HYDROLOGICAL SIMULATION FOR REJUVENATION OF THE HUSSAIN SAGAR LAKE, HYDERABAD

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ABSTRACT

With increasing urbanization and the pressures of population, implementation of major water supply schemes for the increased populations in urban areas in cities are now gradually acquiring shape. The wastewater managers are now faced with the task of managing the additional wastewater from the cities for which the existing wastewater treatment systems are totally inadequate. In many cities, the wastewaters are being discharged into the main city lakes thereby causing deterioration of the urban water bodies. Hyderabad City with a population of 5 533 640 (2001 census) the capital of Andhra Pradesh state in India is one such city where such a problem is being faced. The main city lake, Hussain Sagar, was facing problems of low water levels and severe eutrophication because of the raw sewage being discharged into it from the newly developing areas in it's catchment. This paper describes the hydrological study carried out to assess the hydrology of the receiving waters of Hussain Sagar lake in Hyderabad and to suggest remedial measures for rejuvenation of the receiving lake waters. The study concluded that an additional 18.16 Mld STP would be required to treat the influent to the lake to maintain the prescribed water level in the lake based on 1 in 5 year dry period.

INTRODUCTION

Hyderabad, with a population of 5 533 640 (Census of India, 2001) is the capital of Andhra Pradesh state in India. It receives an annual average rainfall of 805 mm of which 613 mm (76%) occurs during the southwest monsoon period from June to October (Indian Meteorological Department -IMD, 2002). The city is drained by the Musi river and by numerous small tributary courses. The old city of Hyderabad has 1629 km length of existing sewers in 50 catchments of which 1546 km are vitrified clay pipes and 83 km are concrete and brick pipes. The excess sewage is discharged into the storm channels. The Hyderabad Municipal Corporation (HMC), the Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB) and the Hyderabad Metropolitan Development Authority (HMDA) are in charge of the drainage system of the city. sometimes with overlapping areas. Attempts have been made to divert the sewage flows from the open drains to the primary treatment plant situated on the north bank of River Musi (Amberpet) with a capacity of 113 Mld (Million liters per day). Most of the open drains were earlier exclusively storm drainage channels, but due to rapid urbanization and population growth, settlements quickly developed in the upcoming suburbs and on the banks of the open drains. Most of these settlements are getting either piped water supply or water through tankers. However, the underground sewerage system has not developed as quickly, with the net result that raw sewage from the recently developed settlements is discharged into the existing open stormwater drains. Four of these open stormwater drains feed the Hussain Sagar Lake in Hyderabad (Figure 1).

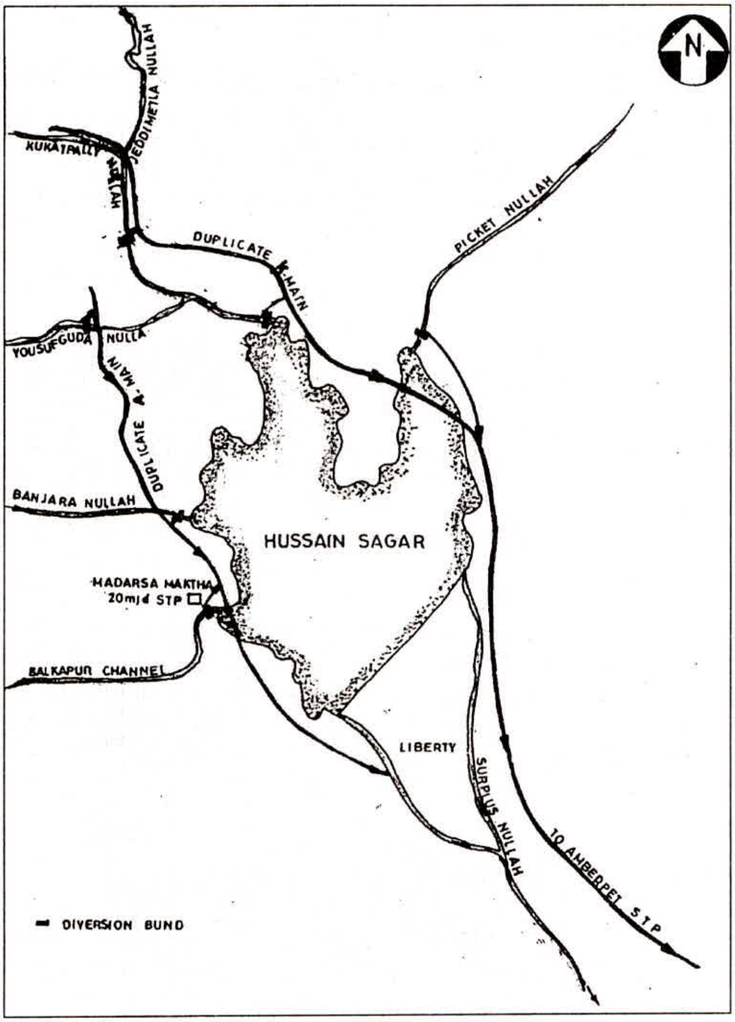

Figure 1. Plan of Hussain Sagar Lake showing the four inflow drains and existing STP (HMWSSB, 1992)

Hussain Sagar Lake was built in Hyderabad about 500 years ago for public water supply and irrigation. However, due to urbanization, irrigation water supply was discontinued although the lake continued to be used as a source of drinking water from 1894 until the 1930s. Since 1950s there was a rapid development of industries in the catchment area of the lake which discharged effluents into the lake. As a result, Hussain Sagar Lake is now no longer used for drinking water supply. Pollution from uncontrolled domestic discharges has resulted in an increasing nutrient (nitrogen and phosphorus) loading to the lake leading to severe eutrophication, DO depletion in the subsurface waters, large fish kills and malodour generation. This resulted in a monoculture of water hyacinth which during 1981 blanketed almost 70 % of the lake surface. An immediate measure was to spray the water hyacinths with 2,4 D (dichlorophenoxy- acetic acid) and subsequent mechanical removal of the biomass. Subsequently, hydrologic studies were commissioned by the HMWSSB (Hyderabad Metropolitan Water and Sewerage Board) on the basis of which the HMWSSB constructed a 20 Mld Sewage Treatment Plant (STP) for treating and discharging the treated effluents into the Hussain Sagar lake for maintaining the hydrological water balance of the lake. In addition six diversion units were constructed on four incoming drains to divert the dry weather flows away from Hussain Sagar lake into the nearby sewers (Figure 1). Both these improvements were commissioned in 1998. Subsequently, significant areas of the lake periphery have been reclaimed for urban developments which include the development of a housing estate, a new circular ring road on the periphery of the lake and an entertainment park.

However, four years later, in 2002, it was observed that some of the diversion structures on the incoming drains were overflowing into the lake due to the increase in quantity of DWF due to new urban developments in the catchment area of the lake. Moreover, it was observed that the extended aeration treatment process of the 20 Mld capacity STP installed at Hussain Sagar lake was unable to remove the nutrients fully. Hence, the study described in this paper was carried out during 2002, the aim of which was to examine the interaction between the urban wastewater system, the treatment plant, the (lake) receiving waters and to suggest remedial measures for rehabilitation of the receiving lake waters.

PRESENT WORK AND METHODOLOGY

The catchment characteristics of the lake have changed due to rapid urbanization in the catchment area. Hence a fresh analysis of the most recent available hydrological data for the catchment including rainfall, runoff, evaporation and sedimentation rates in the lake was carried out. A mass balance of the flows into the Hussain Sagar Lake was carried out with the objective of determining the amount of flow to be added to the lake to maintain a predetermined lake level. This full tank level (FTL) was set to 513.43 m considering 1 in 5 dry years. An additional consideration was that the HMWSSB would be supplying 45 Mld of treated water to the newly developed suburbs in the catchment area of the lake some of which would eventually return to the lake as wastewater.

DATA

Revised estimates of the Hussain Sagar Lake data were obtained during May to July 2002. Updated monthly rainfall and evaporation data recorded from 1974-2001 (28 years) were also obtained from the Indian Meteorological Department (IMD). The comparisons of the changes to the salient features of the lake data are summarized in Table 1. It can be seen that the decrease in the lake area, volume and catchment area is in the range of 33- 43 % over 14 years (1988-2002). The measured DWFs have increased by 4 times. The average annual evaporation has decreased by about 10 %. Because of the decrease in the area of the lake from 5.7 sq km to 3.621 sq. km. and also due to the decrease in the average annual evaporation rate, there has been a decrease in the value of the average evaporation loss rate from 12.78 Mm^3/yr to 7.236 Mm^3/yr. However, the detailed analysis of the 28 years rainfall data indicated that the average annual rainfall has increased by about 4 %.

Table 1. Summary of key features of the Hussain Sagar Lake, Hyderabad

S. N.	Feature	(1988) survey	(2002) survey	Remarks
1	Water spread at FTL	5.7 km^2	3.621 km^2	36.5 % reduction
2.	Water spread at MWL	6.6 km^2	4.426 km^2	33 % reduction
3.	Volume of the lake	28.6 Mm^3	18.1 Mm^3	36.7 % reduction
4.	Average depth of the lake	5.02 m.	5.0 m.	Almost same
5.	Total catchment area of HS lake:	240 km^2	136.8 km^2	43 % reduction
6.	(Kukatpalli nullah	-	90.90 km^2	-
	Picket nullah	-	26.20 km^2	-
	Banjara nullah	-	5.00 km^2	-
	Balkapur nullah	-	14.68 km^2)	-
	Measured DWF:			
7	Kukatpalli nullah	13.64 Mld	67.8 Mld	Increase by almost 5 times
	Picket nullah	3.18 Mld	14.6 Mld	Increase by almost 5 times
	Banjara nullah	4.5 Mld	14.2 Mld	Increase by over 3 times
	Balkapur nullah	6.8 Mld	18.4 Mld	Increase by almost 3 times
	Total DWF	28.19 Mld (0.084 Mm^3/month)	115.0 Mld (3.45 Mm^3/month)	Increase by over 4 times
8.	Average Annual Evaporation	2214 mm (14 years data)	1999 mm (28 years data)	Decreased by 10 %
9.	Average evaporation loss from lake	12.78 Mm^3/yr	7.236 Mm^3/yr	Decrease due to decrease in lake area
10.	Average percolation loss	3.0 Mm^3/yr	3.0 Mm^3/yr	Same
11.	F.T.L.	513.43 m.	513.43 m.	Same
12.	Unfiltered water from H.S.	(0.276 Mm3/mth)	9.2 Mld (0.276 Mm^3/mth)	Same
12.	Average Annual rainfall (Hyderabad airport)	806 mm (14 year data)	840.8 mm (28 year data)	4 % increase
13.	1:5 year rainfall	540 mm (14 years data)	703.8 mm (28 years data)	30 % increase

INFLOWS TO THE LAKE

Direct rainfall

The monthly rainfall recorded from 1974 to 2001 (28 years) at the Hyderabad Airport meteorological station have been obtained from the IMD (Indian Meteorological Department) and used for the present analysis. These data are shown in Table 2. Monthly values for the average year and their standard deviations are also shown. A comparison of the 14 year monthly standard deviations and the 28 year monthly standard deviations indicates that the annual variability has declined. However, the variability of monthly rainfall for all the months (based on monthly averages) has increased except for the months of September and November for which the variability has decreased.

For the 28 years rainfall data set using Gumbel's probability law, the 1 in 5 dry year annual rainfall has been computed as 704 mm and this value of rainfall corresponds to the annual event year 1979. Hence, monthly data for the year 1979 has been utilized to determine the behavior of the lake during 1 in 5 year drought period.

DRY WEATHER INFLOW INTO THE HUSSAINSAGAR LAKE

The values of the dry weather inflows (DWF) have been estimated as 115 Mld (3.45 Mm^3/month) based on the increased population. It has been mentioned that these flows has been measured in the summer and the flows are higher by 25-35 % more in the other months (HMWSSB, 1991). Hence, for the purpose of this analysis, the inflows during the months of June to September are taken as 4.657 Mm^3/month (1.35 times the mean monthly value). These inflows have been used to simulate the flows for the situation to examine the flow conditions with measured rainfall data.

RUNOFF ESTIMATION FROM THE CATCHMENT OF HUSSAIN SAGAR LAKE

The inflow due to direct rainfall has been computed considering a water spread of 4.426 km^2 corresponding to the Maximum Water Level (MWL). This value has been taken because it is expected that the lake would occupy the area corresponding to MWL during times of excess rainfall and subsequent overflow conditions.

There has been a substantial decrease (43 %) in the catchment area of the lake to 136.80 sq km. As updated details of the break up of the free catchment and the intercepted catchment were not available, it has been assumed that the free catchment area bears the same proportion to the total catchment as determined in the earlier studies, i.e. it is about 39 % of the total catchment area, the rest being the intercepted catchment area. In this analysis, the "free catchment" is that which still drains to the lake whilst the flows from the "intercepted catchment" are drained elsewhere. The revised estimates are shown in Table 3.

Runoff from the free catchment

The runoff from the free catchment has been computed using the simple relationship:

Monthly runoff = S R C
(1)

S = Area of free catchment (km^2)

R = Monthly rainfall (mm)

C = Runoff coefficients.

As it was not possible to estimate the recent values of C within the time frame of this study, the values of these have been taken from the earlier study and these are reproduced in Table 4.

However, it should be noted that because of rapid urbanization in the catchment of the lake, the runoff coefficients would be much higher, hence the inflows form the free catchment may be significantly higher.

Runoff from the intercepted catchment

Data for the flows from the intercepted catchment were not available. For the present assessment, it has been assumed that because of rapid urbanization in the catchment, the flows from this area are no longer reaching the lake because of severe depletion of groundwater levels, withdrawals, etc. Hence, the flow contributions from the intercepted catchment areas have been ignored. It may be mentioned that some flows may reach the lake during the excess rainfalls (> 250 mm) per month which usually occur in the monsoon season when the lake is already in the overflow condition. However, the mass balance analysis has shown that in this case, this excess volume would simply overflow as spillover and would not therefore be relevant for estimating the artificial inflow required to maintain the FTL at 513.43 m.

LOSSES FROM THE LAKE

Evaporation Data

Daily mean evaporation rates for the years 1988 to 2001 were obtained from the IMD (Hyderabad airport) and the data summary is shown in Table 5. For the purpose of the simulation, the monthly evaporation losses have been computed from this data and used for the analysis.It may be noted that the evaporation data as provided by IMD is for the Class A pan. For lakes, the pan evaporation data should be corrected to take into account the greater lake area, hence it has been multiplied by the pan coefficient of 0.82 for lakes to get the evaporation loss from the lake area.

Losses due to evaporation are calculated according to the surface area of the lake. This is determined from the surface area - storage capacity- water elevation curve of the lake (Figures 2 and 3).

Percolation Losses

An average value of 3.0 Mm^3/yr (0.25 Mm^3/month) has been provided by HMWSSB and this value has been used in the present analysis.

Artificial Outflows

The artificial outflows (withdrawal) of 9.2 Mld (0.276 Mm^3/month) have been provided by HMWSSB and this value has been used in the present analysis.

Leakage Through Spillway

Leakages through the spillway wall had been computed in the HMWSSB report. However, during the site visit in April 2002, it was observed that the cracks in the wall had been repaired and no such leakages from the spillway wall were visible. Hence, these have assumed to be negligible in the present analysis.

Surface Area-Storage Capacity-Water Elevation Curve

The decrease in both the surface area as well as the volume of the lake will significantly alter the surface area -storage capacity-water elevation characteristics of the lake. At the time this study was made, fresh assessment of these characteristics were not available. Hence for the purpose of this analysis, it has been assumed that the lake retains the earlier characteristics of surface area-storage capacity-water elevation curve up to elvn. 509.00. This is because other than sedimentation, there may not be any other factors contributing to the decrease in volume of the central deep core of the lake (Sedimentation rates were not available and have been ignored for the present assessment).

From elvn. 509.000 to 513.430, it has been assumed that the reservoir behaves as a linear reservoir. This is consistent with the observation that there has been all round development on the sides of the tank, for example construction of the Necklace Road on the periphery of the lake and other structures.
Based on the above rationale, fresh surface-area-storage capacity-water elevation curves have been plotted (Figures 2 and 3). These have been used in the subsequent simulation.

SIMULATION

It is assumed that the reservoir is full at the start of simulation of the mass-balance. The inflows and losses for a particular month are then computed. If the volume is less than the full volume of the lake, the difference is assumed to be the artificial inflow required for that particular month. Thus, for each month the volume required to be added is computed. Otherwise, it will result in spillover and the tank will be full. These simulations have been carried out for the entire 28 years of record. The analysis has been carried out for the following two cases to determine the amount of inflows required to maintain the lake level at elvn. 513.430 MSL.

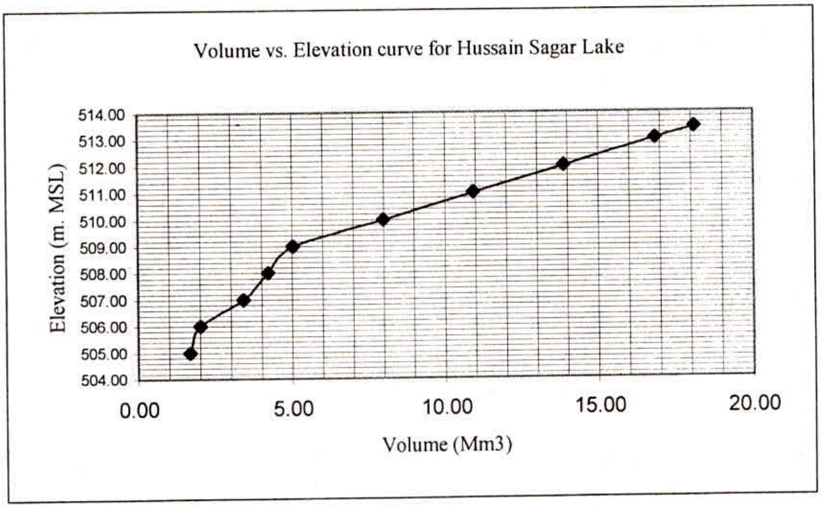

Figure 2. Volume Elevation curve for the Hussain Sagar Lake, Hyderabad.

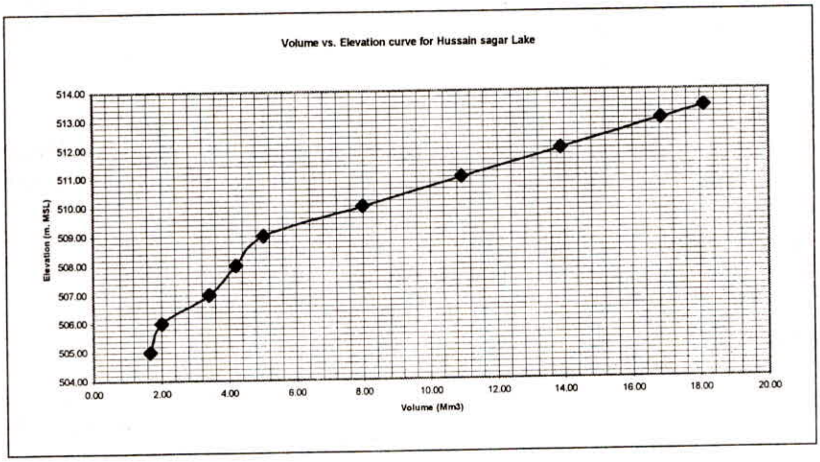

Figure 3. Area Elevation curve for the Hussain Sagar Lake, Hyderabad

Case I: No dry weather inflow into the lake

Based on the Gumbel's frequency analysis, the year 1979 is the year corresponding to one in five year drought (annual rainfall is 704 mm). Hence, for the year 1979, from the simulations of the hydrological mass balance, it is seen that the maximum required artificial inflow is 38.16 Mld and this corresponds to the month of March 1979 (zero rainfall). The simulations for the entire period of rainfall record (1974-2001) were also carried out.

Case II: Artificial inflow (DWF) into the lake

For this case, the updated DWF values are used. The total DWF from the four drains discharging into the lake is 115 mld (3.45 Mm^3/month). As these values were measured in peak summer when water supply was curtailed, the flows in other seasons are expected to be 25-35 % more. Therefore, for the months of June to September the DWF values are taken as 4.657 Mm^3/month (1.35 times the mean monthly DWF). The simulations for the complete period of rainfall record from 1974 - 2001 were also carried out. It was observed that when all the DWFs are diverted into the lake, this resulted in overflow throughout the year. While this may not be relevant for the present objective of maintaining the lake water level, the flood hazard due to the overflows occurring in the monsoon for the downstream areas of the overflow points need to be considered in the overall master plan for the city.

SUMMARY AND DISCUSSION

1. The lake is no longer used for irrigation or water supply.
2. Losses from evaporation and percolation are modest (about 10 Mm^3/yr).
3. Significant areas of the lake periphery have been reclaimed for urban developments which include the development of a housing estate, a new circular ring road on the periphery of the lake and an entertainment park. This has resulted in 43% of the catchment being lost, but this has been compensated for by increased hardening – although the resulting runoff generally only reaches the lake during the monsoon period when it is generally full anyway.
4. A 20 Mld sewage treatment plant discharges into the lake on a continuous basis (about 7 Mm^3/yr).
5. The dry weather flows (presumably of sewage) amounting to some 46 Mm^3/yr, less the 7 Mm^3/yr going through the sewage treatment plant, are diverted out of the catchment. Not all sewage is treated and only the sewage coming into one of the four largest drainage channels is treated presently.
6. The main problem is during the dry period when the losses (from evaporation and percolation) exceed the gain from the sewage treatment plant and rainfall.
7. The maximum required artificial inflow is computed as 38.160 Mld based on 1:5 dry year (Year 1979). As 20 Mld is already being supplied by the existing STP, it is concluded that an additional 18.16 Mld STP would be required to treat the influent to the lake to maintain the FTL of 513.45 m. based on 1:5 dry years.
8. In India, it is observed that the monsoon generally follows a 11-year cycle and therefore 33 years data is considered adequate for hydrologic analysis. At the time this study was carried out, only 28 years data was available.

CONCLUSIONS

This paper has presented a rapid assessment through hydrological analysis of the interaction between the urban wastewater system, the treatment plant and the receiving lake waters in Hyderabad city in India and has suggested remedial measures for rehabilitation of the receiving lake waters. In this study, it was found that a solution to lake pollution was by means of providing an additional STP for treating the influents before discharging into the lake to maintain a predetermined lake water level. It is concluded that for planning future rehabilitation measures caused by increasing population in the catchment areas of the receiving waters, a hydrological assessment of the catchment characteristics enables the determination of the possible remedial measures for rehabilitation of the receiving lake waters. Detailed studies are required to compute each of the parameters, for example sedimentation rate, infiltration rate, runoff coefficients, etc. to present an accurate picture of the complex processes involved in the lake hydrology and it's interactions with the drainage system.

ACKNOWLEDGEMENTS

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Table 2. Summary of the statistical analysis of the monthly rainfall records for Hyderabad Airport from 1974 to 2001

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Av28 yr (1974-2001)	8.5	9.8	16.5	19.4	35.1	114.1	161.1	197.3	138.1	106.[illegible]	29.8	4.8	**840.8**
SD28 yr	16.3	20.9	24.2	18.8	43.5	52.0	77.7	87.6	95.3	86.9	48.1	10.3	207.8
Av14 yr (1974-1988)	7.9	8.2	16.3	18.2	31.4	115.2	145.9	165.0	160.4	98.3	36.7	2.9	**806.5**
SD14 yr	15.7	13.5	23.8	17.8	37.5	40.7	56.8	77.5	126.8	83.6	60.9	5.0	246.4

Table 3. Estimated catchment area of Hussain Sagar Lake for computing catchment runoff

S. N.	Catchment Area	1988 study	Present study (2002)
1	Free catchment area (km^2)	67	38.19
2	Intercepted catchment area (km^2)	173	98.61
3	Total (km^2)	240	136.80

Table 4. Coefficients of runoff corresponding to different monthly rainfall

S No	Monthly rainfall (mm)	Runoff coefficient
1.	< 40 mm	0.00
2.	40-90	0.20
3.	90-150	0.25
4.	150-200	0.30
5.	200-250	0.35
6.	>250	0.40

Table 5. Summary of the statistical analysis of the monthly evaporation data for Hyderabad Airport from 1974 to 2001 (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Av28 yr (1974-2001)	133	154	211	232	256	189	150	138	140	151	129	116	1999
SD28 yr	39.4	28.1	34.2	36.6	50.6	50.5	28.0	30.1	27.4	39.2	32.6	24.1	288.2
Av14 yr (1974-1988)	151	169	227	254	279	212	166	154	157	177	141	127	2214
SD14yr	48.2	22.9	28.9	32.0	43.1	48.0	29.6	29.5	27.1	33.5	23.6	23.1	217.6