LAKE WATER BALANCE

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1 INTRODUCTION

The Technical Assistance in the Lake component of the Green Hyderabad Environmental Programme involved the development of methodologies and software in different fields of expertise. This report is directed towards hydrology, hydraulics and water quality. It aims to be a background document for the HUDA – engineers in the Lake Divisions to be available and used after the TA has finished.

2 HYDROLOGY ISSUES

Knowledge of the hydrology of a water system is a key factor to planning and design of any water structure. A proper estimate of the components of the water balance of a lake is therefore a first requirement. The type of wastewater treatment and the design capacities of treatment facilities and bypasses rely on this knowledge.

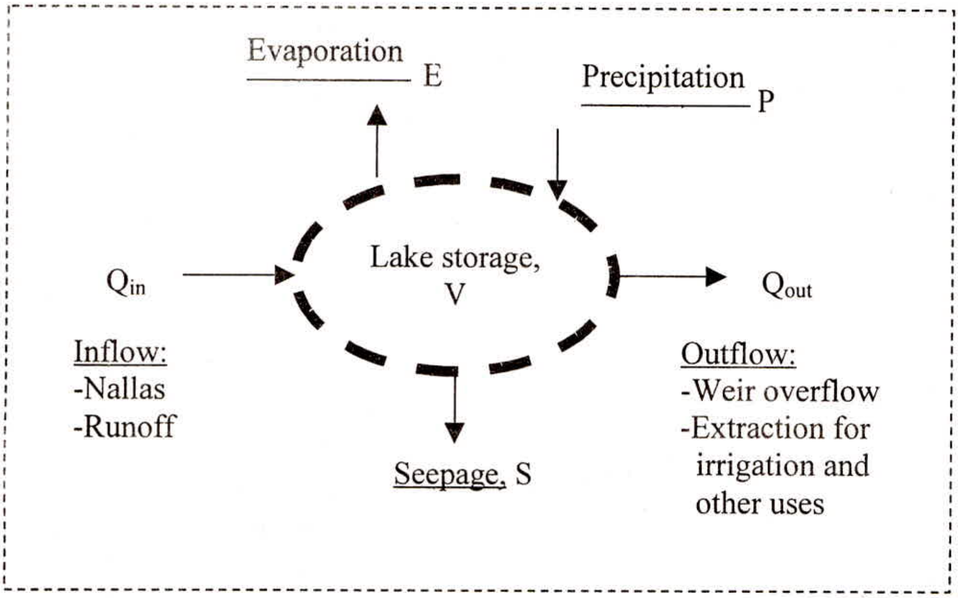
2.1 Components of the Water Balance

Calculating the water balance of a lake over a certain period involves determining the following components over that period:

1. Change of volume of the lake
2. Inflow
3. Precipitation
4. Outflow
5. Evaporation
6. Groundwater seepage

The change of water storage in a lake over a certain period is the sum of all water volumes entering and leaving the lake, where outgoing volumes have a negative sign. This system is depicted in Figure 1. Water balance of a lake..

Figure 1. Water balance of a lake



The water balance is always calculated over a certain period of time, depending on availability of data, and simply reads as:

All Inflow = All Outflow + Change in storage **...(1)**

Substituting for the the various components this equation becomes:

Change of volume (1) = Inflow (2) +Precipitation (3)– Outflow (4) – Evaporation (5) – Seepage (6) ...(2)

The change of volume equals the water spread area multiplied by the change in lake level. Over a certain period, one may average the water-spread area. All components of the water balance must be expressed in the same units, e.g. m^3 (cubic meters) or ML (million liters).

Once all but one of the components are known the remaining component follows from the equation. Accuracy is an issue that must always be given attention, but which is however often forgotten in design. Knowledge of the uncertainty in a calculated figure is required to take sufficient safety into account. If one or more of the components of the equation can be eliminated, it will make the calculation both more accurate and easier.

The components are fluctuating throughout the year, and the seepage component is probably the most stable, although it may still vary over the seasons due to variations in lake level and groundwater head. In many cases, the outflow of the lakes is negligible in the dry summer period. Components (1), (2) and (4) can be measured directly in the field. Component (3) and

(5) can be obtained from the Meteorological Service. Although evaporation data are published only on a monthly basis, daily records are kept, which are essential for proper calculation of the seepage component (6).

This seepage component cannot be measured directly, but can only be calculated once the other components of the water balance are known.

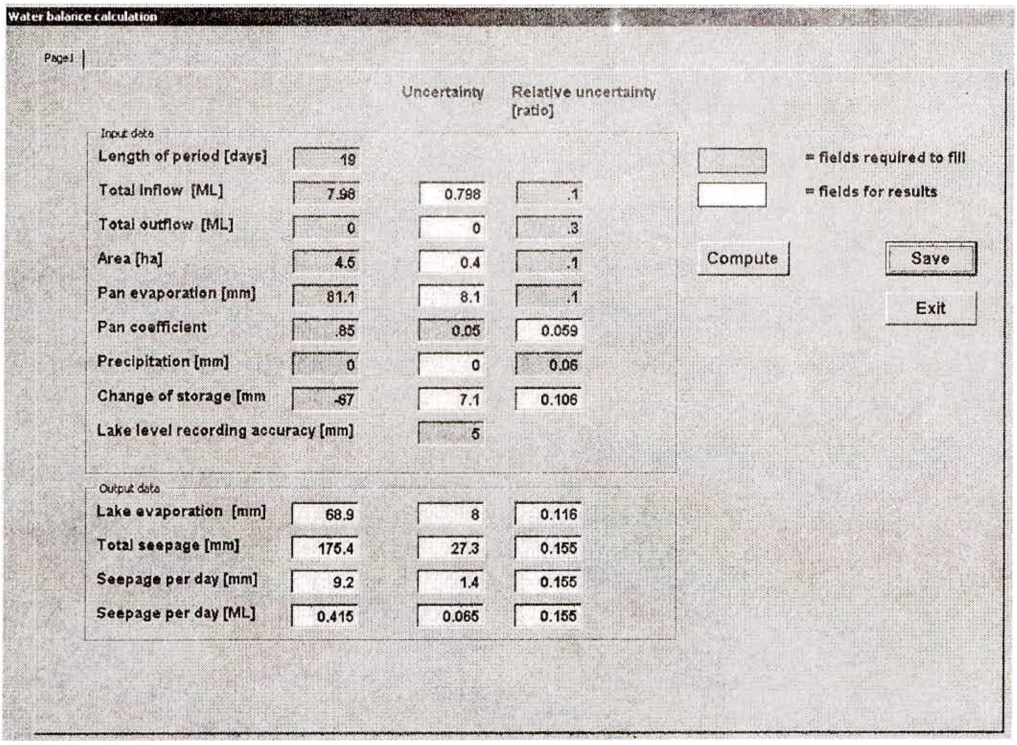
So basically the procedure is to collect all information about the components that can be measured, and calculate the unknown component (seepage) from the water balance equation ...(2).

We can read the water balance formula in terms of the thickness of a water slice instead of thinking in terms of volume. When we speak of groundwater seepage as well as evaporation, the usual unit is [mm]. So we wish to express the water balance for a particular lake in the same unit. This means that inflow, outflow and change of storage are expressed in mm. Change of storage is then simply the change in water level.

It is possible to make a good estimate of the seepage in the pre-monsoon period, because there is likely to be no outflow - unless initiated for irrigation purposes - and the inflow is only Dry Weather Flow (DWF). This means that with a proper estimate of the DWF, the seepage component can be calculated. The longer the period over which the calculation is done, the more accurate this calculation will be. In order to know what magnitude of uncertainty is involved in the calculation of the seepage, the uncertainties of all other input parameters in the equation must be taken into account. Then it requires basic knowledge of error analysis to determine the combined uncertainty in the final answer. The basics of error analysis are provided in the Methodology Guide provided by the TA-team (August 2004). An Excel model has been developed by the TA to assist in the calculations and provide immediate results of the uncertainty in the seepage component, after providing information about the uncertainties in all other components. This Excel model sheet has simply been called "Water balance" and been handed over to HUDA.

Figure 2 presents the main screen of the model. The data in this calculation were used to estimate the seepage in Sudulavani Kunta.

Figure 2 Main screen of Excel water balance model



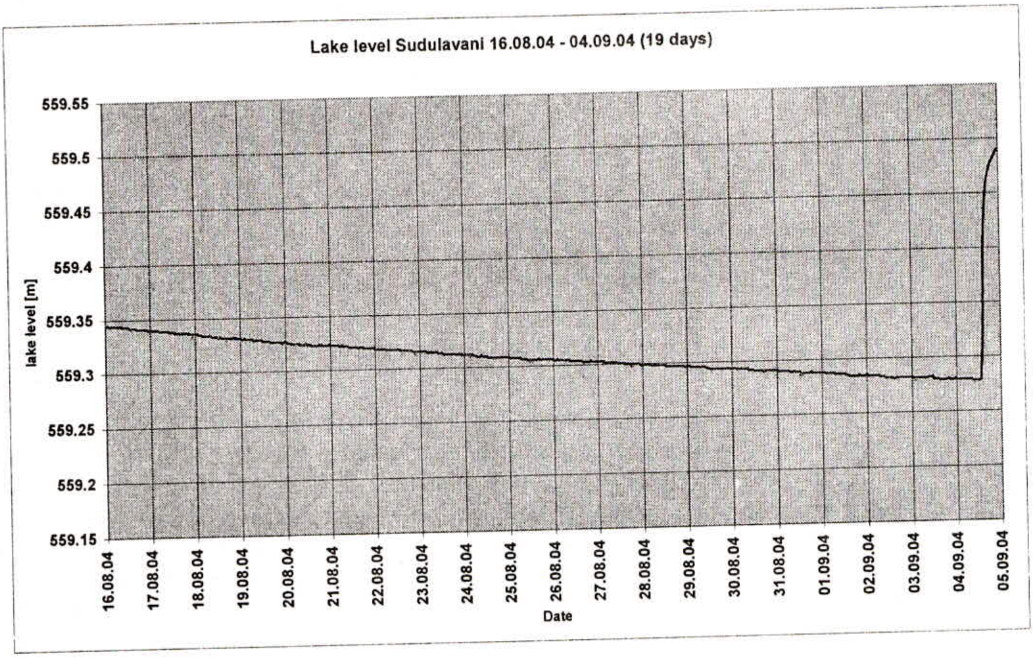
All blue fields of Input data have to be provided. The left column of Input data (blue color) requires field data input, the other blue fields are best judgement estimates of the uncertainty of these input data, either as an absolute value, or as a percentage. In the example the uncertainty in the total inflow has been taken as 0.1 (10 %) and the uncertainty in lake level recording as 5 mm.

Example calculation: #9 Sudulavani Kunta

Based on evaporation data for August/September 2004, an accurate water balance has been elaborated as follows.

In the period 16.08 – 04.09 the lake level has shown a steady decline, without any rise (see Figure 3) No rainfall was recorded in the same period, concluding that the only inflow into the lake was Dry Weather Inflow (DWF). On 04.09 at 14.00 hrs the lake level started to rise sharply due to rainfall. Evaporation data have been made available by the Meteorological Department.

Figure 3. Lake level of Sudulavani Kunta (16.08.04 – 04.09.04)



The water balance data for the period of 19 days (16.08, 00.00 hrs – 04.09, 00.00 hrs) are as follows:

Water spread area 4.5 ha				
DWF (from 48-hrs field measurements)			0.42 MLD	
DWF-Inflow over 19 days			7.98 ML	(1)
Lake level data:				
16.08 (00.00 hrs)	559.345 m			
04.09 (00.00 hrs)	559.278 m			
Change of storage:	- 0.067 m =	- 67 mm	- 3.015 ML	(2)
Pan-Evaporation (meterological department)			81.1 mm	
Pancoefficient .85				
Water evaporation			68.9 mm	
Water loss through evaporation			3.102 ML	(3)
Assuming no outflow:			0 ML	(4)
Seepage-loss (19 days) = (1)-(2)-(3)-(4)			7.893 ML	(5)
=7893/45 (Volume over area)		=	175.4 mm	

Seepage rate per day = 175.4/19 9.2 mm/day

Assuming a potential uncertainty of 10% in inflow, outflow, area and pan-evaporation, and an uncertainty of 5 mm in each of the two lake level recordings at the beginning and end of the observed period, the uncertainty margin in the seepage rate is ± 1.4 mm (see Figure 2), thus

Seepage 9.2 ± 1.4 mm/day

So with the assumed uncertainties in input parameters, the relative uncertainty in the seepage becomes 15.5 % and the maximum estimated seepages becomes:

maximum estimated seepage 10.6 mm/day

2.2 Design water loss

The water loss from a lake expressed in mm/day is the sum of seepage, evaporation and water release from the lake through a sluice, gate or other unintentional leakage. For dimensioning STP-capacity a practical design water loss needs to be defined, It has been defined as the sum of seepage plus the average evaporation of the top 25% values. This 25% values has been adopted with the reasoning that this reflects a period of the 3 months of the year with the highest evaporation. Details of historic evaporation data are provided in Figure 4 and Figure 5. The average value of the top 25% of historic evaporation data is 7.65 mm/day. So the design water loss equals 7.65 mm/day plus the calculated maximum value of the seepage in a particular lake.

WATER QUALITY ISSUES

Introduction

The Technical Assistance team prepared the so-called HUDALQUA-model in EXCEL using the programming language VBA (Visual Basic for Applications) within EXCEL. HUDALQUA simulates the water balance and BOD-DO relationship in a lake as function of the relevant lake parameters involved. The BOD-DO relationship is used as an overall indicator for the water quality status of a lake. As such the application of the model is to gain a basic understanding of water quality effects under different conditions of pollution load and water discharge into a lake. The model may serve to analyse different scenarios of treatment and diversion of inflowing water.

General description of the model

The HUDALQUA-model simulates one year of water balance and mass-balance of BOD and DO by numerically solving the related set of differential equations. The basic timescale is typically one day, being the smallest scale on which rainfall data are available.

Figure 4 **Evaporation probability (1992-2003)**

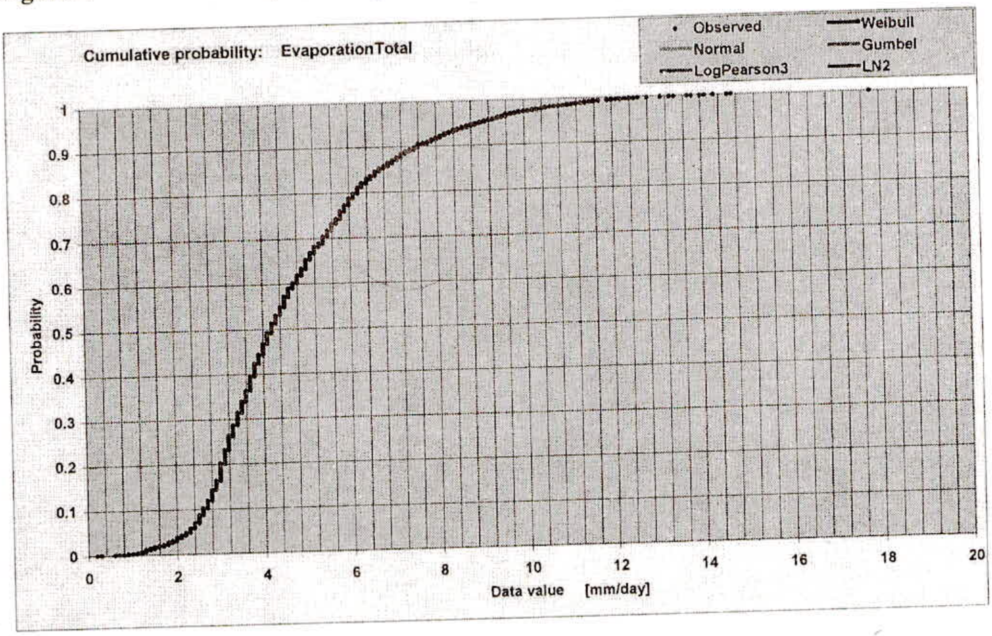
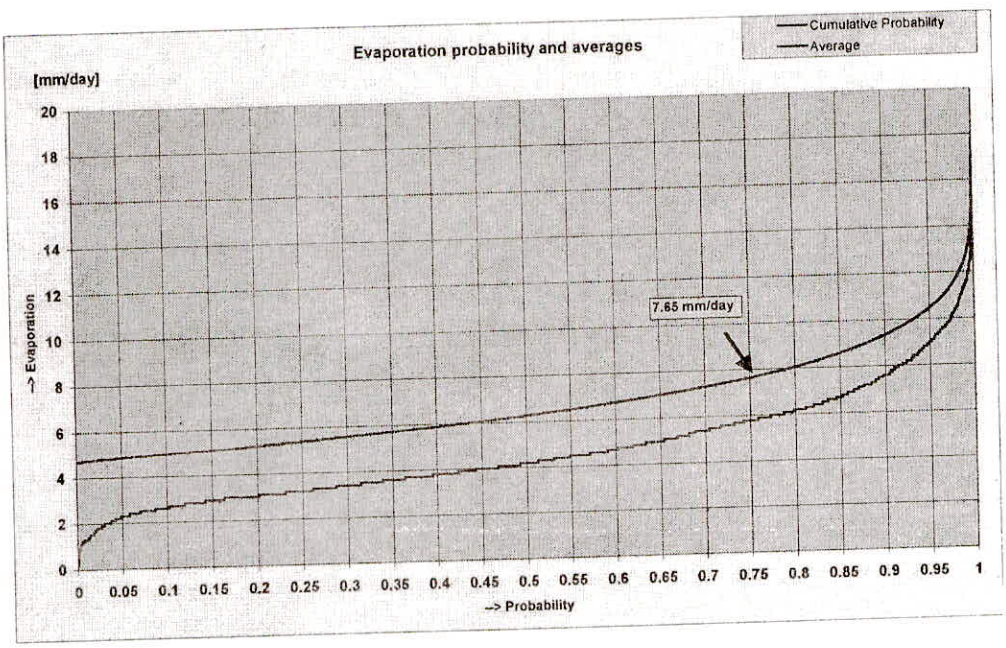


Figure 5 **Evaporation average of values above a certain cumulative probability**



Input parameters

Essential water quantity parameters related to the water balance are:

1. Characteristic data of the lake
   - morphometric data, i.e. depth/volume and depth/area relation
   - Full Tank Level
   - Weir length
   - Catchment area
2. Rainfall on daily basis
3. Evaporation on monthly basis
4. Windspeed data
5. Estimated dry weather flow
6. Estimated seepage

Essential water quality input parameters are:

7. BOD-inflow per day
8. STP-capacity
9. STP-efficiency in BOD-removal
10. BOD-decay coefficient
11. Diversion capacity

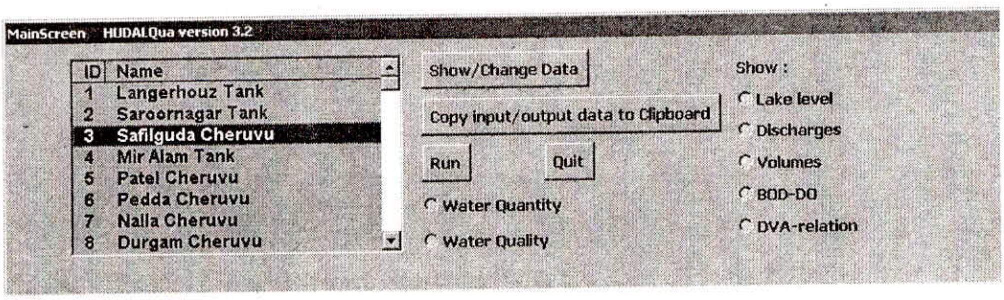
Output

Output of the model consists of a number of graphs:

12. Simulated lake level Simulated BOD-DO
13. Flow rates
    - inflow
    - STP
    - outflow
    - bypass
14. volumes
    - lake volume
    - cumulative volumes of inflow, STP, outflow and bypass
15. Depth/Volume/Area-curves

The model operates through interactive screens. The opening screen is depicted in Figure 6

Figure 6 Opening screen of HUDALQUA



From the list a lake is to be selected, after which particular data of the lake are to be entered through the Show/Change Data button. Pressing this button will lead to the next screen, depicted in. Fig. 7.

A description list of parameters is presented in Table 1

Table 1. List of parameters

Parameter	Description
FTL	Full Tank Level
FTL-Volume	Volume at FTL
Catchment	Associated catchment area that contributes to run-off into this lake
DWF	Dry Weather Flow
BOD-conc.	BOD-concentration in the DWF
Seepage	Seepage as calculated for the lake from the water balance
Runoff-coef.	Characteristic runoff coefficient for the catchment
PanCoeff.	Pan-evaporation coefficient
STP cap.	STP-capacity
STP-eff.	STP efficiency in BOD-removal
Bypass cap.	Capacity of bypass/diversion constructions
BOD-inflow	Total BOD-mass inflow in [kg/day] as calculated from BOD-conc. and DWF
BOD-decay	BOD decay coefficient
BOD-initial	Initial BOD concentration in the lake on Jan. 1 of simulation
DO-initial	Initial BOD concentration in the lake on Jan. 1 of simulation
DO-saturation	Dissolved oxygen saturation level
Level-initial	Initial lake level on Jan. 1 of simulation
Withdraw	Water release from the lake per month expressed as [MLD]

Under the input box "Run #", an identification code of the scenario can be marked by the user for easy reference. This identification code will reappear in all the graphs generated under this scenario. The input data are rather straightforward. Because no year is the same in terms of climatological conditions, a choice is possible from a particular year of rainfall. If the interest lies in average conditions, the year 1998 is recommended, while the cumulative rainfall in that year is nearly average. One parameter that is difficult to determine accurately, is the runoff coefficient. The model transforms the daily rainfall in the catchment area to a daily volume that will enter the lake on the same day. Transformation of this rainfall goes through a runoff factor. Under the Hyderabad conditions a value of 0.3-0.4 is recommended, although this is a weak point in the simulation. No data for this factor are available, so it is only an educated estimate. If more accurate become available, they can be used later. For the Pan-evaporation coefficient, a value of .85 is regularly used in this Indian climate.

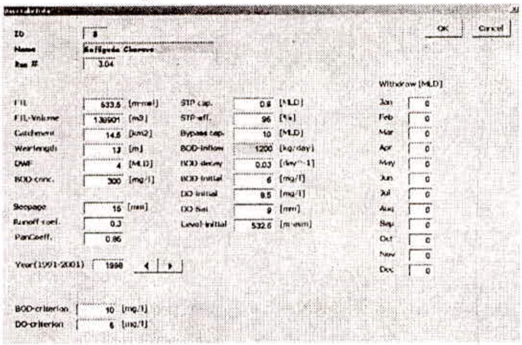
The BOD-decay coefficient is an important parameter about the rate with which BOD is reduced under aerobic conditions. In a calibration process of the model with lake water quality data for 2003, a value in the order of 0.03 usually gave the best results, so we recommend using it, unless the simulated values become unrealistic as compared with the real data. This value is also within the margins as presented in the literature.

The saturation value of DO is approximately 10 mg/l at sea level and in the order of 9 mg/l at the altitude of Hyderabad. To initialise the simulation process, starting values of lake level, BOD and DO have to be supplied to the model. To supply realistic values, it is required to run the model several times, and supply such initial values that the final values in the end of December correspond with the initial values.

The possibility to account for water being released for irrigation, monthly estimated values may be entered.

Finally, in the lower lefthand corner of the input data, standard levels for BOD and DO may be entered. These values are water quality objectives for the lakes. Using these values, the model calculates the time of exceeding these targets, and presents this time of failure in the main sheet. The example graph in
Figure 9 shows the influence of storm water flow on the lake water quality, in spite of the functioning of an STP. Please note that this is only an example to show the capabilities of the graphs and output. In the right hand upper corner, the times of failure for BOD and DO are listed in months.

Figure 7 Data screen



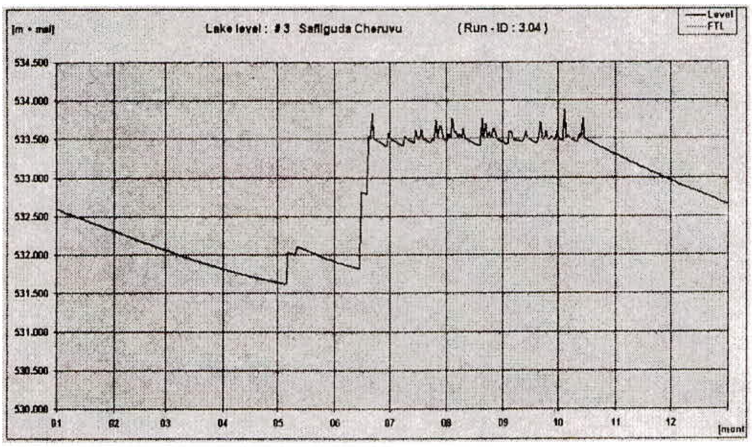


Figure 8. Example of graph of lake level

This graph shows the decline in water level after the monsoon period caused by insufficient inflow. This situation was typical for the summer season of 2004, when untreated water was diverted from Safilguda and the STP capacity was at 0.6 MLD.

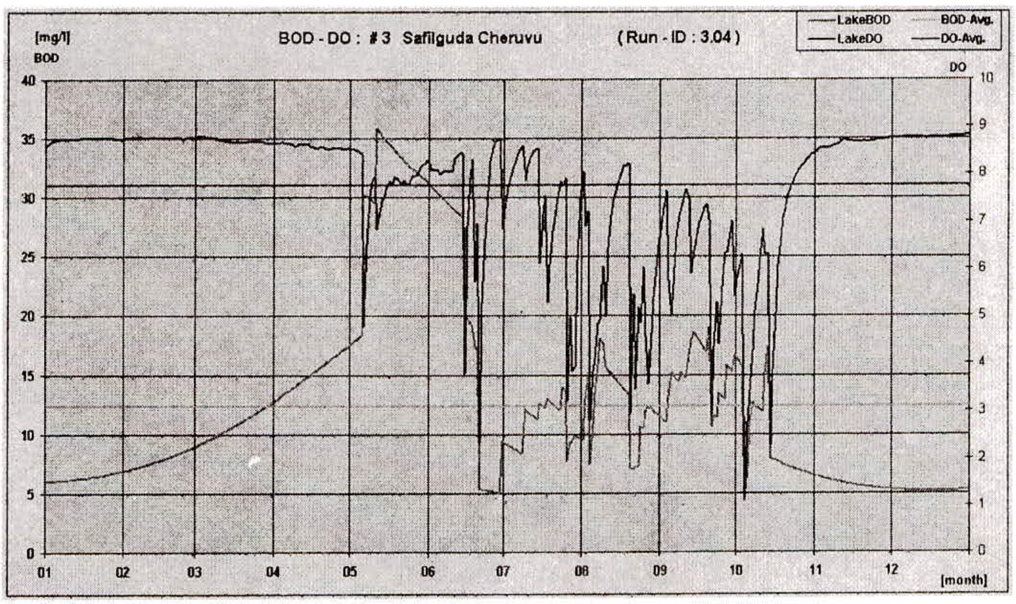


Figure 9 Example of graph of BOD-DO relation

To have input/output data available for reporting a summary can be copied to the Windows Clipboard by pressing the command button "Copy input/output data to Clipboard" (see Figure 6) from where it may be inserted into a Word-document as a table.

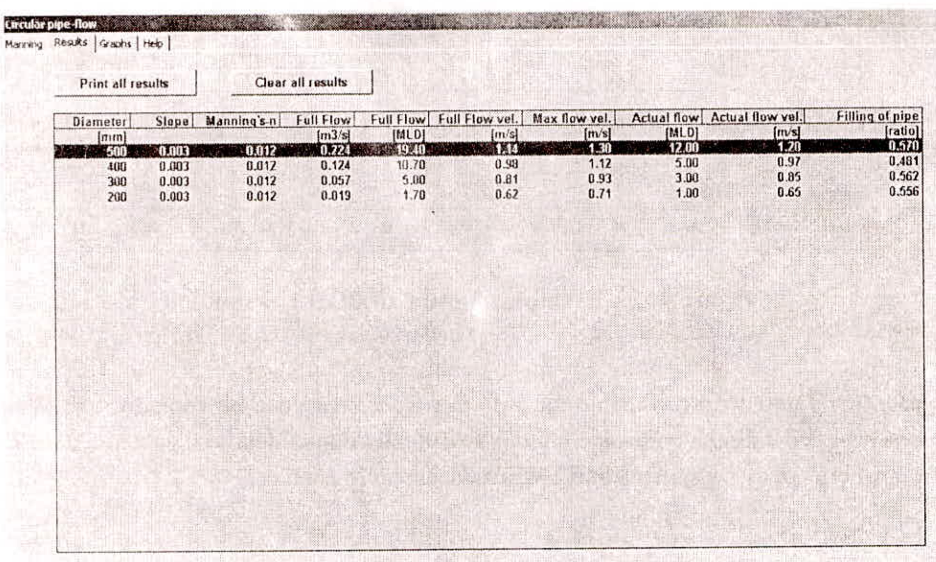
HYDRAULIC ISSUES

Diversion sewers are to be designed based on a certain required hydraulic capacity. This capacity will follow from an analysis of the present and expected wastewater production and required waterflow to the lake for maintaining the waterbalance. Traditionally the [illegible] between hydraulic capacity, pipe diameter, slope and friction factor, was presented in tables. The hydraulic capacity for a given pipe diameter is derived from such tables, which may be a quite lengthy exercise. To overcome this issue, the TA has developed a Excel-VBA program that will generate the required pipe diameter for a given discharge or vice versa, taking into account a certain minimum flow velocity. The main screen of the model is presented in Figure 1.

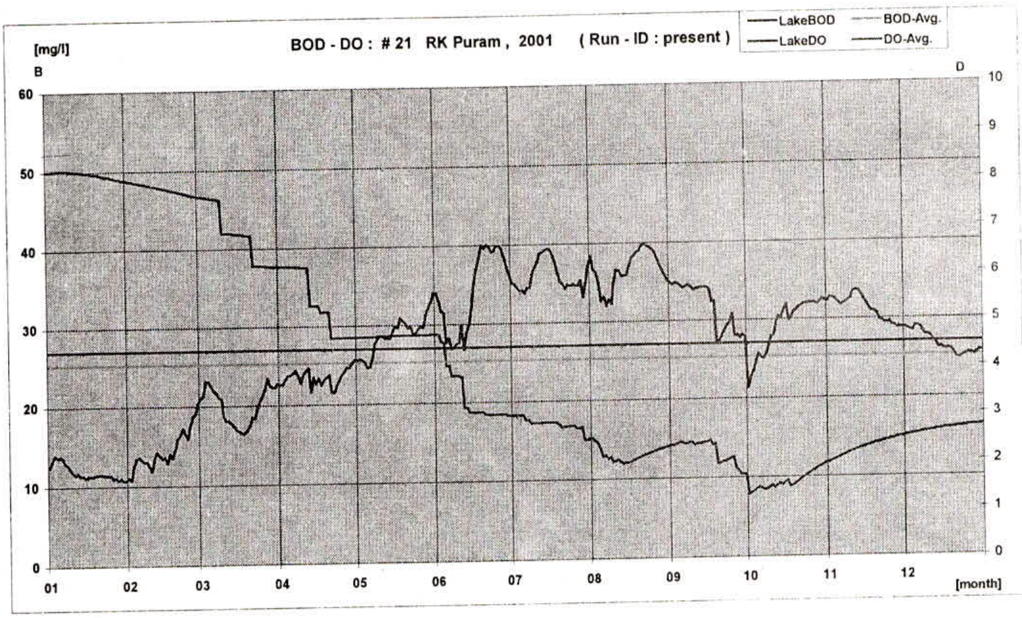
This model calculates circular pipe-flow by using the Manning formula. In frame4 one should provide the maximum and minimum permissible flow velocity for the pipe. In frame 1 the full flow capacity for a given pipe-diameter, slope and Manning-coefficient is calculated. In frame 2 the flow velocity and pipe-filling is calculated for a given actual flow, using the pipe-characteristics provided in frame 1. In frame 3 the required pipe-diameter for a given discharge, slope and Manning's coefficient is calculated. If the actual flow velocity falls outside the permissible limits, a warning message will be flashed. Under the tab Graphs you will find the relation between flow (discharge) and flow velocity, and flow, flow velocity and filling of the pipe.

Results of the calculations can be saved and viewed under the tab Results (see Figure 10). Also from this tab the results can be printed as a hard copy with the button "Print all results".

Figure 10 The Saved Results-screen



Diameter [mm]	Slope	Manning's-n	Full Flow [m3/s]	Full Flow [MLD]	Full Flow vel. [m/s]	Max flow vel. [m/s]	Actual flow [MLD]	Actual flow vel. [m/s]	Filling of pipe [ratio]
500	0.003	0.012	0.224	19.40	1.14	1.30	12.00	1.20	0.570
400	0.003	0.012	0.124	10.70	0.98	1.12	5.00	0.97	0.481
300	0.003	0.012	0.057	5.00	0.81	0.93	3.00	0.85	0.562
200	0.003	0.012	0.019	1.70	0.62	0.71	1.00	0.65	0.556



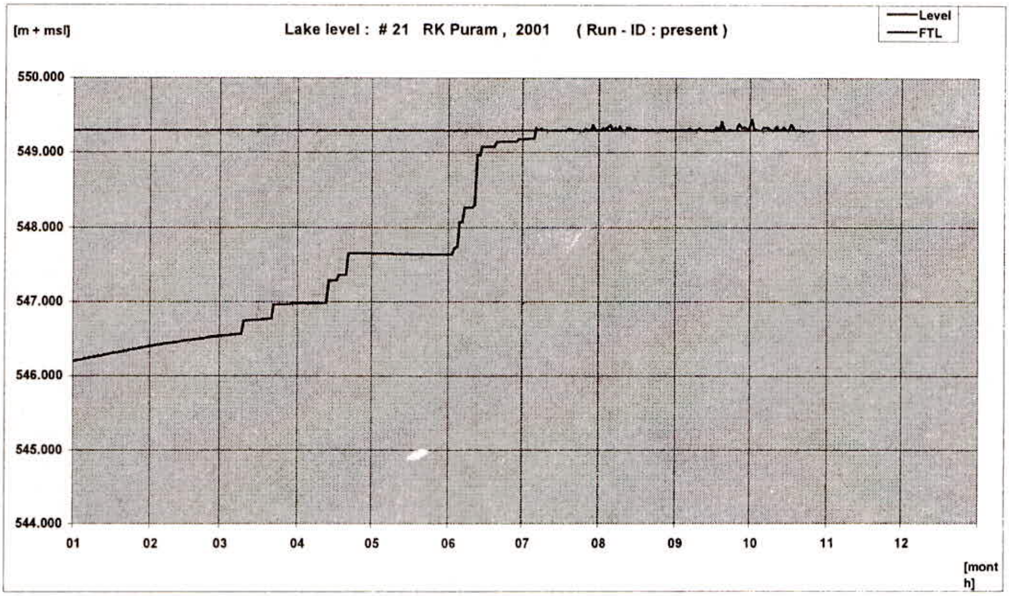
Lake-ID	21
Lake Name	RK Puram
Run – ID	present

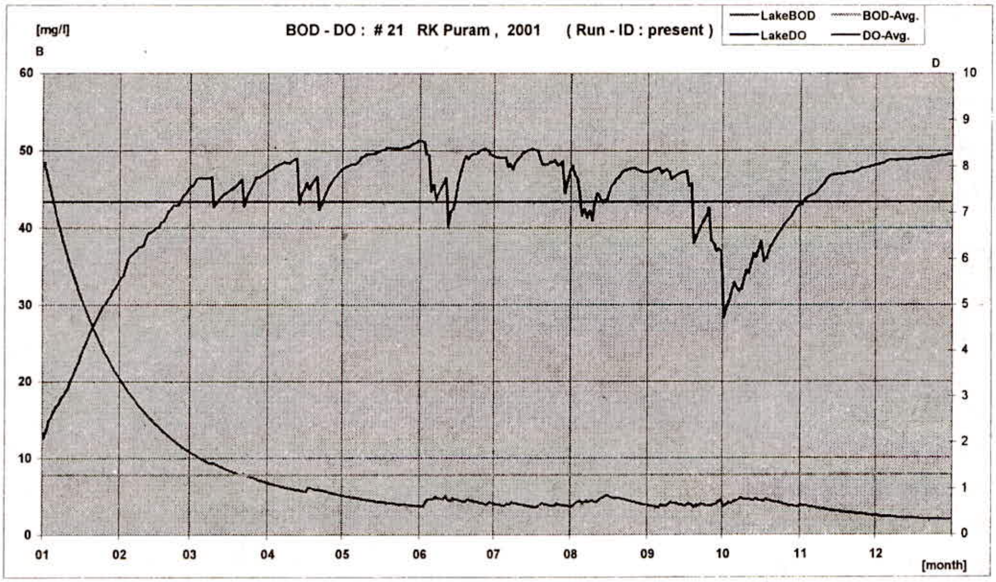
Inputdata Quantity	
FTL [m asl]	549.294
FTL-Volume [m3]	750000
CatchArea [km^2]	3.58
RunoffCoeff.	0.5
DWF [MLD]	2
Seepage [mm/day]	4
WeirLength [m]	30
LevelBegin [m asl]	546.2

Inputdata Quality	
QstpMax [MLD]	0
QbypassMax [MLD]	0
StpEfficiency [%]	0
BodDecayRate [1/day]	0.03
DO-Saturation [mg/l]	9
BOD-Inflow [kg/day]	400
BOD-Initial [mg/l]	50
DO-Initial [mg/l]	2
BOD in DWF-conc.	200

Various characteristics	
Avg. Retention Time [mth]	2.80
Avg. Filling [%]	0.76
BOD fails [mth]	11.3
DO fails [mth]	7.2

WQ-effect parameters	
BOD-average [mg/l]	25.3
BOD-max [mg/l]	50.1
DO-average [mg/l]	4.5
DO-min [mg/l]	1.8


[m + msl]
Lake level : # 21 RK Puram , 2001 (Run - ID : present)
Level
FTL
550.000
549.000
548.000
547.000
546.000
545.000
544.000
01
02
03
04
05
06
07
08
09
10
11
12
[month]


[mg/l]
B
BOD - DO : # 21 RK Puram , 2001 (Run - ID : present)
LakeBOD
BOD-Avg.
LakeDO
DO-Avg.
D
60
50
40
30
20
10
0
10
9
8
7
6
5
4
3
2
1
0
01
02
03
04
05
06
07
08
09
10
11
12
[month]

stp without diversion for present flows only

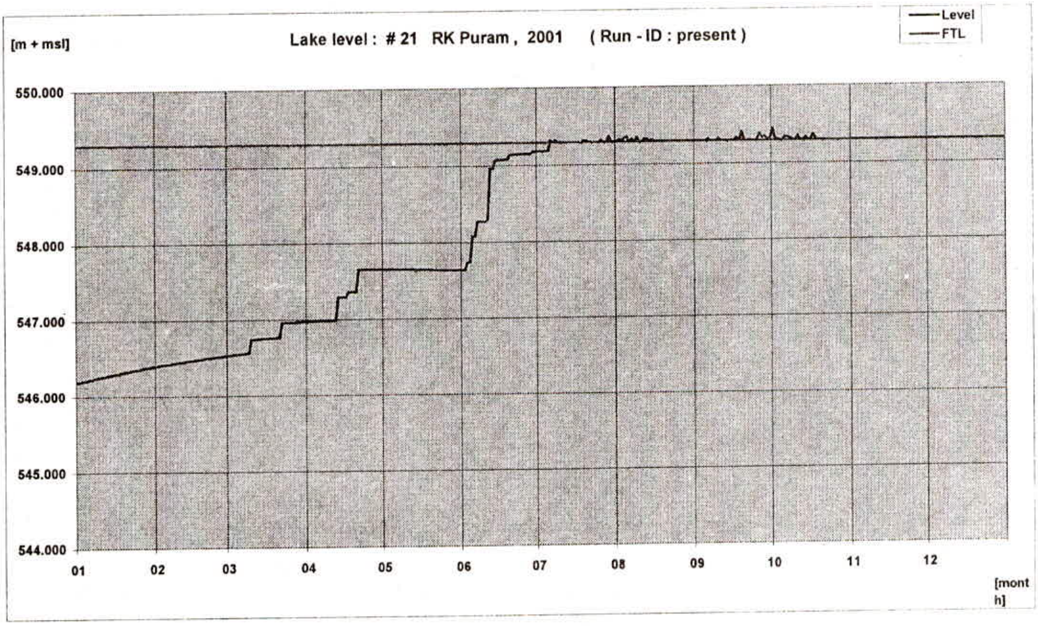
Lake-ID	21
Lake Name	RK Puram
Run – ID	present

Inputdata Quantity	
FTL [m asl]	549.294
FTL-Volume [m3]	750000
CatchArea [km^2]	3.58
RunoffCoeff.	0.5
DWF [MLD]	2
Seepage [mm/day]	4
WeirLength [m]	30
LevelBegin [m asl]	546.2

Inputdata Quality	
QstpMax [MLD]	2
QbypassMax [MLD]	0
StpEfficiency [%]	90
BodDecayRate [1/day]	0.03
DO-Saturation [mg/l]	9
BOD-Inflow [kg/day]	400
BOD-Initial [mg/l]	50
DO-Initial [mg/l]	2
BOD in DWF-conc.	200

Various characteristics	
Avg. Retention Time [mth]	2.80
Avg. Filling [%]	0.76
BOD fails [mth]	2.1
DO fails [mth]	0.9

WQ-effect parameters	
BOD-average [mg/l]	7.8
BOD-max [mg/l]	50.0
DO-average [mg/l]	7.2
DO-min [mg/l]	2.0

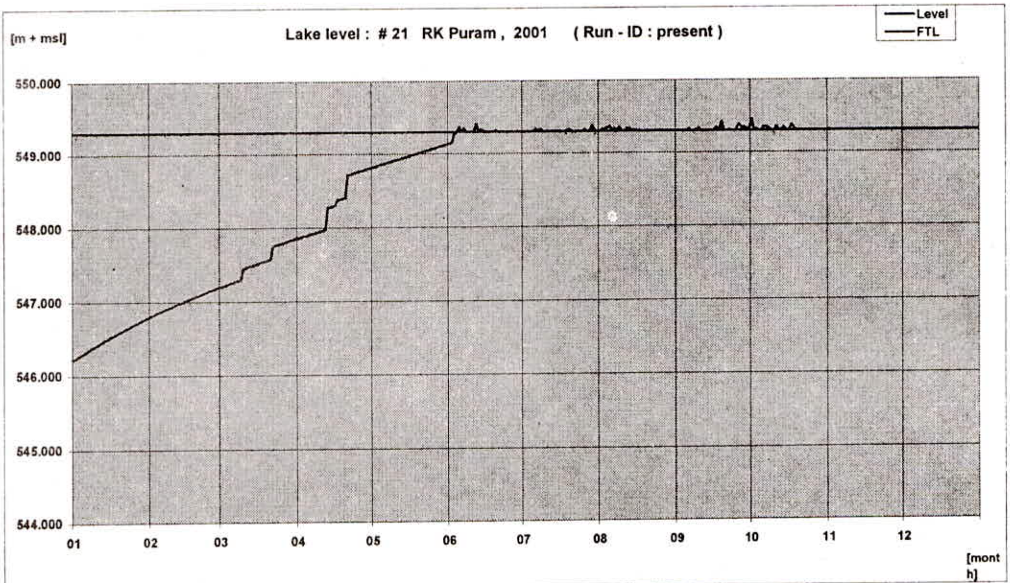


stp without diversion for 2011 flows

Lake-ID	21
Lake Name	RK Puram
Run – ID	present

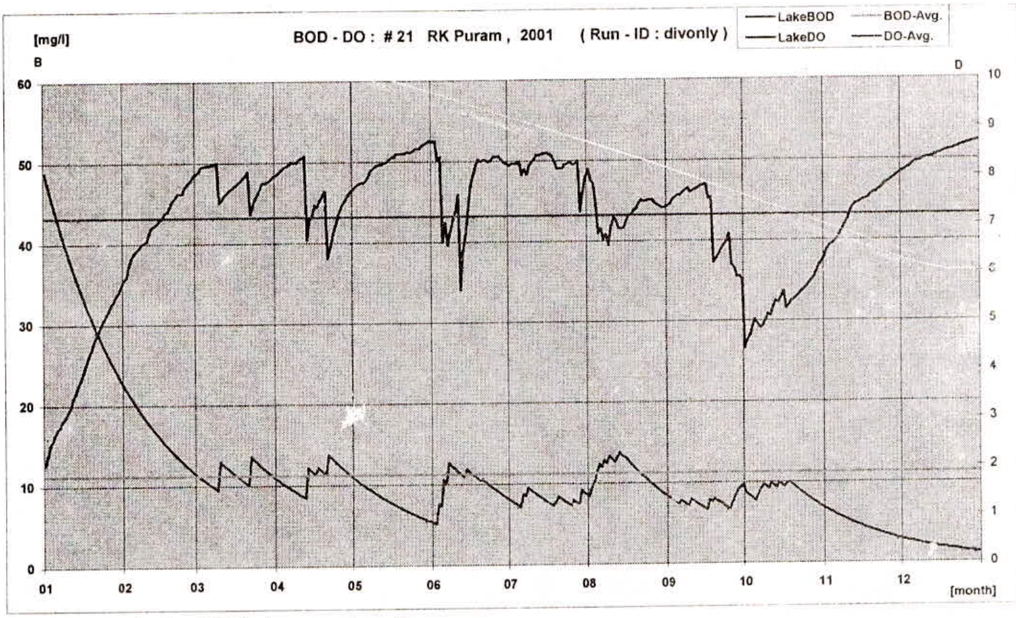
Inputdata Quantity	
FTL [m asl]	549.294
FTL-Volume [m3]	750000
CatchArea [km^2]	3.58
RunoffCoeff.	0.5
DWF [MLD]	4
Seepage [mm/day]	4
WeirLength [m]	30
LevelBegin [m asl]	546.2

Inputdata Quality	
QstpMax [MLD]	2
QbypassMax [MLD]	0
StpEfficiency [%]	90
BodDecayRate [1/day]	0.03
DO-Saturation [mg/l]	9
BOD-Inflow [kg/day]	400
BOD-Initial [mg/l]	50
DO-Initial [mg/l]	2
BOD in DWF-conc.	200



Various characteristics	
Avg. Retention Time [mth]	2.39
Avg. Filling [%]	0.85
BOD fails [mth]	5.1
DO fails [mth]	1.8

WQ-effect parameters	
BOD-average [mg/l]	13.3
BOD-max [mg/l]	50.0
DO-average [mg/l]	6.0
DO-min [mg/l]	2.0



diversion only for 2031 dry weather flows

Lake-ID	**21**
Lake Name	**RK Puram**
Run – ID	**divonly**

Inputdata Quantity	
FTL [m asl]	**549.294**
FTL-Volume [m3]	**750000**
CatchArea [km^2]	**3.58**
RunoffCoeff.	**0.5**
DWF [MLD]	**8**
Seepage [mm/day]	**4**
WeirLength [m]	**30**
LevelBegin [m asl]	**546.2**

Inputdata Quality	
QstpMax [MLD]	**0**
QbypassMax [MLD]	**16**
StpEfficiency [%]	**0**
BodDecayRate [1/day]	**0.03**
DO-Saturation [mg/l]	**9**
BOD-Inflow [kg/day]	**1600**
BOD-Initial [mg/l]	**50**
DO-Initial [mg/l]	**2**
BOD in DWF-conc.	**200**

Various characteristics	
Avg. Retention Time [mth]	**3.76**
Avg. Filling [%]	**0.55**
BOD fails [mth]	**5.1**
DO fails [mth]	**1.0**

WQ-effect parameters	
BOD-average [mg/l]	**11.2**
BOD-max [mg/l]	**50.0**
DO-average [mg/l]	**7.2**
DO-min [mg/l]	**2.0**

diversion only