

## **NILE RIVER WATER RESOURCES ANALYSIS**

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### **ABSTRACT**

Nile River is one of the longest rivers in the world. It has a total length of about 6500 kilometers. The Nile basin consists of about three million square kilometers in different countries. The Nile Basin characteristics are very unique since it extends in different countries with different climate and the watershed has varied topography, soil nature and flow conditions. The major Nile water supply sources are coming from Ethiopian Plateau through the Blue Nile and Atbara during the period from August to December. Following this period, most of the water supply comes from the White Nile and its tributaries (the Sobat at first, then the Great Lakes Plateau). The contribution of these sources are studied and evaluated during this research. The monthly flow data for the Blue Nile, Atbara River and Blue Nile were analyzed during the study period and statistical tests were applied to monitor any observed changes during the study period. Study results were presented and evaluated.

**Keywords:** Nile River Water Resources, Nile Discharges Analysis, Nile Basin Climatic Changes, Lake Victoria Water Level.

### **INTRODUCTION**

The Nile River is one of the longest rivers all over the world. The river length is about 6500 kilometers measured starting from its remote sources to the Mediterranean Sea. The main water supply sources are the Equatorial Lakes, Bahr El-Gazal Watershed and the Ethiopian Plateau. Figure 1 shows the Nile River map from its sources to the Mediterranean Sea. Nile River is considered a very unique and special river for many reasons. It conveys its water from equatorial and Ethiopian sources to the Mediterranean Sea along the Great Desert for about 2700 kilometers between Atbara River and the sea without getting any additional amount of water through this journey except for some minors and few rainfalls. The Nile River has this unique and exceptional ability because of its geological and hydrological unique characteristics. It has two major water sources, the first is the Equatorial Lakes which is a continuous source and has a limited variability from one season to another and the second is the Ethiopian Plateau which is a seasonal and a wide varied source. The special climatic and hydrological parameters along the Nile Basin play very important role in

controlling river discharges. During this paper an attempt was made to monitor water discharges and their changes along Nile River major sources.

## **ANALYZED NILE RIVER MAJOR SOURCES**

The major Nile River sources are the White Nile (from the Equatorial Lakes), Blue Nile and Atbara River (from the Ethiopian Plateau). The analyzed selected stations for these Nile sources are listed in Table 1. This table shows the selected stations for the White Nile, Blue Nile, and Atbara. Malakal Station is selected for the White Nile, Atbara Station is selected for Atbara River, and Khartoum Station is selected for the Blue Nile. Both Atbara and Khartoum Stations are the end stations for both sources Atbara River and Blue Nile respectively. However, Malakal Station is located about 800 kilometers from the joint of the Blue and White Niles but is the only available down stream station which has enough and continuous flow records representing the White Nile. The White Nile evaporation and seepage losses from Malakal Station to Khartoum are estimated by an average of 3.5 billion cubic meters (Saied, [1]).

**Table 1. Selected water discharge stations**

<b>Basin</b>	<b>River</b>	<b>Discharge Station</b>	<b>Kilometer from OAD</b>	<b>Date of operation</b>
White Nile	White Nile	Malakal	2652	1907
Ethiopian Plateau	Atbara	Atbara	1522	1913
Ethiopian Plateau	Blue Nile	Khartoum	1845	1906

## **SELECTED STATION DISCHARGES**

Figures 2 to 13 show the recorded monthly discharges at the selected stations for the study period 1912-1973. The time period is selected according the availability of the continuous data and to study the flow changes during this period.

### **January Flow:**

Figure 2 shows the recorded discharge for January from 1912 to 1973. It can be concluded from this figure that the minimum recorded flow for Khartoum Station is 198 million cubic meters (MCM) and the maximum recorded flow for the same station is 1730 MCM and the average flow is 738 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 165 MCM and the station average flow is 20 MCM. For Malakal Station, the minimum recorded flow is 1400 MCM, the maximum flow is 6060 MCM and the station average flow is 2448 MCM.

### **February Flow:**

Figure 3 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 168 MCM and the maximum recorded flow for the same station is 1020 MCM and the average flow is 458 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 135 MCM and the station average flow is 7 MCM. For Malakal Station, the minimum recorded flow is 1040 MCM, the maximum flow is 4620 MCM and the station average flow is 1735 MCM.

### **March Flow:**

Figure 4 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 136 MCM and the maximum recorded flow for the same station is 1020 MCM and the average flow is 408 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 29 MCM and the station average flow is 1 MCM. For Malakal Station, the minimum recorded flow is 963 MCM, the maximum flow is 5340 MCM and the station average flow is 1706 MCM.

### **April Flow:**

Figure 5 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 158 MCM and the maximum recorded flow for the same station is 1140 MCM and the average flow is 383 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 126 MCM and the station average flow is 4 MCM. For Malakal Station, the minimum recorded flow is 860 MCM, the maximum flow is 3070 MCM and the station average flow is 1484 MCM.

### **May Flow:**

Figure 6 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 142 MCM and the maximum recorded flow for the same station is 1380 MCM and the average flow is 477 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 190 MCM and the station average flow is 8 MCM. For Malakal Station, the minimum recorded flow is 1040 MCM, the maximum flow is 2800 MCM and the station average flow is 1650 MCM.

### **June Flow:**

Figure 7 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 439 MCM and the maximum recorded flow for the same station is 3610 MCM and the average flow is 1137 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 415 MCM and the station average flow is 73 MCM. For Malakal Station, the minimum recorded flow is 1560 MCM, the maximum flow is 2910 MCM and the station average flow is 2015 MCM.

### **July Flow:**

Figure 8 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 1880 MCM and the maximum recorded flow for the same station is 10300 MCM and the average flow is 5371 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 5160 MCM and the station average flow is 1616 MCM. For Malakal Station, the minimum recorded flow is 2110 MCM, the maximum flow is 3500 MCM and the station average flow is 2505 MCM.

### **August Flow:**

Figure 9 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 7520 MCM and the maximum recorded flow for the same station is 23000 MCM and the average flow is 15853 MCM. For Atbara Station, the minimum recorded flow is 1430 MCM, the maximum flow is 13200 MCM and the station average flow is 5533 MCM. For Malakal Station, the minimum recorded flow is 2330 MCM, the maximum flow is 4150 MCM and the station average flow is 2871 MCM.

### **September Flow:**

Figure 10 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 3780 MCM and the maximum recorded flow for the same station is 22900 MCM and the average flow is 13945 MCM. For Atbara Station, the minimum recorded flow is 590 MCM, the maximum flow is 7470 MCM and the station average flow is 3512 MCM. For Malakal Station, the minimum recorded flow is 2460 MCM, the maximum flow is 5200 MCM and the station average flow is 3080 MCM.

### **October Flow:**

Figure 11 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 2037 MCM and the maximum recorded flow for the same station is 16100 MCM and the average flow is 7657 MCM. For Atbara Station, the minimum recorded flow is 80 MCM, the maximum flow is 2140 MCM and the station average flow is 812 MCM. For Malakal Station, the minimum recorded flow is 2330 MCM, the maximum flow is 6090 MCM and the station average flow is 3396 MCM.

### **November Flow:**

Figure 12 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 549 MCM and the maximum recorded flow for the same station is 6050 MCM and the average flow is 6050 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 607 MCM and the station

average flow is 176 MCM. For Malakal Station, the minimum recorded flow is 2220 MCM, the maximum flow is 6210 MCM and the station average flow is 3310 MCM.

### **December Flow:**

Figure 13 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 242 MCM and the maximum recorded flow for the same station is 2960 MCM and the average flow is 1262 MCM. For Atbara Station, the minimum recorded flow is 0 MCM, the maximum flow is 173 MCM and the station average flow is 58 MCM. For Malakal Station, the minimum recorded flow is 1600 MCM, the maximum flow is 6420 MCM and the station average flow is 3141 MCM.

### **Annual Flow:**

Figure 14 shows the recorded discharge from 1912 to 1973. The minimum recorded flow for Khartoum Station is 23388 MCM and the maximum recorded flow for the same station is 77211 MCM and the average flow is 50176 MCM. For Atbara Station, the minimum recorded flow is 4917 MCM, the maximum flow is 27051 MCM and the station average flow is 11821 MCM. For Malakal Station, the minimum recorded flow is 22593 MCM, the maximum flow is 48640 MCM and the station average flow is 22593 MCM.

### **Flow Changes**

It can be noticed from all, previously mentioned, monthly flows and also from the annual flow that the flows from the three major Nile sources have been subjected to some changes starting from the early sixties. To study more about this phenomenon, Some of the different water flow characteristics for the two periods 1912-1961 and 1962-1973 were illustrated. Tables 2 to 4 show the annual flow characteristics for Khartoum, Atbara, and Malakal stations respectively. For space limitations, only the monthly averages for the three stations for both periods 1912-1961 and 1962-1973 are shown in table 5. The changes in flow averages in monthly and annual data for both periods are observed further more, the frequency diagrams changes are noticed in table 4 from the different skew and kurtosis values for both periods. This means that frequency diagrams have gone through some changes for both periods. Student T test was performed to determine if the flow records for the periods 1912-1961 and 1962-1973 are likely to have come from the same population. The probability of accepting the null assumption that both records have come from the same population are computed and illustrated in table 6. From this table it can be approved that the null assumption will be rejected for all case. For Khartoum Station, only two months of low flow have high probability of accepting the assumption and for the rest, the assumption would be rejected. For Atbara Station, only one month of almost zero flow has high probability. This means that the null assumption would be rejected for all months. For Malakal Station, all months have almost zero probability of accepting the null assumption. For annual data, the null assumption would be rejected for all stations. This means that there was a major flow change during the early sixties and it

has affected some or all of these stations. The contribution ratios for the three stations Khartoum, Atbara, and Malakal representing the Blue Nile, Atbara River, and White Nile are computed as the ratio between any of the three stations and the sum of the three stations. Figure 15 shows the annual ratios for the three stations. It is obvious from the figure the occurred change during the sixties for the flow ratios. Figure 16 shows the change of these ratios for both periods 1912-1961 and 1962-1973. For Blue Nile, the ratio has been decreased from 0.57 to 0.47. The same for Atbara River, the ratio has been decreased from 0.13 to 0.11. On the other hand, the ratio for White Nile has been increased from 0.30 to 0.43.

### **Flow Change Causes**

Many researchers have studied the explanation of the possible causes of previously mentioned changes. One of the direct causes for the increase of the White Nile is the increase of outflow from Lake Victoria during this period. The outflow from Lake Victoria has been increased from 23 billion cubic meters (BCM) during the period 1896-1961 to 41.4 BCM during the period 1962-1965 and 33.3 BCM during the period 1962-1982 (Saied, [1]). This increase in outflow has been attributed to the sudden increase of the lake water level during this period.

**Table 2. Khartoum Station**

<b>Variable</b>	<b>1912-1961</b>	<b>1962-1973</b>
Average	52154	41935.9
Median	51417	40591
Mode	51044	40311
Standard deviation	9396.34	9380.39
Minimum	25493	23388
Maximum	77211	62663
Skewness	0.407136	0.387158
Kurtosis	1.52727	2.2886

**Table 3. Atbara Station**

<b>Variable</b>	<b>1912-1961</b>	<b>1962-1973</b>
Average	12354.6	9595.67
Median	11805.5	8058
Mode	11727	8054
Standard deviation	3909.99	2940.59
Minimum	4917	6613
Maximum	27051	15223
Skewness	1.19675	0.770928
Kurtosis	3.14706	-0.7894

**Table 4. Malakal Station**

Variable	1912-1961	1962-1973
Average	27380.3	37501
Median	26542	35673.5
Mode	25410	35407
Standard deviation	3702.82	5661.15
Minimum	22593	30043
Maximum	44350	48640
Skewness	2.56322	1.13329
Kurtosis	9.55241	0.690308

**Table 5. Monthly data averages for 1912-1961 (1), 1962-1973 (2)**

M	Khartoum		Atbara		Malakal	
	1	2	1	2	1	2
1	754	670	19	27	2199	3475
2	458	458	5	17	1523	2617
3	419	362	1	1	1546	2372
4	363	466	0	17	1351	2036
5	481	457	3	28	1528	2157
6	1189	919	79	49	1915	2433
7	5625	4315	1688	1312	2396	2959
8	16120	14742	5654	5033	2746	3391
9	14574	11325	3750	2524	2934	3688
10	8145	5627	891	483	3200	4214
11	2683	1670	201	75	3117	4111
12	1343	926	64	30	2924	4049

**Table 6. Probability percentage for student T test**

M	Khartoum	Atbara	Malakal
1	32	40	0
2	100	5	0
3	26	84	0
4	7	0	0
5	74	1	0
6	9	35	0
7	2	15	0
8	13	32	0
9	0	1	0
10	1	0	0
11	0	0	0
12	1	2	0
<b>Sum</b>	<b>0</b>	<b>3</b>	<b>0</b>

Figure 17 shows the changes in Victoria and Albert Lakes water levels during the early sixties. It can be shown from this figure that water level has increased about 2.20 m for Lake Victoria and about 3.00 m for Lake Albert during the early sixties. It is somewhat difficult to explain the sudden increase in lake water levels. Some researchers have attributed this change to some earthquake activities that affected the subsurface reservoir and increase the lake level, some people accused the Egyptian engineers controlling the outflow of Owen Dam of this change but it was proved that any change from this dam would not increase the lake water level more than three centimeters (Saied, [1]). There were some arguments about the possibility of the sudden increase of rainfall to cause this increase in water level but the available records have not confirm or deny this possibility. The most accepted cause for this water level changes has been attributed to climatic changes. This increase in Lake water level has caused the increase in White Nile discharges and on the same time the Ethiopian Plateau, Blue Nile and Atbara, water flows have been reduced to form the new previously mentioned water discharge ratios (Saied, [1]).

## **CONCLUSIONS**

The monthly flow data for the Blue Nile, Atbara River and Blue Nile were analyzed during the study period and statistical tests were applied to monitor any observed changes during the study period.

It was observed that during the early sixties, the discharge contribution from the White Nile has been increased while the discharge contributions from both Blue Nile and Atbara River have been decreased.

The reason for these changes has been traced. The Most accepted cause for these changes is the occurrence of some climatic changes which are discussed in this paper.

## **REFERENCES**

1. Saied, R. The Nile River. Dar El-Helal. Egypt. pp. 342. 1993.





**Figure 1. Nile River map**

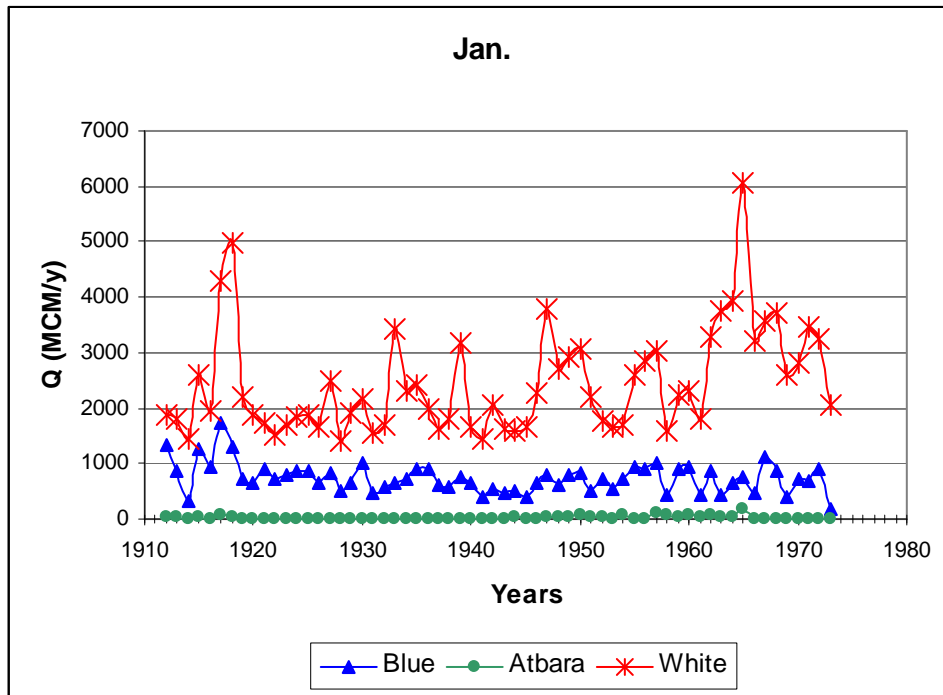


Figure 2. January flow for different stations

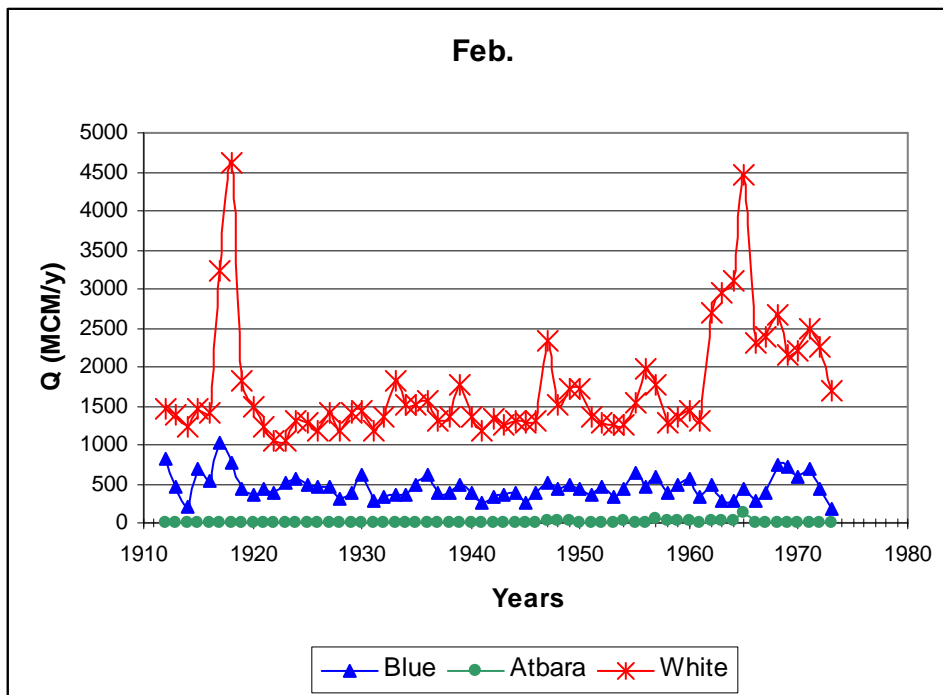


Figure 3. February flow for different stations

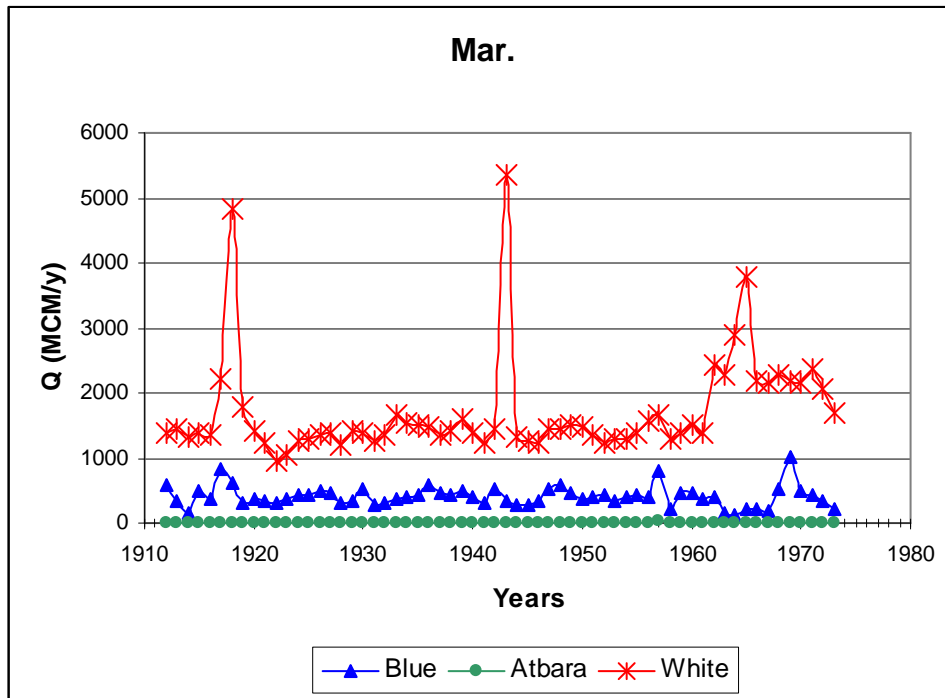


Figure 4. March flow for different stations

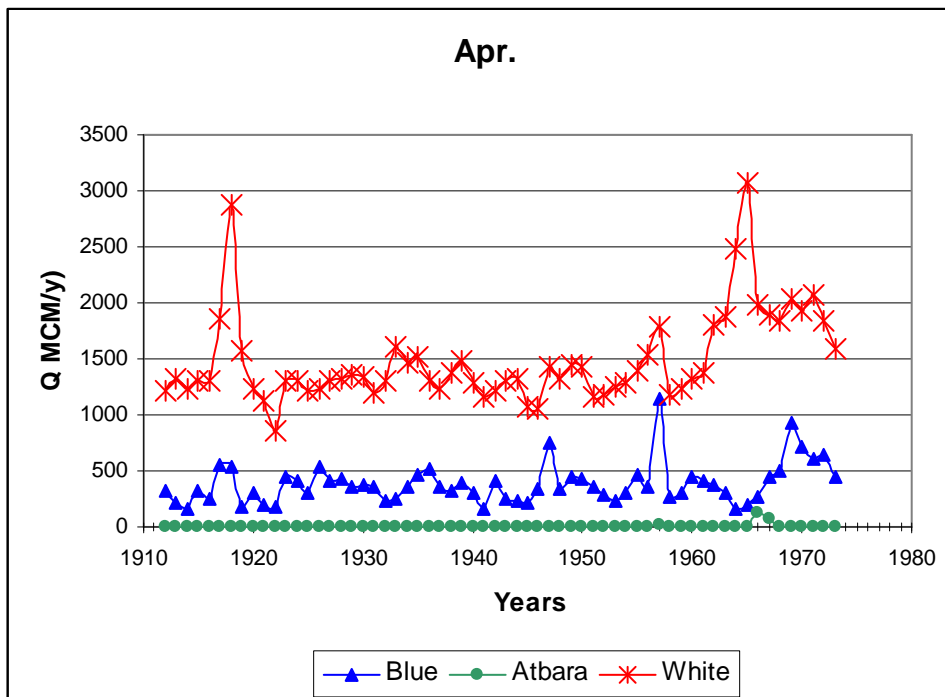


Figure 5. April flow for different stations

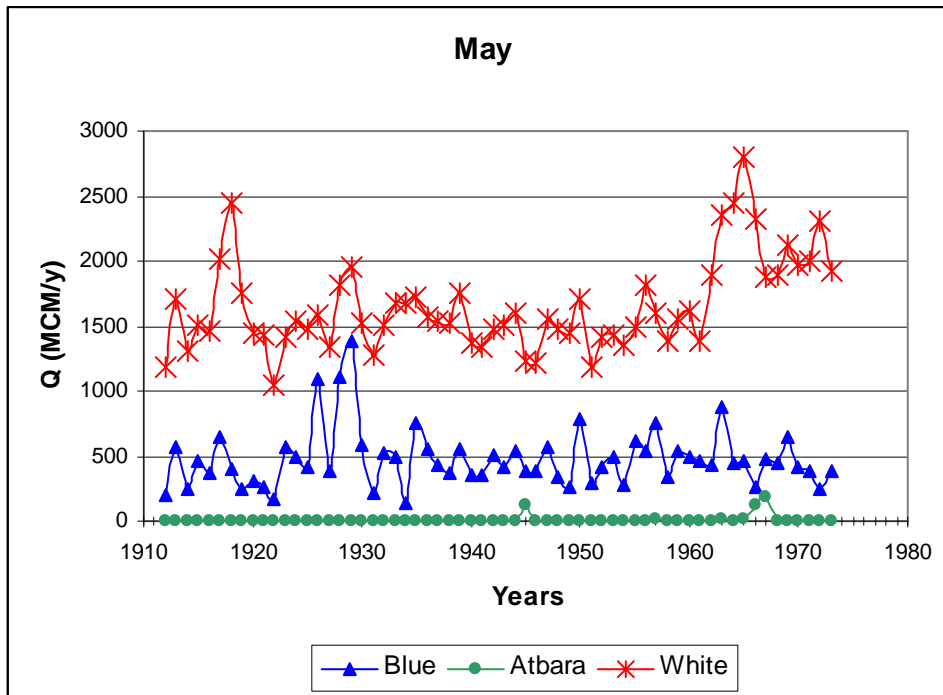


Figure 6. May flow for different stations

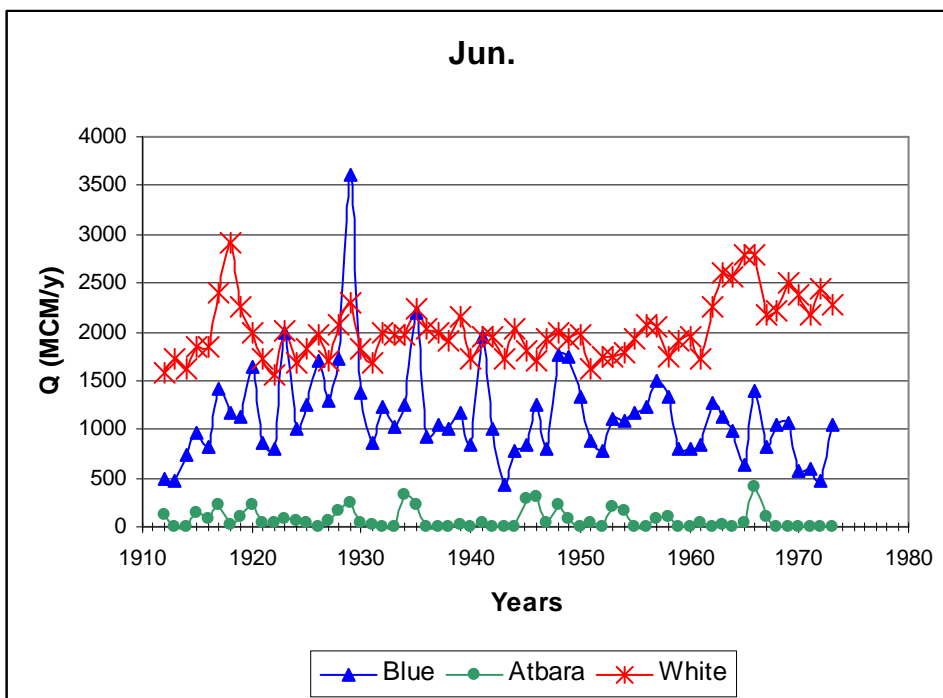


Figure 7. June flow for different stations

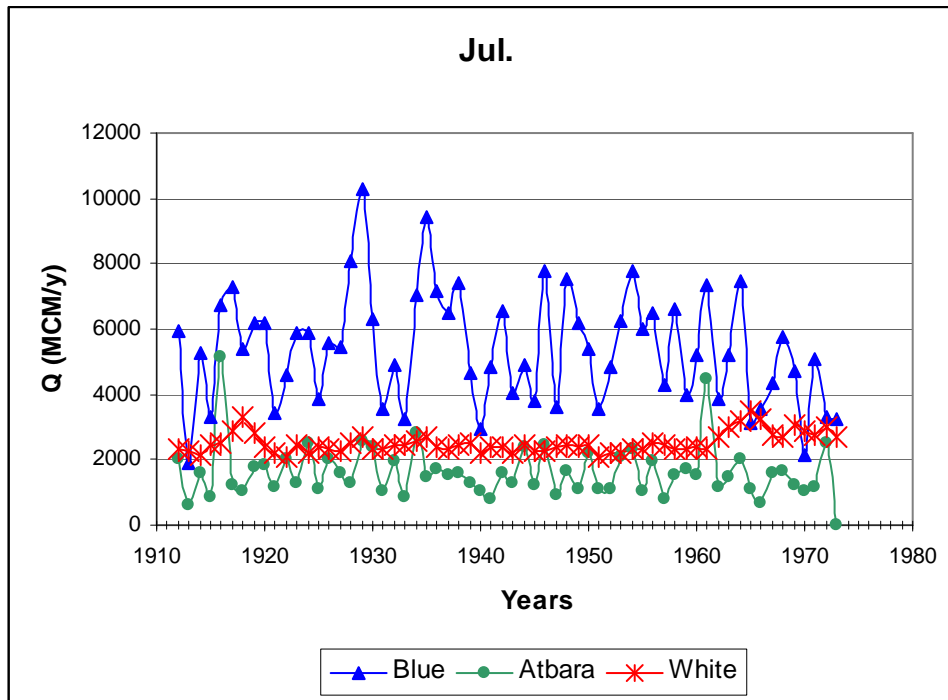


Figure 8. July flow for different stations

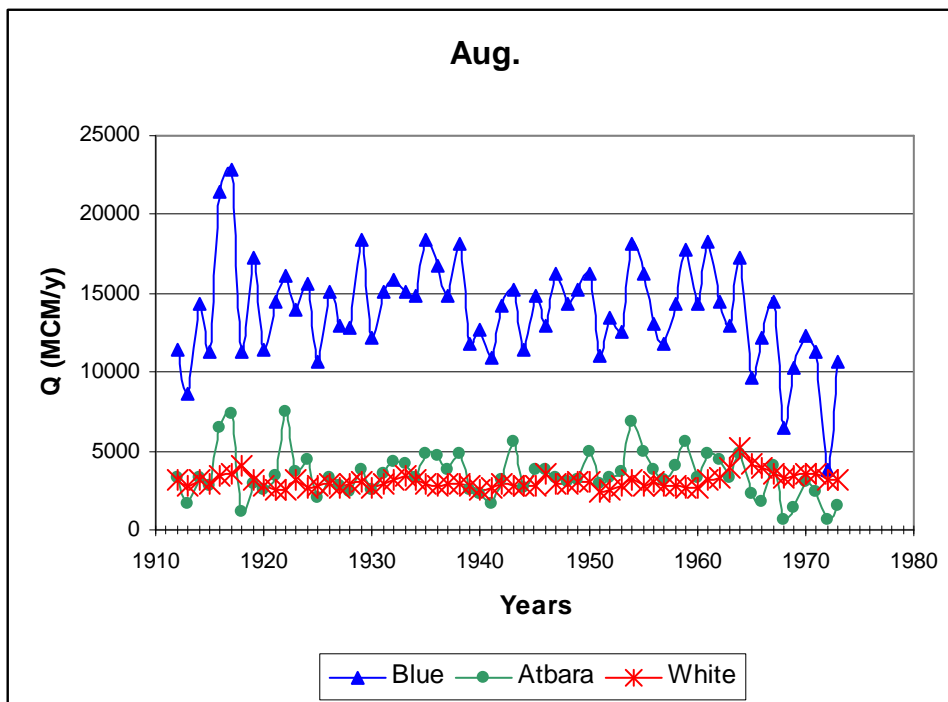


Figure 9. August flow for different stations

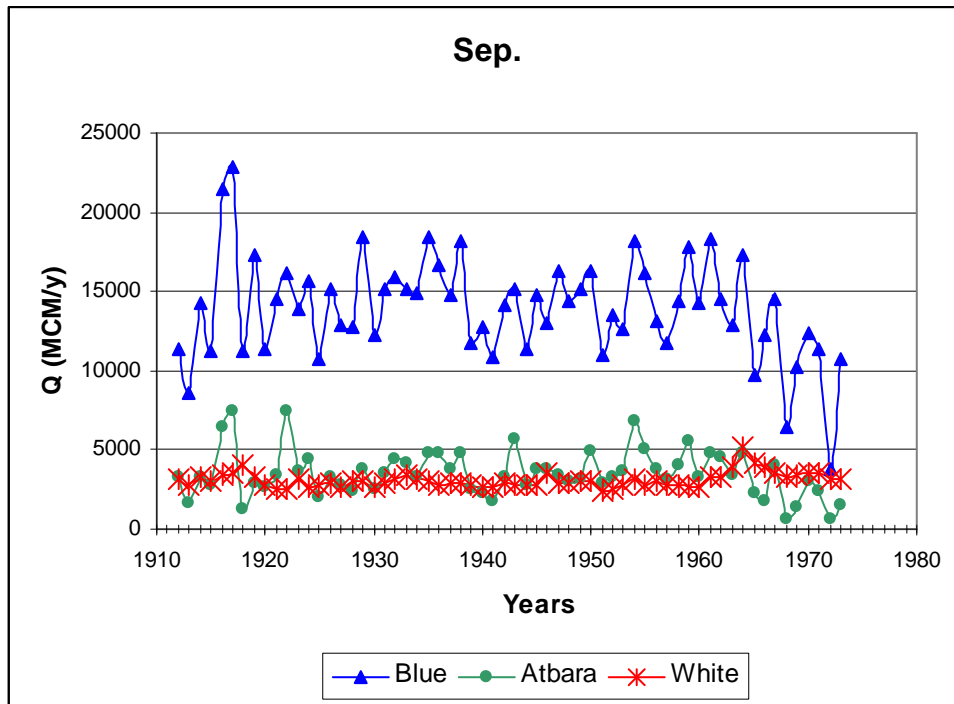


Figure 10. September flow for different stations

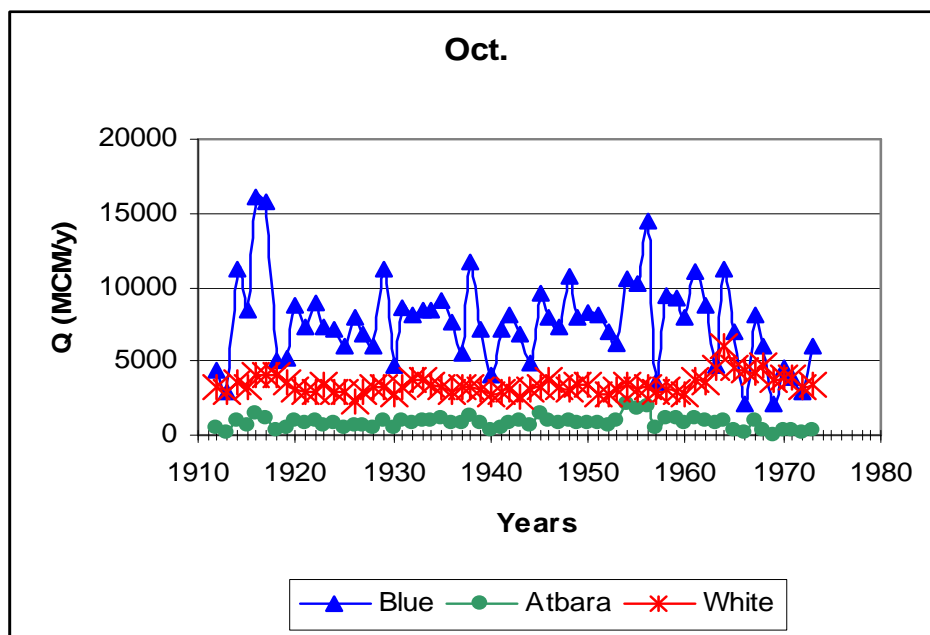


Figure 11. October flow for different stations

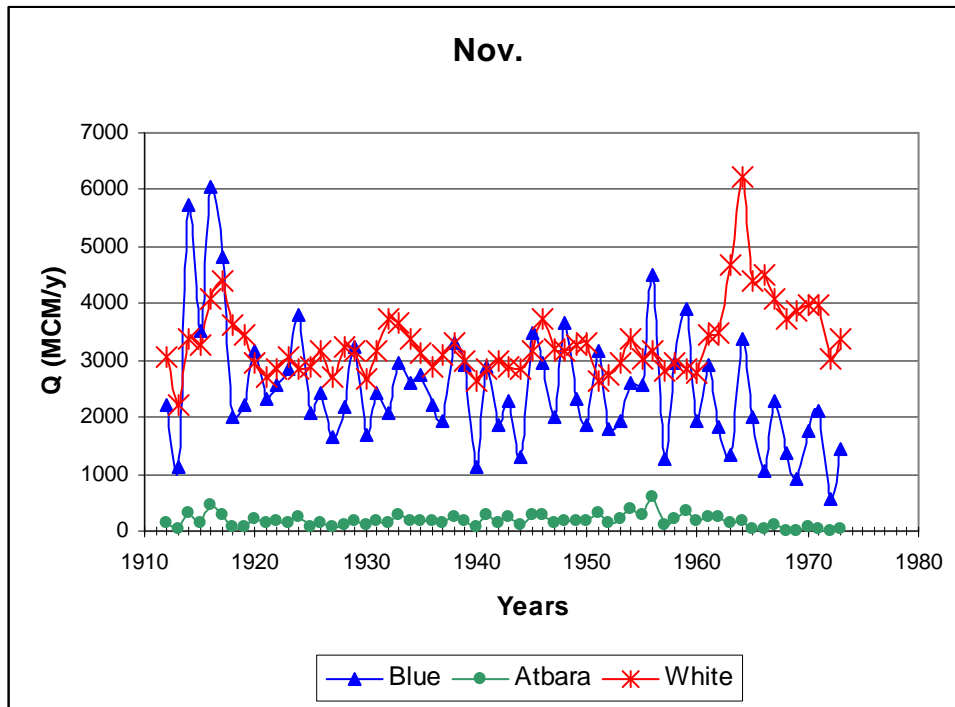


Figure 12. November flow for different stations

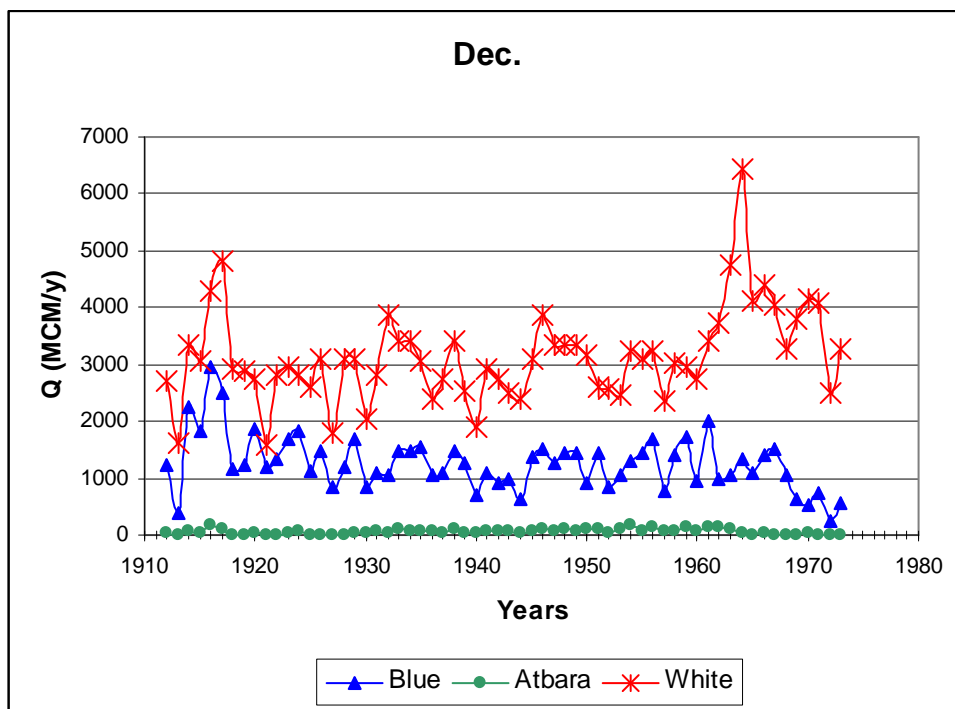


Figure 13. December flow for different stations

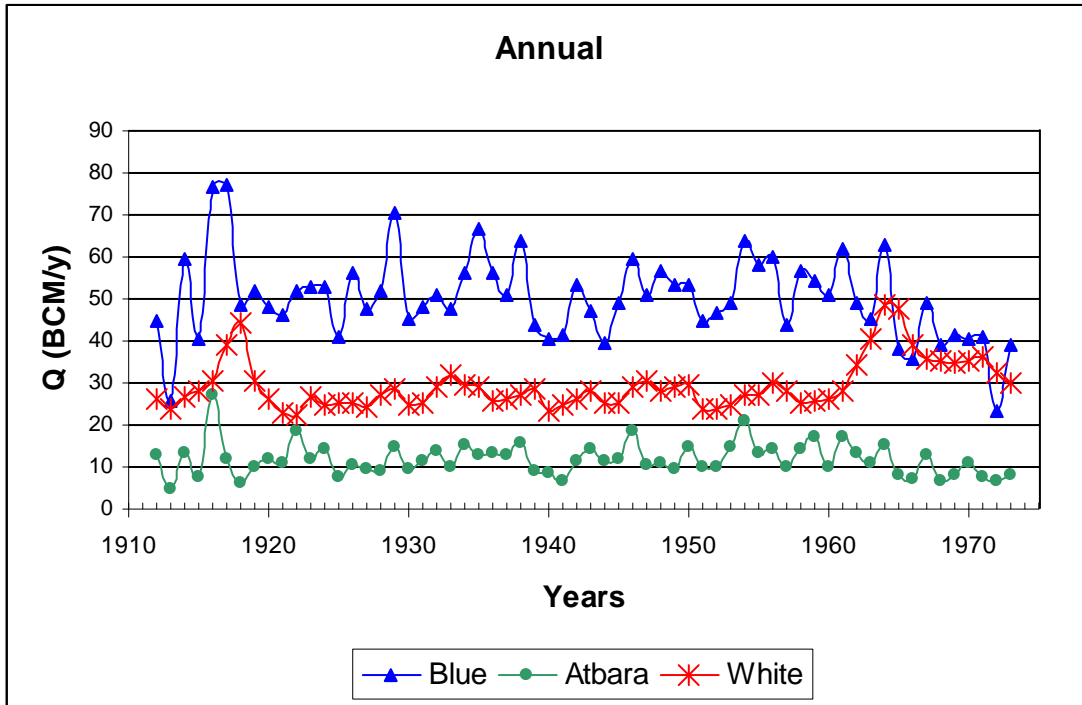


Figure 14. Annual flow for different stations

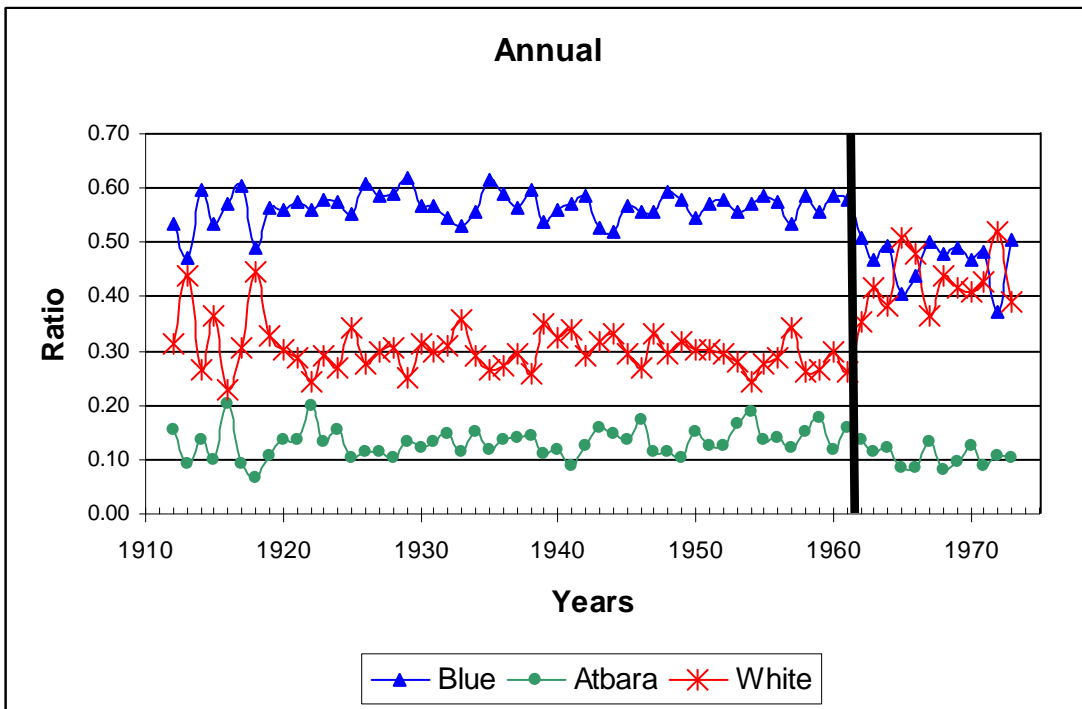
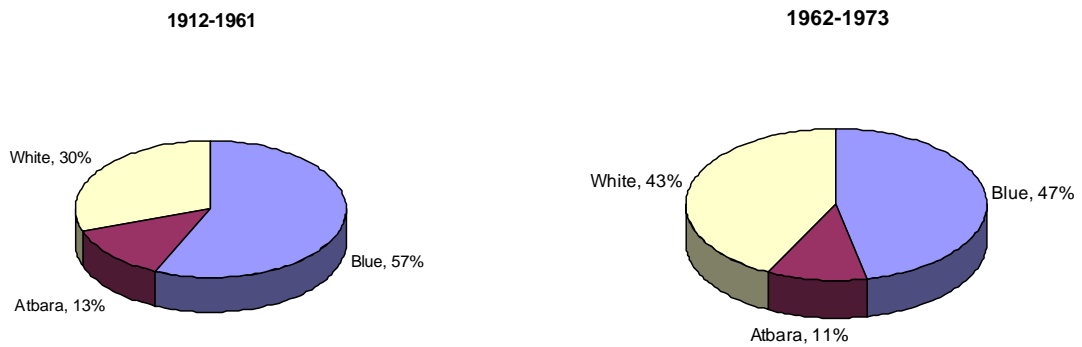
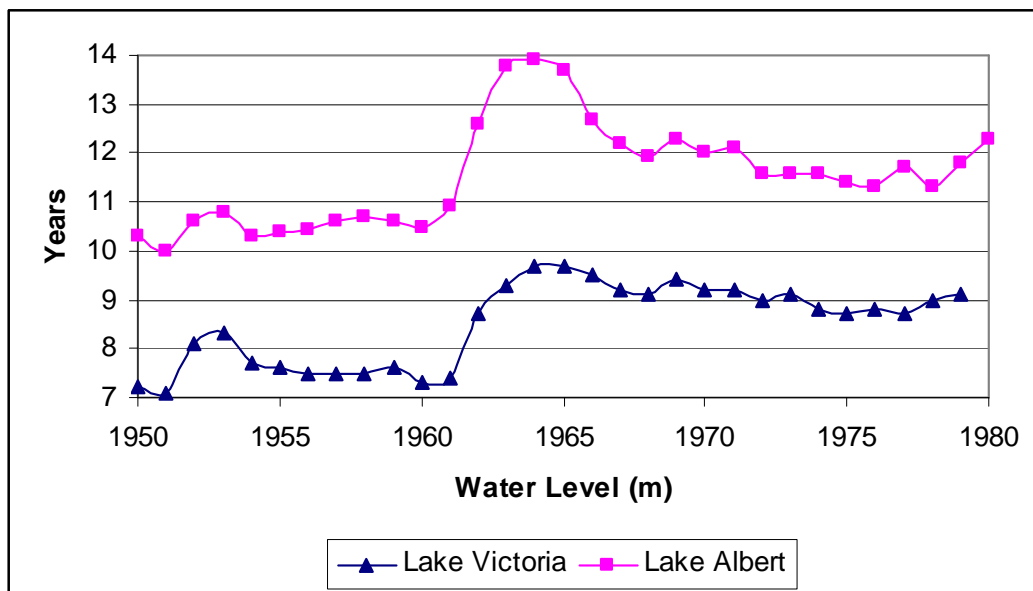


Figure 15. Annual flow ratios for different stations





**Figure 16. Annual flow ratio changes for different stations**



**Figure 17. Victoria and Albert Lakes water levels**