Water Abundance and Effect of Glacier Melting at Priyadarshini Lake in Antarctica

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Priyadarshini lake also called Zub lake covers an area of 0.29 km² and forms the major source of water supply to the Maitri. The consumption of water at Maitri is relatively more in austral summer compared to the rest of the year and it fluctuates between 1.70 m³/day in winter and 5.7 m³/day in summer. Although the inflow volumes to the lake can vary widely from one summer to another owing to temperature differences, changes of annual losses over both summer and winter take place. Melt water runoff from surrounding glaciers during the short austral summers is the only significant source of water that maintains the lake. Using the paddle boat, marked string with weight and GPS, depth and boundary line was recorded. The maximum recorded depth was 7.2 m. From 2nd January to 29th January, 2000 the water level recorded continuously has shown the increase in water level. The total area of the lake was estimated is around 2 76 944 m² after accumulation of feed water, which is 4.49% less than the GPS monitored area. Further volume calculated is 6 50 358 m³. The average water consumption at Maitri is around 900 m³ / year. The inflow of water due to annual glacial melt is around 61132 m³. Therefore even in the winter period sufficient water is available to be consumed by Maitri. This water abundance through Priyadarshini Lake will sustain for many years even if there is no inflow of water. The water quality of the lake is unchanged by the intrusion of seepage water channel from the wastewater pond due to less quantity and high dilution ratio and due to replenishment of water from glacial melt.

Keywords: Lake; Volume; GPS; Glacier melt; Water quality

INTRODUCTION

Antarctica is the largest and most pristine wilderness on earth, covering an area of approximately[3] 13.6 million km². It is inhospitable due to extreme cold, presence of a massive permanent ice sheet and the floating ice shelves. Less than 2.0% of the continent here is ice free. Scientific research is the major human activity being carried out in Antarctica. 'Maitri', India's indigenously designed polar research station in Antarctica is located on the Schirmacher Oasis at 70°45'53" S latitude and 11°44'03" E longitude. It is built on an ice-free rocky moraine at an elevation of 117m above mean sea level. Maitri is an all year round base which is situated on Schirmacher Oasis which is on the Nunatak, Vassfjellet close to the ice shelf. The Nunatak is located on Dronning Maud Land. Maitri is surrounded by a number of small lakes. A glacier to the south of the station covers parts of the nunatak and ends about 400 m from the main building.

The Maitri station consists of four blocks that comprise of lodging, medical facilities, communication control system, computer room, gymnasium, cold storage, sports room, lounge, dining, kitchen, boiler–room, laundry room, bathrooms and toilets. Three containerized modules of generators are located outside on the southern side of the Maitri station.

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SITE DESCRIPTION

Priyadarshini Lake covers an area of 0.29 km² and forms the major source of water supply to the Maitri station. The lake is situated about 225 m away north of the Indian permanent research station 'Maitri'. The consumption of

Table 1 Monthly water consumption pattern at Maitri

Month	Maximum Water Supply in a Day, m³/day	Minimum Water Supply in a Day, m³/day	Total Water Supply in a month, m³/day	Average Water Supply m³/day	Summer Camp Consumption, m³/day
January	9.0	2.5	121.8	3.92	24.8
February	7.0	5.0	164.5	5.67	23.8
March	4.0	1.5	66.3	2.21	4.0
April	4.5	2.5	50.4	1.68	0.0
May	4.2	3.1	56.6	1.82	0.0
June	4.0	3.0	53.1	1.77	0.0
July	7.5	3.0	58.9	1.90	0.0
August	5.0	3.2	63.5	2.04	0.0
September	5.0	3.0	67.7	2.25	0.0
October	5.0	3.5	52.3	1.69	0.0
November	5.0	3.0	57.2	1.90	0.0
December	5.5	1.8	62.3	2.09	0.0

Figure 1 Location of Maitri and Priyadarshini lake

water at Maitri is relatively more in austral summer compared to the rest of the year. The volume of the water fluctuates between 1.70 m^3/day in winter and 5.7 m^3/day in summer (Table 1). It is during the austral summer that most of the scientific activities are carried out. The number of consumers are more during the summer as total strength reaches to around 75 in a day. However during winter it remains around 25. Lake is surrounded by small hill along east and north direction, the south and western side is fairly sloppy terrain.

Although inflow volumes to the lake can vary widely from one summer to another owing to temperature differences, annual losses over both summer and winter may also change. Melt water runoff from surrounding glaciers during the short austral summers is the only significant source of water that maintains the lake, during winter sublimation from the ice cover is the dominant loss from the lake.

MATERIALS AND METHODS

Area Measurement

In the year 1987 the area of the Priyadarshini lake was estimated[4] as 0.297km^2. In the year 2000, global positioning system (GPS) of make Corvallis Microtechnology Inc. version 2.4 has used as a mapping tool without differential correction[5]. The accuracy of this instrument was quoted as 10 m – 30 m. In the last week of the January when the ambient temperature was around – 4°C to – 2°C and there was no inflow of water, instrument (GPS) was calibrated with necessary inputs and it was set to record the position at every five seconds. Holding the GPS in handheld positions of the points were recorded while moving on foot just nearby the edge of the water around the lake, keeping the instrument vertically above the water except at few locations where easy approach was not possible. After getting all the coordinates it was converted into graphical data and with the application of GPS and SURFER total area was computed.

Depth Measurement and Volume of Lake

Before feeding of glacial melt water the depth of water at various places were recorded using a marked string with around 2 kg weight, which was attached at bottom to keep

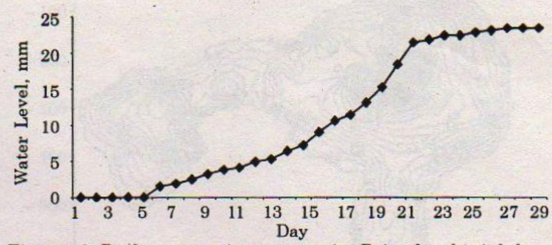

Figure 2 Daily water increment in Priyadarshini lake

the string vertically over the point. Using the paddle boat and GPS, depth was measured and coordinates were recorded at the respective points at 55 locations within the lake. Care was taken to lower the string gradually into water and so as to avoid penetration into algal mats present at bottom of the lake. As soon as the string was slack, the depth was recorded. Maximum depth recorded was 7.2 m at Priyadarshini lake.

Additional Feed Water Measurement

The volume of water of Priyadarshini lake never remains the same because of the Schirmacher glacier, which is around 1200 m away from the lake and melts when ambient temperature reach as to +1°C to + 5°C for couple of days. This melted water joins glacial lakes formed adjacent to glacier and from these lakes ultimately it joins Priyadarshini lake. After reaching a certain level, the water outflows from Priyadarshini lake to adjacent lake. To measure the inflow into the lake two iron rods at the bank of the lake were fixed at two feet distances. A cotton string was tightened in between the iron rods and leveled with the help of spirit level, keeping in view that it just touched to the water surface level when there was no inflow in to the lake as ambient temperature recorded was –2 °C. After a few days when the temperature started raising, the glacier started melting and the melt water started feeding into Priyadarshini lake through connecting glacial lake. Daily at evening, level of the lake water was measured over the string using a scale. From 2nd January to 29th January 2000 (Figure 2) the water level recorded continuously showed the increase in water level upto 18th January and after that it remains constant for three days. It was noted that the excess water started diverting to a connecting lake situated downward side of the Priyadarshini lake and after three days temperature went down and glacier melting stopped which was the barrier feeding of water into the lake. Maximum air temperature recorded on 9th and 20th January, was + 4.4°C.

Sample Collection and Preservation

Samples from various locations of the lake were collected twice in the year 2000 and 2004 using grab sampler from the same locations. The temperature was measured at each of the sampling point. Collected samples brought to the laboratory at Maitri and processed to measure the basic physicochemical parameters, such as, pH, BOD, COD, conductivity, TSS, Cl, NH_3–N, DO, total alkalinity and turbidity. The rest of the samples collected were preserved with HNO_3 for heavy metal analysis and with H_2SO_4 for organic, oil and grease analysis. The samples were sealed properly and brought to India for further analysis in the laboratory. Samples were filtered with 0.45 μm Whatman filter papers. All the analyses were performed using standard methods[1]. The analysis of heavy metals were carried out on GBC, atomic spectrophotometer in the laboratory.

RESULTS AND DISCUSSIONS

Total demand of water estimated based on the average consumption of water as approximately 353 m^3 during the summer and 522 m^3 during the winter. During the summer in the month of January lake water melts and water is available for intake. From the month of February onwards the water starts freezing. So the water from the bottom of lake is drawn using the submersible pump and with the help of heating coils. However it is necessary to estimate the quantity of water available at the lake for avoiding the risk associated during a very harsh climate in the winter season. Total area of the lake estimated through GPS (Figure 2) is around 2 89 972 m^2. However the contour map drawn using the SURFER 7 of the same coordinates shows that the total area is 2 76 944 m^2, which is 4.49% less than the GPS monitored area. The range of the accuracy of the GPS used in between 10 m to 30 m without differential correction[5]. The deviation from accurate position may be in any direction. For this purpose this is assumed that the deviation is on an average of 20 m and may be either in or off side. Considering both these options it is estimated that 20 m off gives (Figure 3) the total area of approximately 3 60 802 m^2 (24.4% more) and considering 20 m inside points from the present recorded points(Figure 4) gives the area around 2 23 070 m^2 (23.0% less).

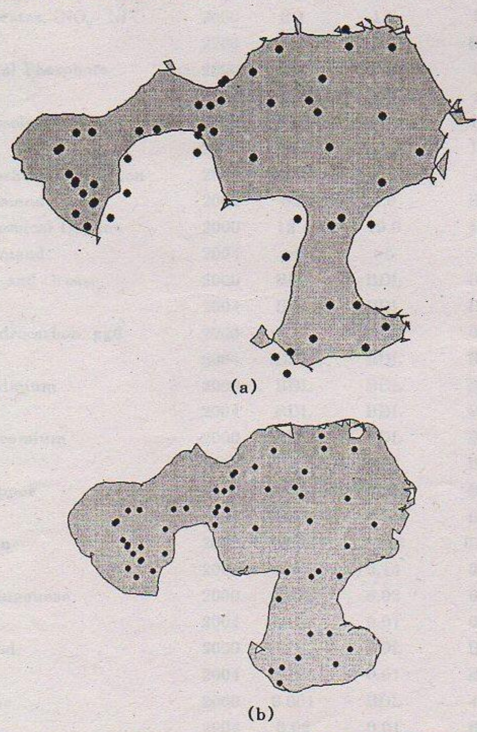

Figure 3 Area of lake (a) 20 m inward correction and (b) 20m outward correction

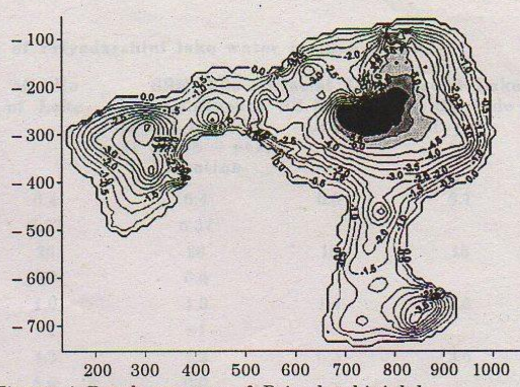

Figure 4 Depth contour of Priyadarshini lake

Volume of the Lake

Considering the same coordinates, contour mapping and GPS data gives average depth which ranges from 2.34 m to 2.24 m. Based on this the volume of water estimated is 6 50 358 m^3. Considering the area of lake of 20 m offside the, volume would be 8 08 197 m^3 and 20 m inside the volume would be 4 99 695 m^3. For more realistic approach to facilitate the calculation of volume within the envelope, the area of lake is considered as 2 76 944 m^2 and volume calculated is 6 50 358 m^3. The recorded rise in the water level was 230 mm, therefore the volume before the water inflow into the lake was estimated to be 5 89 226 m^3. This shows that due to the glacial melt, the total inflow of the water into Priyadarshini lake is around 61132 m^3. The average consumption of water at Maitri is about 900 m^3 / year. Except the Maitri there is no other user who draws the water from the lake and no seepage was observed.

Further in this area due to high wind velocity and dry atmosphere the relative humidity is recorded varying from 5% – 35%. Therefore the water evaporation rate is quite high which is 217.5 l/m^2/year. During the winter period when the upper 3 m of the lake water is freezed the water available below at the lake is estimated as 1 24 429 m^3. This reveals that this lake possesses an inverse thermal stratification with a minimum temperature of –2°C to 0°C at the surface and a positive temperature at the bottom.

Effect on Water Quality

The treated wastewater generated from Maitri is collected in waste stabilization pond. There is minor seepage from the wastewater pond towards lake because it is located at higher elevation than the lake and the bottom soil is

Table 2 Physical demand, nutrient and heavy metal analysis of Priyadarshini lake water in time frame

Sampling Location / Parameter	Year	Near Pump House Channel	SW Side of Lake Near Seepage	WSW Side of Lake	Middle of Lake	SSE Side at Confluence Point of Lake at South – east Direction	Glacial Lake SE Side of Lake	Glacial Lake at SW Side of Lake
pH	2000	6.4	6.3	6.3	6.4	6.4	6.0	6.1
	2004	5.6	5.0	5.2	5.37	5.37		
Conductivity, µs/cm	2000	19	22	19	26	28	10	15
	2004	12.2	16.6	23.6	8.0	6.5		
Turbidity, NTU	2000	1.2	1.0	1.7	1.0	1.0	1.4	1.5
	2004	<1	<1	<1	<1	<1		
Alkalinity	2000	4.0	4.8	4.6	4.3	4.2	5.3	3.5
	2004	8.0	4.0	4.0	5.0	6.0		
Total Hardness as $CaCO_3$	2000	6.5	8.4	7.4	7.5	8.3	10.1	6.2
	2004	12.0	8.0	7.0	7.0	13.0		
Calcium Hardness	2000	4.5	6.2	5.6	5.5	6.3	7.6	4.8
	2004	6.0	5.0	5.0	5.0	12.0		
Chloride	2000	2.8	2.4	2.8	2.6	2.9	2.8	2.9
	2004	2.1	2.2	3.1	6.4	5.2		
Sulphate	2000	1.2	1.2	1.6	1.7	1.8	1.5	1.1
	2004	2.0	3.0	1.0	2.0	1.0		
Sodium	2000	1.6	1.5	1.5	1.5	1.5	1.4	1.2
	2004	3.0	3.0	3.0	3.0	3.0		
Potassium	2000	0.4	0.8	0.4	0.5	0.8	0.4	0.3
	2004	1.0	1.0	1.0	0.0	1.0		
Nitrates, (NO_3– N)	2000	0.1	1.2	0.2	0.2	0.3	0.09	0.05
	2004	0.5	0.4	BDL	BDL	BDL		
Total Phosphate	2000	0.4	0.8	0.5	0.8	BDL	0.4	1.8
	2004	2.3	2.0	2.5	4.2	6.3		
Dissolved Oxygen	2000	14.0	12.8	13.7	13.7	14.0	13.4	11.8
	2004	14.4	14.2	14.0	14.8	14.8		
Biochemical Oxygen Demand	2000	3.9	4.2	3.6	3.8	3.1	2.1	2.2
	2004	0.5	4.0	BDL	3.0	BDL		
Chemical Oxygen Demand	2000	12.4	19.6	12.0	21.4	8.0	10.8	5.6
	2004	>5	>5	>5	>5	>5		
Oil and Grease	2000	BDL	BDL	BDL	BDL	BDL	Not measured	Not measured
	2004	BDL	BDL	BDL	BDL	BDL	Not measured	Not measured
Hydrocarbon, µg/l	2000	0.17	0.10	0.10	0.13	0.11	Not measured	Not measured
	2004	BDL	BDL	BDL	BDL	BDL	Not measured	Not measured
Cadmium	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	BDL	BDL	BDL	BDL	BDL		
Chromium	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	0.01	0.01	0.01	0.01	0.01		
Copper	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	BDL	0.01	BDL	0.03	BDL		
Iron	2000	0.568	0.129	0.995	0.615	0.574	0.601	1.655
	2004	0.07	0.14	0.17	0.06	0.09		
Manganese	2000	0.011	0.02	0.03	0.071	0.017	0.04	0.175
	2004	BDL	0.01	0.01	0.01	BDL		
Lead	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	BDL	0.01	BDL	0.01	0.01		
Zinc	2000	0.001	BDL	47.9	0.132	0.072	0.119	0.15
	2004	0.02	0.01	BDL	BDL	BDL	Not measured	Not measured

Note : BDL: Below detection limit; All values are in mg/l.

Table 3 Surface Water Quality – Priyadarshini lake – diversity of zooplankton

Sampling Location	Year	Total Count/m³	Organism in Groups, %					Shannon Weaver Diversity Index
			Protozoa	Rotifera	Copepoda	Nematoda	Insecta	
Near Pump House	2000	360	–	50	–	50	–	1.00
	2004	ND	–	–	–	–	–	–
SW side of lake near seepage channel	2000	180	–	–	100	–	–	0.00
	2004	ND	–	–	–	–	–	–
WSW side of lake	2000	180	–	100	–	–	–	0.00
	2004	ND	–	–	–	–	–	–
Middle of lake	2000	180	100	–	–	–	–	0.00
	2004	ND	–	–	–	–	–	–
SSE side at confluence point of lake at	2000	540	67	33	–	–	–	0.914
south – east direction	2004	ND	–	–	–	–	–	–

permafrost so from the bank of pond seepage starts and joins lake. The quantity is very less according to the visual observations. During the summer period around 2.6 m³ of wastewater is collected in the pond every day[6]. Assuming that the maximum of 5% seepage every day for two months, till freezing starts total quantity of wastewater which would join the lake water is 7.8 m³, get diluted, sedimentation starts as well as the suspended and colloidal particles further travel towards middle of the lake and then towards outlet of the lake. If it is assumed that due to bottom slope of lake towards middle and high wind velocity, which in range of 20 km/h–150 km/h a complete mixing occurs and a dilution ratio found to be range of 7820 times which is quite higher side.

The samples collected in the year 2000 were before the glacier melting, and in the year 2004 the samples from the same location were collected after glacial melting. During the year 2004, the value of pH is low because the ambient temperature was –2°C, (in year 2000 ambient temperature was 4°C during sampling) which would result the mixing of CO_2 into the lake water and reducing the pH. It is dilution effect that the turbidity is reduced to <1 at all the sampling locations in the year 2004. Dissolved oxygen at all the places including the confluence seepage channel is improved as compared to 2000 where at this point it was recorded as 12.8 mg/l (Table 2). Similarly the pollution indicator NO_3–N, bio–chemical oxygen demand, chemical oxygen demand and hydrocarbon have significantly reduced at all the sampling locations in the year 2004. Among the heavy metals iron, manganese, lead and zinc concentration found to be low except near confluence point where iron concentration found little higher and possible cause is old iron drinking pipeline which would be rusted and contributing to iron concentration. At middle of lake and at confluence point the copper concentration has been found out little higher in the year 2004 than the year 2000. Cadmium and chromium are found below the detection limit in both the samples. There is replenishment of water around 61000 m³, depending upon the ambient temperature of particular year. In the biological sample zooplankton found to be less

Table 4 Surface water quality – Priyadarshini lake – diversity of phytoplankton

Sampling Location	Year	Total Count/m³	Organism in Groups, %				Shannon Weaver Diversity Index
			Chlorophyceae	Bacillariophyceae	Cyanophyceae	Euglenophyceae	
Near Pump House	2000	–	–	–	–	–	–
	2004	136	66	22	12	–	3.412
SW side of lake near seepage channel	2000	440	100	–	–	–	0.000
	2004	123	58	20	–	22	3.612
WSW side of lake	2000	–	–	–	–	–	–
	2004	131	60	29	11	–	3.891
Middle of Lake	2000	440	–	–	100	–	0.000
	2004	129	48	32	–	20	3.408
SSE side at confluence point of lake at	2000	880	–	100	–	–	0.000
south – east direction	2004	135	67	33	–	–	3.671

and diversity as shown from Shannon weaver index, but in the year 2004, it is totally washed off. Among the phytoplankton the diversity index was poor in the year 2000 while in year 2004, it showed a reasonable diversity according to Shannon weaver index. The possible cause is due to the growth of algae, moos and lichen at the channel of glacier melt water which joins lake.

CONCLUSION

Priyadarshini lake situated near Maitri is the source of water for Maitri. The average water consumption by Maitri is around 900 m^3/year. Inflow of water to the lake due to glacial melt, which is around 61132 m^3/year. Even during the winter, sufficient water is also available to consume by Maitri. The water abundance available through Priyadarshini lake will sustain for many more years to come even if there is no inflow of water and even the water evaporation rate is high. The water quality of the lake has not been changed by the intrusion of small quantity of wastewater through seepage water channel from possibly due to maintained high dilution ratio and also due to replenish of water from the glacial melt. However in the interest of maintaining quality of water in the Priyadarshini lake, it is essential to take steps to control the seepage of wastewater to the lake by carpeting the pond liner and permeable reactive seepage barrier[2].

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