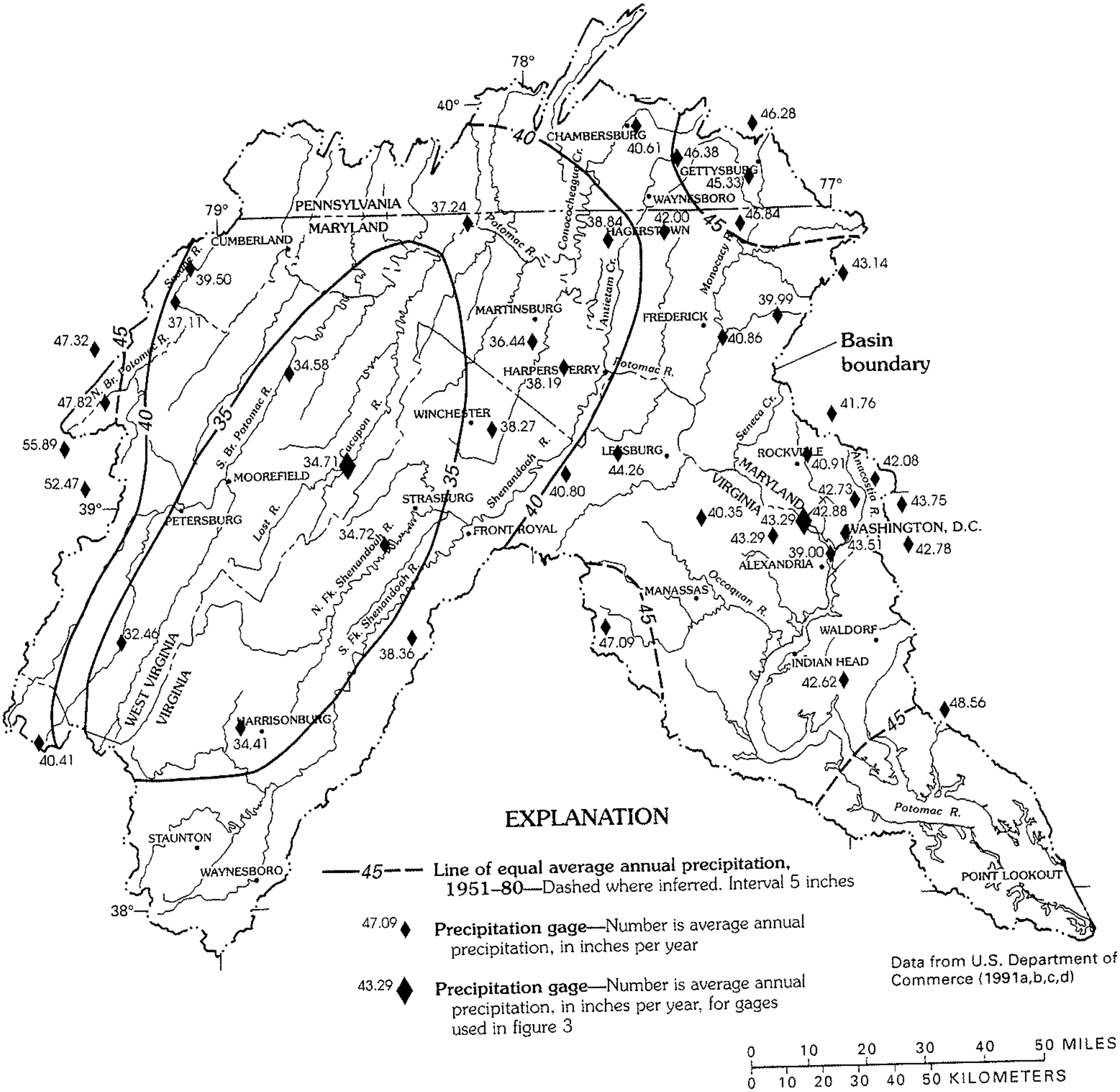


Figure 9: Average annual precipitation in the Potomac River Basin, 1951-80 (Map Source: U.S. Geological Survey (1996 b))

The differences in annual precipitation values correlated with differences in runoff in the watershed, as shown in Figure 10. The comparison in Figure 10 is not ideal since different periods were compared (1938-1948 for the precipitation vs. 1961-1979 for the subwatersheds' annual runoff). However, the average annual 1938-1948 precipitation was 33 percent higher at Bayard than at Luke, which roughly corresponds to the differences found in average annual runoff rates between the upper and lower watershed.

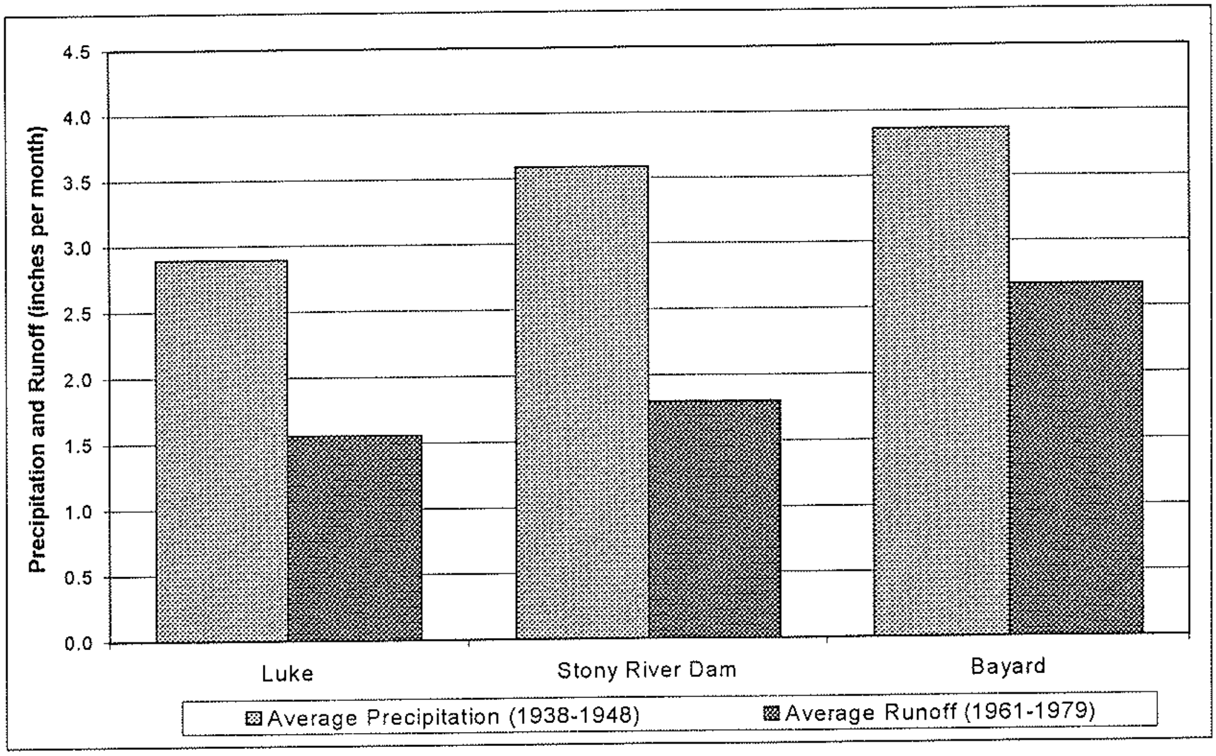


Figure 10: Correlation between average monthly precipitation and average monthly runoff for Luke, Stony River Dam, and Bayard weather stations and sub-watersheds

The differences in annual precipitation probably account for the observed differences in watershed productivity, which in turn accounts for discrepancies in synthetic reservoir inflows. Higher average rainfall in the Steyer sub-watershed causes the Steyer-based reservoir inflow rate to be higher than the Bloomington-based reservoir inflow rate. Higher average rainfall upstream from the Kitzmiller gage causes the Kitzmiller-based inflow rate to be higher than the Bloomington based inflow rate. Differences in watershed productivity can be quantified and used to develop better estimates of reservoir inflow, as discussed below in the section *Inflow development*.

6. Inflow development

Table 2 summarizes the different stream gages and time periods used in the development of each segment of the Jennings Randolph Reservoir inflow record.

Table 2: Stream gages used to develop the Jennings Randolph Reservoir inflow record

Synthetic inflow period of record	U.S.G.S. stream gages used for record generation	Gage number	Drainage Area (Sq. miles)
10/1/1929-9/30/1950	North Branch Potomac River at Bloomington	01596000	287
10/1/1950-6/30/1966	North Branch Potomac River at Kitzmiller	01595500	225
7/1/1966-6/30/1981	North Branch Potomac River at Barnum	01595800	266
7/1/1981-9/30/1985	North Branch Potomac River at Kitzmiller	01595500	225
10/1/1985-9/30/1996	North Branch Potomac River at Steyer	01595000	73.0

The development of each component of the inflow record, throughout the simulation period, is described below. Flow at North Branch Potomac at Barnum gage (Barnum gage) provided a reference against which the flows were compared. The Barnum gage provides the best available estimate of inflow to Jennings Randolph Reservoir since it is located just below the site of the current dam. (The drainage area to Barnum gage is 266 square miles, and the drainage area to Jennings Randolph Reservoir is 263 square miles.) The Barnum gage was operational from July 1, 1966 to September 30, 1985.

1929-1950

The inflow record to Jennings Randolph Reservoir from October 1, 1929 through September 30, 1950 is based on daily stream gage flows measured at the Bloomington gage. This gage was downstream of the current reservoir site and has a drainage area of 287 square miles. The Bloomington gage flows were multiplied by an area-adjustment factor of 0.9164 (equals 263 divided by 287) and increased by a factor of 2.1 percent to develop a set of Jennings Randolph inflows.

The 2.1 percent factor was developed to account for differences in sub-watershed runoff. The drainage area contributing to flow at the Bloomington gage included some area that was not in the Jennings Randolph Reservoir watershed and that had the lowest values of annual runoff and precipitation. Therefore, the inflow based on Bloomington gage under-represented reservoir inflow. A comparison of gaged flow from the Bloomington subwatershed and gaged flow at Barnum was conducted to quantify the difference in sub-watershed runoff.

A comparison of Bloomington gage with Barnum gage was not directly possible, since the gage records do not overlap. However, Luke and Savage gages were used to closely approximate the Bloomington gage record (within 0.9 percent) as shown in the section, *Verification of gage flow measurements—Bloomington gage* on page 8.

The approximated Bloomington flow was converted to a synthetic Barnum flow by area-adjustment and compared to the gaged Barnum flow from July 1, 1966 through September 30, 1985 (Figure 11). Figure 11 shows that the gaged Barnum flow (the best available estimate of inflow) was consistently higher than the synthetic Bloomington based flow-rate. This difference is likely due to differences in runoff characteristics between the two watersheds. Because the best available estimate of inflow is 2.1 percent higher than the approximated Bloomington flow, the Jennings Randolph inflows based on Bloomington gage flow were increased by 2.1 percent to account for the differences in runoff characteristics.

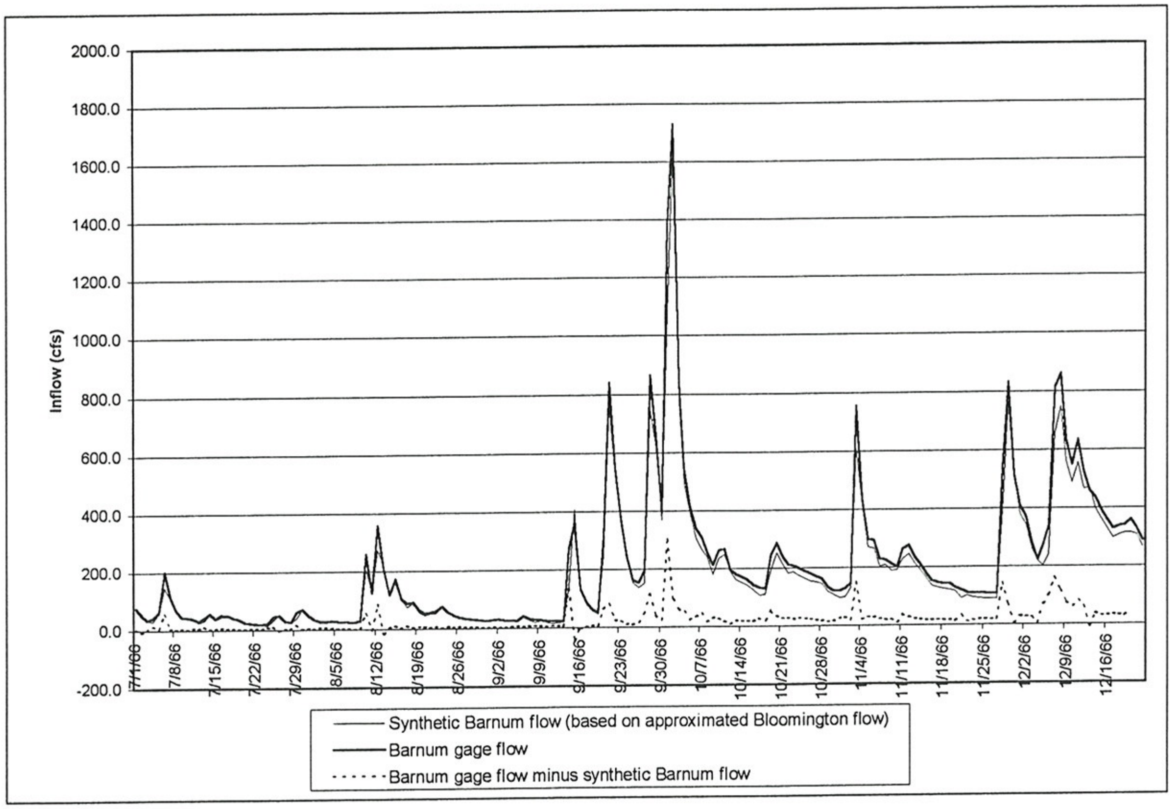


Figure 11: Example comparison of Barnum and synthetic Barnum (Bloomington) inflow prior to adjustment

1950-1966

The inflow record from October 1, 1950 through June 30, 1966 is based on daily stream gage flows measured at the Kitzmiller gage. The Kitzmiller gage is upstream of Jennings Randolph Reservoir and has a drainage area of 225 square miles. The Kitzmiller gage flows were first multiplied by an area-adjustment factor of 1.169 (equals 263 divided by 225) and reduced by a factor of 5.3 percent to develop a set of Jennings Randolph inflows.

The 5.3 percent factor was developed to account for differences in sub-watershed runoff. The area contributing to flow at the Kitzmiller gage included portions of the Jennings

Randolph Reservoir watershed with higher runoff and precipitation values than the rest of the reservoir catchment. Therefore, the Kitzmiller-based area-adjusted inflow over-represented reservoir inflow. A comparison of Kitzmiller and Barnum gage records was used to quantify the effects of this over-representation of inflow.

The Kitzmiller gage flow was converted to a synthetic Barnum gage flow by area-adjustment and compared to gaged Barnum flow from July 1, 1966 through July 1, 1981. (During this period, flow at Barnum is unregulated by Jennings Randolph.) The average Barnum flow-rate was 5.3 percent lower than the Kitzmiller-based flow rate (Figure 12). This difference is likely due to differences in runoff characteristics between the two watersheds. Because the best available estimate of inflow (at Barnum gage) is 5.3 percent lower than the Kitzmiller-based flow, the Jennings Randolph inflow based on Kitzmiller gage flow was reduced by 5.3 percent.

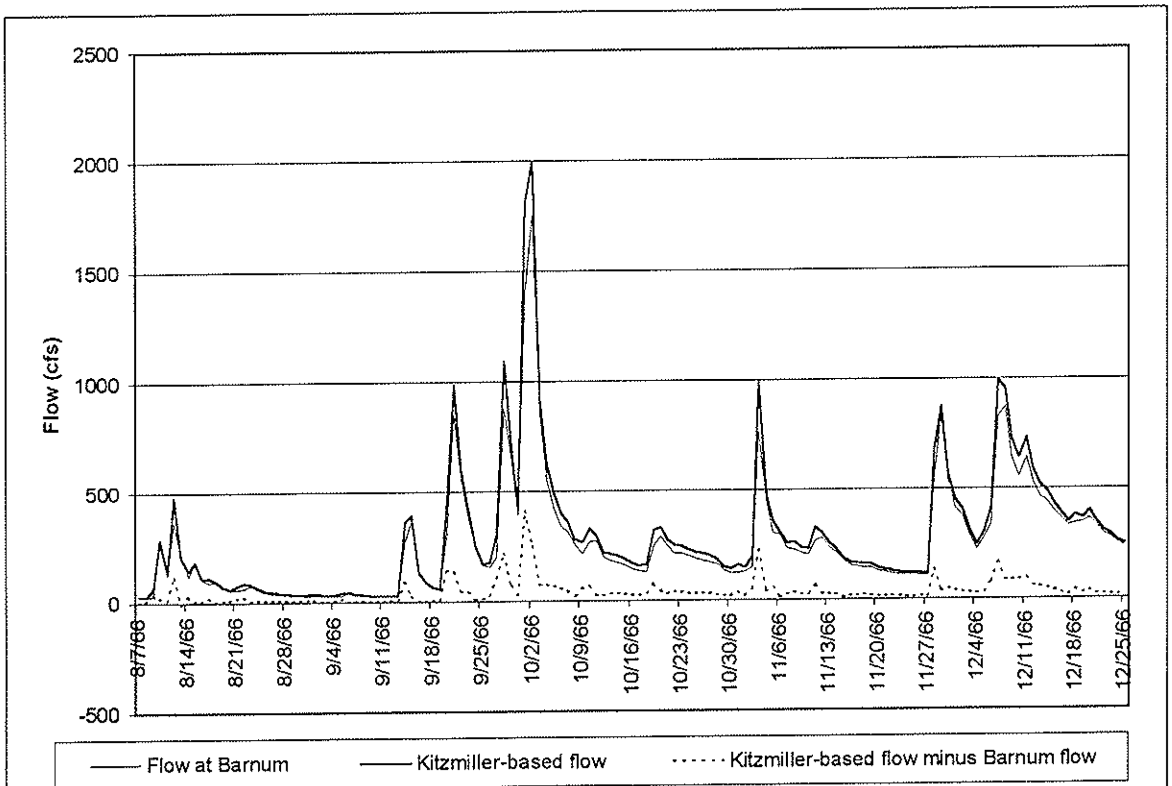


Figure 12: Comparison of best available estimate of inflow (as measured at Barnum gage) and unadjusted Kitzmiller-based inflow

1966-1981

The inflow record from July 1, 1966 through June 30, 1981 is based on daily stream gage flows measured at the Barnum gage. This gage site is just downstream of Jennings Randolph Reservoir and has a drainage area of 266 square miles. The Barnum gage flows were multiplied by an area-adjustment factor of 0.9887 (equals 263 divided by 266) to develop a set of Jennings Randolph inflows.

No adjustment of the Barnum gage flow was needed. The Barnum gage is the best available estimate of flow into the reservoir as it is located very close to the site of the current dam.

1981-1985

Jennings Randolph Reservoir began regulating flow in July of 1981 (USGS, 1993). The Barnum gage was not used to develop reservoir inflows after this time because gaged flows at Barnum were corrupted by reservoir regulation.

The inflow record from July 1, 1981 through September 30, 1985 is based on daily stream gage flows measured at the Kitzmiller gage. The Kitzmiller flow rate was adjusted for differences in subwatershed flow rates and for area-adjustment factors as discussed above in the section for years *1950-1966.*

1985-1996

The USGS ceased auditing and publishing Kitzmiller flow records on September 30, 1985. Although the USCOE maintains hourly stage information for Kitzmiller, this data is not subject to the extensive data verification procedures that are maintained by the USGS in determining flow rates.

Therefore, inflow is based on the Steyer gage for the period from October 1, 1985 through September 30, 1996. This gage site is upstream of Jennings Randolph and has a drainage area of 73.0 square miles. The Steyer gage flows were multiplied by an area-adjustment factor of 3.603 (equals 263 divided by 73.0) and reduced by a factor of 19.3 percent to develop a set of Jennings Randolph inflows.

The 19.3 percent factor was developed to account for differences in sub-watershed runoff. The area contributing to flow at the Steyer gage included portions of the Jennings Randolph Reservoir watershed with the highest runoff and precipitation in the reservoir catchment. Therefore, the Steyer-based area-adjusted inflow over-represented reservoir inflow. A comparison of Steyer and Barnum gage records was used to quantify the effects of this over-representation of inflow.

The Steyer gage flow was converted to a synthetic Barnum gage flow by area-adjustment and compared to gaged Barnum flow from July 1, 1966 through July 1, 1981. (During this period, flow at Barnum is unregulated by Jennings Randolph.) The average Barnum flow-rate was 19.3 percent lower than the Steyer-based flow rate (Figure 13). This difference is likely due to differences in runoff characteristics between the two catchments. Because the best available estimate of inflow (at Barnum gage) is 19.3 percent lower than the Steyer-based flow, the Jennings Randolph inflow based on Steyer gage flow was reduced by 19.3 percent.

7. Effects of upstream regulation

The Mount Storm gage on the Stony River, a tributary to the North Branch, was operational from October 1, 1961 to September 30, 1996 and measured flow upstream of Jennings Randolph Reservoir. The Mount Storm gage was not used in inflow development because it measures flow downstream of Mount Storm and Stony River dams. Stony River dam began regulating flow in 1913, and Mount Storm dam began regulating flow in 1963, so regulation of these dams may have corrupted flows measured at Mount Storm gage.

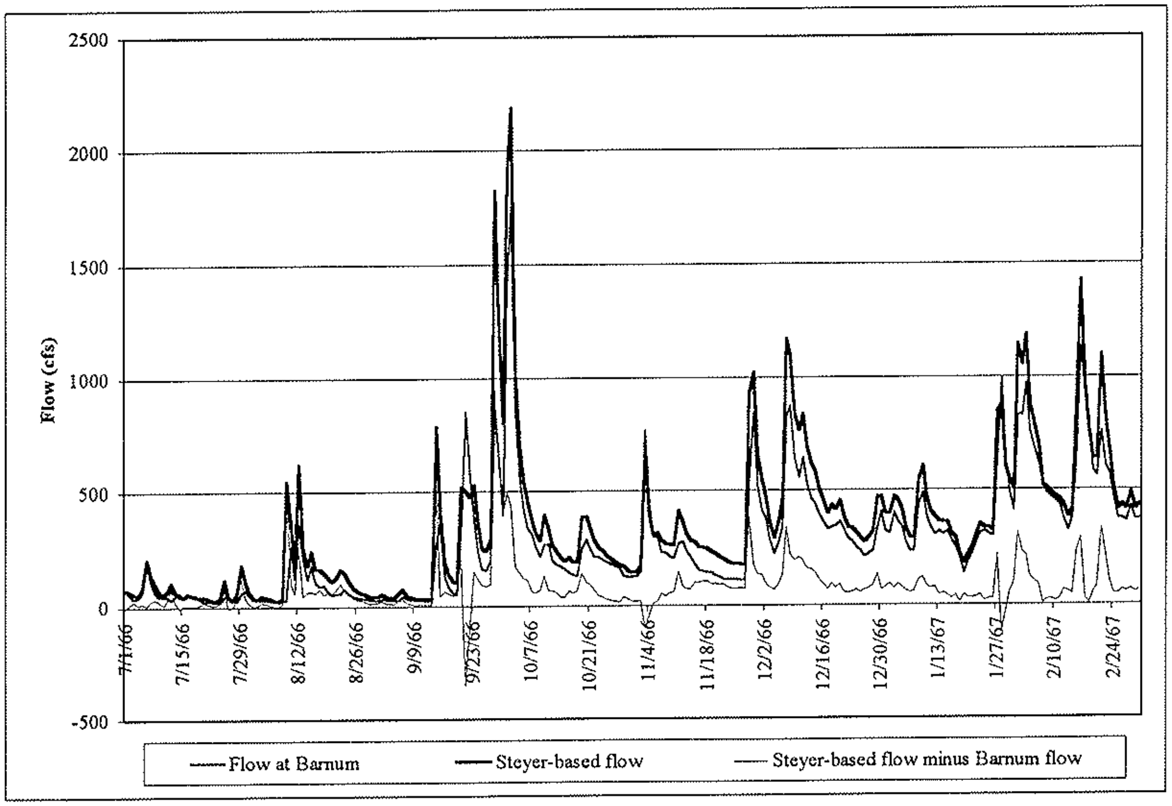


Figure 13: Comparison of best available estimate of inflow (as measured at Barnum gage) and unadjusted Steyer-based inflow

Virginia Power Company uses Mount Storm Lake as a cooling pond for a coal fired power plant. Mount Storm dam is essentially operated as a run-of-the-river reservoir, so the effects on downstream flow are probably negligible (Robert Williams, Virginia Power, personal communication, April 27, 1998). Stony River gage measures flow from a relatively small portion of the watershed. The reservoir is no longer operated for river regulation, so the effects on downstream flow may not be great.

8. Diversions and return flows

There are no significant surface water diversions or return flows above Jennings Randolph Reservoir.

9. Storage loss due to sedimentation

Dead storage is that water volume stored below the lowest water intake structure. The 2,700 acre-foot volume of water in dead storage at Jennings Randolph was allocated to contain anticipated sedimentation. However, sedimentation will affect live storage as well as dead storage, and is likely to have more of an affect on live-storage. This is because most sediment falls out of the water column as soon as it reaches quiescent water in the headwaters of the reservoir, in the live-storage portion of the reservoir. A soon-to-be-released 1998 survey should quantify how much of the live-storage remains, and give a current estimate of sedimentation rates. The current allocation of storage dedicated to water supply is 41,000 acre-feet (13.36 BG).

10. Evaporation and precipitation

Evaporation can be a significant factor in the reservoir water balance equation, especially during summertime periods of drought. The National Climatic Data Center (NCDC) maintains pan evaporation data for the Savage River Dam station located in Garrett County, Maryland, approximately 6 miles from Jennings Randolph Reservoir. Average and maximum monthly pan evaporation for the Savage River Dam station is given in Table 3 for the years 1972 through 1996. Average monthly precipitation for Jennings Randolph Reservoir is given in Table 3 for the years 1938-1965. Precipitation data was compiled from the NCDC for Luke weather station, located near the reservoir.

Table 3: Evaporation and precipitation values for Jennings Randolph Reservoir

Month	Average Pan Evaporation, 1972-1996 (inches)	Maximum Pan Evaporation, 1972-1996 (inches)	Average Precipitation at Luke (inches) 1938-1965
January	--	--	2.3
February	--	--	2.2
March	--	--	3.3
April	4.8	5.9	3.1
May	5.1	6.4	3.6
June	5.1	6.0	3.7
July	5.4	6.7	3.3
August	4.8	6.8	3.8
September	3.6	4.5	2.8
October	2.5	3.9	2.6
November	--	--	2.2
December	--	--	2.2

Note: Evaporation not reported during November through March.

Actual evaporation from the reservoirs is likely to be less than the pan evaporation rates given in Table 3. A coefficient of 0.7 can be used to adjust pan evaporation to approximate reservoir evaporation rates (Linsley, 1949, 1982). Using the adjusted pan evaporation rate, evaporation could account for up to 1.0 billion gallons of water loss from Jennings Randolph Reservoir during the months of April through October. (This calculation assumes no rainfall inputs, the reservoir surface area corresponding to the full-pool reservoir elevation, the maximum pan evaporation rates given in Table 3, and a pan adjustment coefficient of 0.7.)

11. Summary

The prior ICPRB set of daily inflows to Jennings Randolph Reservoir was examined and revised to account for local variation in sub-watershed precipitation and runoff rates. The following changes were made:

1. The prior inflow record from October 1, 1929 through September 30, 1949 was based on a gage at Bloomington, MD downstream from Jennings Randolph. The Bloomington gage included flow from a drainage area outside of the reservoir watershed that had the lowest values of precipitation and runoff. The prior ICPRB inflow record was **increased by 2.1 percent** to account for the under-representation of reservoir inflow.

2. The prior ICPRB inflow record from October 1, 1949 through September 30, 1985 was based on a gage at Kitzmiller, MD upstream from Jennings Randolph. The Kitzmiller gage measured flow from portions of the watershed with runoff values higher than the rest of the reservoir catchment. The Kitzmiller-based inflow record was **decreased by 5.3 percent** to account for the over-representation of reservoir inflow.

3. From July 1, 1966 through June 30, 1981, the gaged flows at Barnum were used instead of Kitzmiller gage flows. On average, the inflow based on Barnum-gage was **5.3 percent lower** than the Kitzmiller-based inflow.

4. The prior ICPRB inflow record from October 1, 1985 through September 30, 1996 was based on a gage at Steyer, MD in the upper reservoir watershed. The Steyer gage measured flow from a subwatershed with the highest values of annual precipitation and runoff. The prior ICPRB inflow record was **decreased by 19.3 percent** to account for the over-representation of reservoir inflow.

Table 4 summarizes the calculated daily inflows to Jennings Randolph Reservoir by month from October 1929 through September 1996. Figure 14 summarizes annual inflow to Jennings Randolph. Data are available in electronic format from ICPRB for both daily and monthly inflows.

Table 4: Monthly inflows to Jennings Randolph Reservoir, 1929 to 1996 (Billion Gallons)

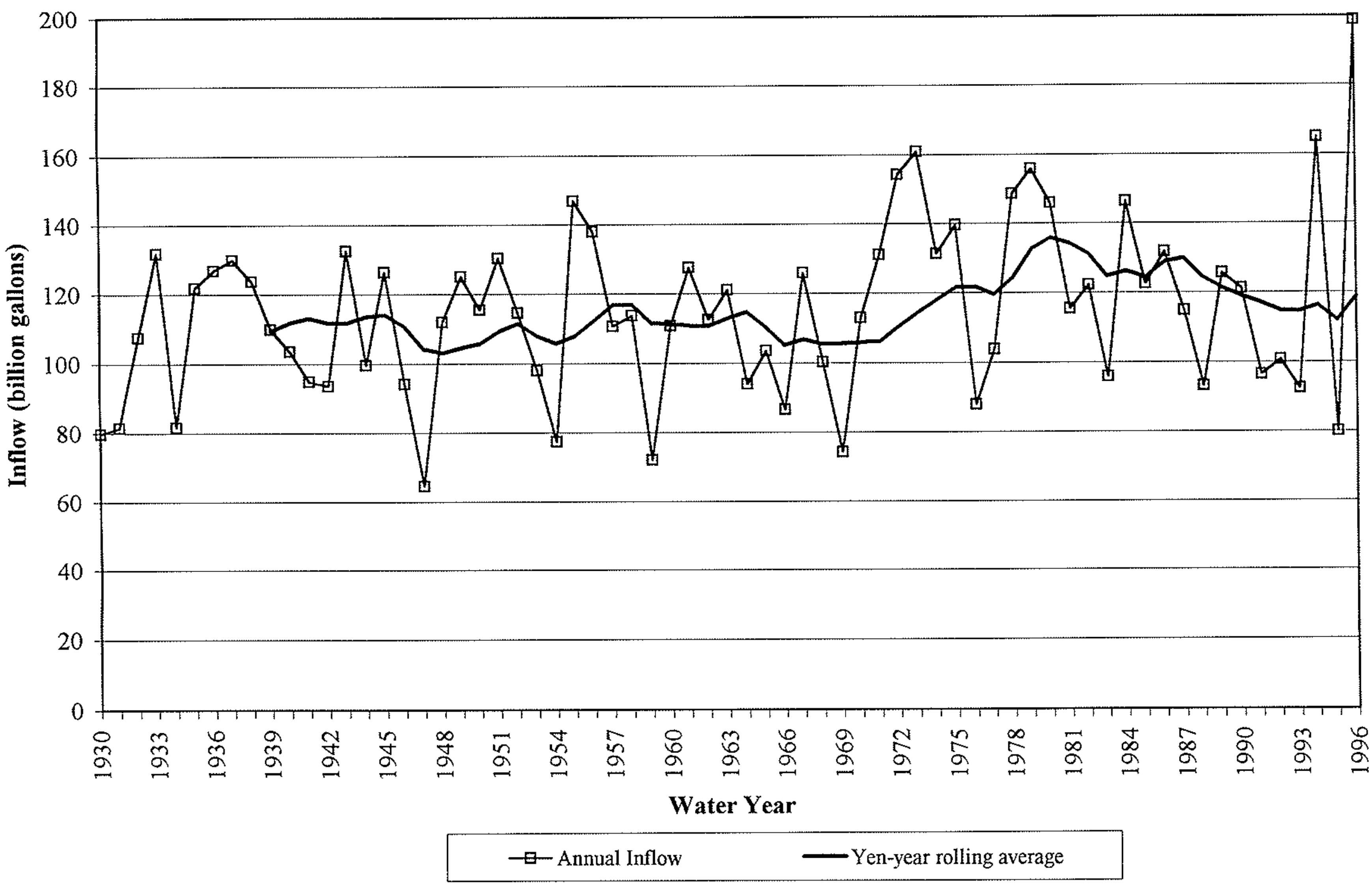
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
January		6.4	4.7	12.1	7.7	17.6	19.2	17.1	35.2	7.0	8.1	2.3	9.8	5.1	18.5	7.1	10.8
February		8.7	8.3	16.2	14.1	3.7	13.4	15.1	16.1	9.8	30.0	10.0	4.7	9.0	18.2	15.2	20.2
March		13.9	11.5	20.1	28.3	17.6	15.7	52.0	16.9	15.1	16.7	18.2	13.3	18.7	15.0	28.1	24.3
April		10.2	19.6	14.3	25.3	12.7	18.7	18.7	19.1	11.1	18.7	27.6	11.7	16.5	14.0	20.1	8.3
May		3.7	21.3	19.3	21.2	3.1	14.8	3.6	11.0	18.9	5.1	10.5	4.4	17.2	7.2	15.6	13.3
June		3.1	5.6	3.8	2.9	1.8	6.5	1.4	5.5	6.9	8.9	9.8	11.3	3.7	2.2	6.2	3.4
July		1.1	2.0	4.7	2.0	1.6	3.8	2.0	1.6	6.7	9.9	5.6	13.7	1.9	5.8	1.4	3.8
August		0.8	2.3	2.0	7.8	3.4	4.2	1.3	4.3	2.7	3.3	4.8	4.9	7.2	3.6	0.6	5.0
September		0.7	3.8	0.7	7.2	2.7	8.1	0.7	2.2	1.2	1.4	5.6	2.2	4.5	1.1	1.2	13.6
October	8.9	0.4	1.9	3.4	1.8	2.4	1.8	4.3	25.3	0.8	2.5	2.5	1.4	18.5	0.8	7.6	4.3
November	11.4	0.3	1.7	6.8	5.1	5.7	4.8	3.4	7.8	1.8	2.8	6.1	2.8	8.7	2.0	3.9	11.5
December	10.6	1.5	10.9	5.2	10.6	9.3	8.5	10.3	11.3	5.2	4.0	10.3	5.4	19.9	1.2	12.0	7.9
Total	**31.0**	**51.0**	**93.6**	**108.5**	**133.9**	**81.5**	**119.4**	**129.8**	**156.3**	**87.1**	**111.3**	**113.2**	**85.7**	**131.0**	**89.5**	**119.0**	**126.6**

	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
January	13.6	11.2	22.2	12.2	21.5	28.8	20.4	7.4	10.0	6.4	21.1	6.3	11.5	16.8	5.4	14.4	11.5
February	3.9	17.1	18.2	20.0	19.2	9.8	15.5	5.9	16.7	34.3	21.9	6.8	14.1	8.6	23.2	15.0	5.1
March	14.1	18.8	11.7	21.2	16.8	19.0	21.4	21.6	26.7	21.8	10.9	13.2	14.6	13.5	30.3	25.7	48.6
April	10.9	19.1	9.9	10.3	17.7	19.7	16.5	7.6	9.9	16.1	15.0	33.5	13.6	22.1	24.5	18.4	8.5
May	9.0	14.1	5.8	14.9	9.1	15.0	10.4	7.7	6.7	19.5	4.7	14.6	7.7	14.5	13.3	9.1	8.7
June	2.6	8.6	11.6	8.3	13.1	2.5	1.9	8.6	8.1	10.9	3.5	2.6	2.8	4.4	11.0	9.2	10.8
July	2.4	6.8	10.2	3.2	3.3	0.6	0.7	2.8	2.6	4.8	1.4	7.3	0.8	2.0	2.3	5.0	3.6
August	1.4	3.3	3.6	1.2	1.2	1.0	1.3	9.6	21.2	14.2	0.7	8.6	0.6	1.5	5.4	1.5	2.4
September	1.0	2.3	1.6	5.2	1.2	0.6	0.4	2.7	1.4	2.8	0.9	2.1	0.6	3.7	1.4	1.0	2.3
October	0.6	4.2	2.2	3.9	0.8	0.7	0.5	17.3	0.9	5.5	2.9	1.0	5.9	2.9	1.3	2.2	0.9
November	5.7	5.1	6.2	6.0	3.4	2.8	0.8	9.2	3.0	5.1	2.4	2.0	5.2	4.3	2.5	11.4	4.8
December	4.0	20.9	10.6	17.5	13.3	6.0	2.3	17.0	3.2	19.7	13.4	2.7	12.6	3.6	9.3	5.7	5.5
Total	**69.3**	**131.7**	**113.8**	**123.7**	**120.5**	**106.6**	**92.0**	**117.2**	**110.4**	**161.2**	**99.0**	**100.7**	**90.0**	**97.8**	**129.8**	**118.7**	**113.0**

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
January	18.4	4.7	7.1	9.4	8.3	16.7	18.5	13.1	8.6	24.2	22.2	15.9	2.4	11.4	20.1	8.2	2.1
February	15.0	17.2	10.7	10.1	8.0	14.0	21.6	15.9	10.5	10.3	20.6	18.9	12.7	3.9	22.3	6.1	15.3
March	25.4	16.2	39.6	24.3	13.8	22.0	19.1	29.0	14.8	11.8	20.3	11.0	24.9	30.4	35.3	22.1	13.4
April	20.6	22.6	8.9	6.8	12.1	31.5	8.6	21.6	30.1	15.8	14.6	7.4	13.9	16.1	16.1	23.0	18.8
May	4.5	14.3	23.8	20.7	5.2	4.9	13.7	14.5	13.0	7.0	15.8	4.5	4.8	18.7	16.0	17.1	15.3
June	1.7	1.4	4.2	6.6	1.3	1.9	4.8	11.8	9.7	19.9	4.3	5.9	2.6	5.0	4.4	14.1	22.0
July	1.8	1.0	7.5	0.8	2.0	2.1	1.3	9.3	2.2	5.1	2.5	2.4	1.7	19.5	3.6	7.2	4.2
August	0.5	1.6	4.0	1.3	5.9	3.0	2.7	3.4	4.2	1.7	9.5	1.4	2.0	5.1	3.3	10.9	1.5
September	0.4	3.9	1.1	0.6	3.4	1.5	10.5	1.4	2.6	2.5	8.2	1.1	0.9	1.6	9.7	1.6	6.4
October	0.8	6.6	2.1	0.6	2.2	2.2	9.0	10.0	6.5	1.7	9.1	20.5	3.2	1.0	19.5	1.4	4.0
November	1.0	4.8	3.6	5.3	5.2	9.6	7.8	20.5	9.3	2.9	4.2	8.6	17.1	2.9	8.3	6.7	4.7
December	2.0	7.8	13.9	8.3	7.9	18.5	17.5	34.6	17.3	17.0	6.2	8.8	16.7	21.1	7.9	8.2	12.2
Total	**92.1**	**102.0**	**126.4**	**94.7**	**75.4**	**128.0**	**135.1**	**185.0**	**128.9**	**119.8**	**137.6**	**106.3**	**102.9**	**136.8**	**166.4**	**126.6**	**119.9**

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Grand Total
January	3.8	5.1	6.0	9.8	11.2	12.6	14.8	17.7	16.1	10.0	10.3	19.4	12.7	26.4	**856.2**
February	8.7	21.0	18.9	23.2	8.2	9.5	14.4	12.0	13.4	15.0	3.4	31.0	11.8	20.0	**946.3**
March	18.6	26.4	18.5	16.4	13.5	10.7	18.8	6.3	15.8	16.3	25.1	34.4	8.7	23.5	**1372.6**
April	22.6	27.4	11.2	11.4	20.2	9.3	8.7	11.0	12.8	9.0	21.5	19.2	4.3	12.0	**1067.0**
May	18.5	13.7	12.1	6.3	8.6	21.1	15.5	17.6	3.9	6.9	4.8	16.9	13.2	30.6	**804.5**
June	4.5	2.3	13.5	2.5	4.8	3.5	11.3	11.1	2.1	4.5	3.0	3.9	4.0	7.3	**431.7**
July	1.9	6.6	10.6	6.5	1.8	1.4	13.0	11.5	3.6	16.4	1.9	6.4	2.4	17.0	**312.5**
August	1.1	8.0	3.2	1.7	1.9	1.1	5.8	3.1	1.3	4.4	1.0	7.7	8.3	20.2	**271.9**
September	0.7	1.2	0.6	3.2	5.9	2.3	6.0	2.9	0.9	2.1	2.0	3.2	1.5	18.6	**200.0**
October	3.8	2.8	5.1	7.1	3.2	2.3	9.5	6.1	1.1	1.5	2.4	1.4	2.2		**296.5**
November	11.0	6.5	32.3	17.9	5.6	7.5	9.9	3.8	1.9	3.4	8.4	2.5	8.9		**416.9**
December	19.9	18.6	13.4	13.8	13.2	7.4	8.6	16.7	13.0	14.5	11.9	9.3	12.0		**731.9**
Total	**115.1**	**139.6**	**145.3**	**119.9**	**98.0**	**88.7**	**136.3**	**119.8**	**85.9**	**104.1**	**95.7**	**155.2**	**90.0**	**175.7**	**7707.9**

Figure 13: Annual inflow to Jennings Randolph Reservoir, 1930-1995



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