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From the Editor

We are happy to bring forth yet another number of SCITECH Nepal before our readers. We hope our efforts have been successful, at least in some measure, in developing a research temper among the technical community of Nepal.

Research in technical institutions is carried out mostly through Master's and Ph.D. programs. Good quality research can come about only if the scholars are well motivated. The ground reality, however, is quite different. An engineering graduate often takes up postgraduate education for all wrong reasons. He keeps his eyes open for a suitable job, while simply passing time, pretending to be a scholar. The moment he lands a job, his scholarly pursuit is easily forgotten. Even the Ph.D. scholars pursue research not out of any intellectual curiosity but because research qualifications are insisted upon for all senior jobs in teaching. The kudos attached to research degrees has tempted large numbers of the wrong type to clutter space in the laboratories, libraries and computer centres with their mercenary zeal in pursuit of a Ph.D. Once a Ph.D. is acquired, a paper or two get published, he gets the expected promotion or lands an administrative job with some perks, the research bug would never be heard of again. The true seeker after knowledge, the research leader who is stimulated by contact with younger minds and who in turn, inspires them, is a rare species. Lack of facilities and the chores of humdrum teaching are often trotted out as excuses for their lack of any research initiative, but the spirit of research can flourish even in the humblest of environs if only one has the zeal. It is time we learn to weed out 'professional' researchers and recognize only genuine research.

CONTENTS

Estimating Groundwater Recharge with a Soil Water Budget Model Using Different Models to Estimate Actual Evapotranspiration in the Dry Zone of Sri Lanka

*R.P. de Silva**

ABSTRACT

The estimation of groundwater recharge is essential in the development of the groundwater resource, which has become necessary due to the inadequacy of the surface water sources and rain in the dry zone of Sri Lanka. The soil water balance method is widely used in estimating this groundwater recharge rate. One of the most important components of the soil water balance is the actual evapotranspiration. There are different models of estimating actual evapotranspiration and this paper compares the use of these different models in the soil water balance in the estimation of groundwater recharge. The results obtained clearly show that there is no significant difference between the estimates of recharge obtained by different models of estimation of actual evapotranspiration at 4 different study locations in the dry zone of Sri Lanka.

Abbreviations & Notations

AKP = Angunakolapelessa (Study location)
AWC = Available water capacity of soil in the root zone (mm/m)
EMB = Embilipitiya (Study location)
ETa = Actual evapotranspiration (mm/day or mm/y)
ETp = Potential evapotranspiration (mm/day or mm/y)
F = The ratio of ETa/ETp when soil moisture deficit is greater than root constant
FC = Field capacity of soil (%)
Isc = Interception (rainfall) storage capacity (mm/day)
KAL = Kalpitiya (Study location)
MI = Maha Illuppallama (Study location)
PFc = Preferential flow coefficient
PFt = Threshold of daily rainfall above which preferential flow occurs (mm/day)
PWP = Permanent wilting point of soil (%)
R = Rainfall (mm/day or mm/y)
RC = Root constant (% of AWC)
ROc = Runoff coefficient
ROt = Threshold of daily rainfall above which runoff occurs (mm/day)
SMD = smd = Soil moisture deficit (mm)

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INTRODUCTION

The rate of replenishment of the groundwater table (rate of groundwater recharge) is the most essential parameter one needs to know in developing the groundwater resource. Since most areas of the dry zone of Sri Lanka remain short of surface water especially during the dry months of the year (June, July, August and early September), it has become necessary to tap the groundwater resource at least on a supplementary basis.

Of the methods that are available to estimate recharge, the soil water balance method is widely used and often is the only method that can be used in a given situation (Lerner *et al.*, 1990; de Silva, 1998). One important variable in this method is the actual evapotranspiration which is estimated from pan evaporation values using different models. One such model has been found to perform well in the United Kingdom (Grindley, 1969). However, no such information is available for the conditions in the dry zone of Sri Lanka. Therefore, this paper determines the effect of using different models to estimate actual evapotranspiration in the estimation of recharge with a soil water balance in the dry zone of Sri Lanka.

MATERIALS AND METHODS

The methodology adopted is as follows :

(a) Select suitable study locations.

(b) Collect all relevant data (i.e., daily rainfall and pan evaporation for a few years, information on rainfall interception, runoff and preferential flow).

(c) Experimentally determine the field capacity and permanent wilting point of soil and also observe the type of vegetation and depth of roots at each location.

(d) Form a suitable soil water budget model to estimate recharge.

(e) Estimate recharge with different models to estimate actual evapotranspiration at all the study locations and compare them statistically to see if they are significantly different from each other or not.

The locations chosen in the dry zone are shown in Fig. 1 along with the mean annual rainfall distribution and mean annual pan evaporation distribution for each location. In choosing these locations, the factors considered were the availability of climatic data and the different types of soil types and vegetation. Climatic, soil and vegetation details at the study locations are shown in Table 1.

Full details of climatic data are given in De Silva (1996). The number of years these data collected is given in Table 2. The soil properties at each site (which were experimentally determined) are as shown in Table 2.

A soil water budget model to estimate the groundwater recharge was formed and the flow chart is shown in Fig. 2. A detailed explanation of the soil water budget model is given in De Silva (1996) with an explanation of the spreadsheet model used for the calculations.

As seen from Fig. 2, parameters of rainfall interception storage capacity (Isc), Runoff threshold (ROt), runoff coefficient (ROc), Preferential flow threshold (PFt), Preferential flow coefficient (PFc) and root

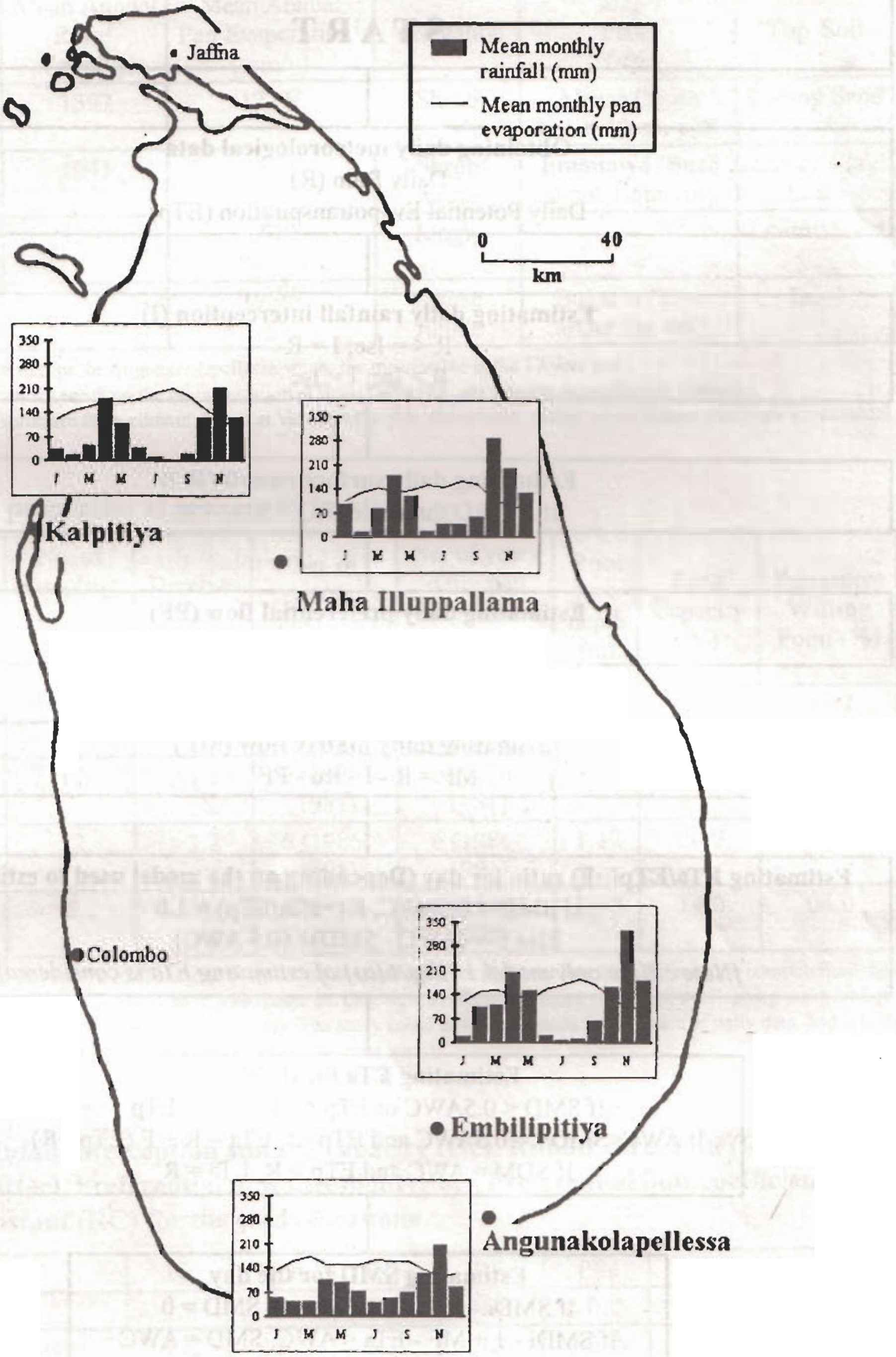

Fig. 1. Study locations in the drv zone of Sri Lanka (Mean monthly rainfall and pan evaporation for each location are also shown).

START

Obtaining daily meteorological data
Daily Rain (R)
Daily Potential Evapotranspiration (ETp)

Estimating daily rainfall interception (I)
$R <= Isc; I = R$
$R > Isc; I = Isc$

Estimating daily surface runoff (RO)
If $R >$ RO threshold, $RO = ROc * R$

Estimating daily preferential flow (PF)
If $R >$ PF threshold, $PF = PFc * R$

Estimating daily matrix flow (MF)
$MF = R - I - Ro - PF$

Estimating ETa/ETp(=F) ratio for day (Depending on the model used to estimate ETa)
If $SMD < 0.5AWC$, $F (=ETa/ETp) = 1.0$
Else $F = (AWC - SMD) / (0.5\ AWC)$
[Note : Here only model 1 {Fig. 6(a)} of estimating ETa is considered]

Estimating ETa for the day
If $SMD < 0.5AWC$ or $ETp <= R<ETa = ETp$
If $AWC<SMD<= 0.5AWC$ and $ETp>R$, $ETa = R + F (ETp - R)$
If $SDM = AWC$ and $ETp > R$, $ETa = R$

Estimating SMD for the day
If $SMDi - 1 + MF = ETa > 0$, $SMD = 0$
If $SMDi - 1 + MF - ETa < AWC$, $SMD = AWC$
Else $SMD = SMDi - 1 + MF - ETa$

Fig. 2. Flow chart of the soil water budgeting model to estimate soil moisture deficit

Table 1. Details of study locations in the dry zone

Location	Mean Annual Rain[1] (mm/y)	Mean Annual Pan Evaporation[1] (mm/y)	Vegetation	Major Plant Type	Top Soil
Embilipitiya	1397	1729[2]	Shrub Jungle	Maana (Grass about 30 cm tall)	Loamy Sand
Angunakola-pellessa	1041	1868	Shrub Jungle	Eraminiya (Bush about 1.5m tall)	Sandy Clay Loam
Maha Illuppallama	1305	1579	Jungle	-	Loamy Sand
Kalpitiya	955	1958[3]	Sparse Jungle	Bolpana (Tree about 3m tall)	Sand

[1] 6 year mean value except for Angunakolapellessa where the mean value is the 17 year one.
[2] Pan evaporation values are from the climate station at Sevanagala (i.e., the nearest agro-climatic station).
[3] Pan evaporation value are from climate station at Vanathavillu (i.e., the nearest station where evaporation data is available).

Table 2. Soil properties at each study location

Location	No. of sampling points in the location	Depth to water table (m)	No. of years daily rainfall data collected	No. of years daily pan evaporation data collected	Root zone depth (m)	Field Capacity (%)	Permanent Wilting Point (%)
Embilipitiya	8	>2.9	6 (1989-1994)	6 (1989-1994)	0.69	21.4	15.7
Angunakola-pellessa	12	>4.1	6 (1976-1981)	6 (1976-1981)	0.95	20.2	12.0
Maha Illuppallama	12	>3.2	6 (1986-1991)	6 (1986-1991)	1.17	20.9	11.0
Kalpitiya	5	2.3	6 (1970-1975)	6 (1970-1975)	1.50	14.0	04.0

(Note: The number of years rainfall and pan evaporation data collected for different locations differ as the computerised data were available for these years only. Also in some cases the data were available for more years, but, overlapping years for both types of data could be obtained for these years only. The study could have been made for 10 years of daily data, had it been available, but the end result is unlikely to differ as will be seen later.)

Table 3. Rainfall interception storage capacity (Isc), Runoff threshold (ROc), runoff coefficient (ROc), Preferential flow threshold (PFt), Preferential flow coefficient (PFc) and root constant (RC) for the study locations

Location	Isc	ROt	ROc	PFt	PFc	RC
Embilipitiya	1.8	12.5	0.25	10	0.075	50% of AWC
Angunakolapellessa	1.6	12.5	0.32	10	0.075	50% of AWC
Maha Illuppallama	2.0	12.5	0.27	10	0.075	50% of AWC
Kalpitiya	1.2	15.0	0.00	10	0.075	50% of AWC

constant (RC) for a particular location are required for the soil water budget model. Table 3 shows the values of these parameters obtained by considering the vegetation, rainfall distribution and soil types at each location. A detailed explanation of obtaining these parameters for each location are given in De Silva (1996).

The following equation is used to estimate actual evapotranspiration from pan evaporation data.

If $SMD < RC$ *or* $ETp \leq R$, $ETa = ETp$
If AWC $SMD \leq RC$ *and* $ETp > R$, $ETa =$
$R + F\,(ETp - R)$ ....(1)
If $SMD = AWC$ *and* $ETp > R$, $ETa = R$

The 4 models chosen to estimate F in equation 1, (i.e., the ratio of ETa/ETp when SMD > RC) are graphically shown in Fig. 3 (a), (b), (c) and (d) with the corresponding equations describing each model mathematically.

RESULTS

Table 4 shows the estimate of recharge for the 4 different locations with the 4 different models of estimating Eta from Etp. As seen in Table 4, the difference between estimates of recharge with different models at a location in insignificant. This is true for all the 4 study locations. Table 5 shows the estimate of recharge for different years at Angunakolapellessa. Again, the difference of recharge by different models are insignificant.

Table 6 shows the analysis of variance test (Gomez and Gomez, 1976) to see if the difference estimates shown in Table 4 are significant or not. As expected the difference or recharge estimates are not significant at 5% significance.

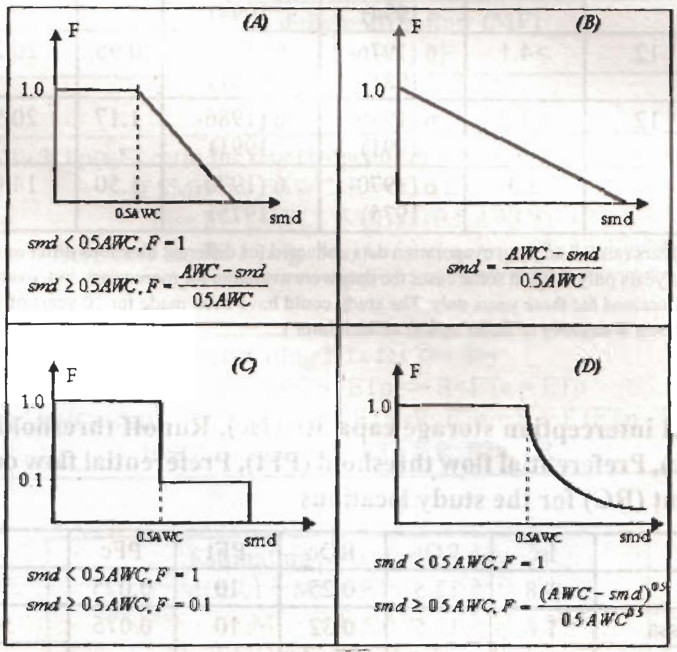

Fig. 3. (a), (b), (c) & (d) Graphical and mathematical representation of the 4 models of estimating ETa from ETp used in this study

Table 4. Groundwater recharge estimated from the 4 different models for 4 different locations

Location	Period considered	Rain (mm/y)	Etp (mm/y)	Groundwater recharge (mm/y)			
				Model 1	Model 2	Model 3	Model 4
EMB	1989-1994	1397	1729	331	350	359	323
AKP	1976-1981	1048	1920	90	100	117	84
MI	1986-1991	1305	1579	193	204	223	187
KAL	1970-1975	955	1960	179	194	207	168

Table 5. Groundwater recharge estimated with 4 different models for Angunakolapellessa for different years

Year	Rain (mm/y)	Etp (mm/y)	Groundwater recharge (mm/y)			
			Model 1	Model 2	Model 3	Model 4
1976	1020	2015	129	142	154	121
1977	1182	1695	140	145	161	134
1978	993	1866	78	87	96	72
1979	1124	1748	45	54	61	39
1980	1137	2056	106	118	123	98
1981	830	2140	49	57	60	44

Table 6. Analysis of variance test results (5% significance) for comparing estimates of recharge in Table 4

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	Fcrit
Between Groups	4883.4	3.0	1627.8	0.2	3.5
Within Groups	126060.7	12.0	10505.1		
Total	130944.1	15.0			

In comparing the estimates of recharge by different models, it is not sufficient to compare only yearly totals or averages of so many years. One must compare the distribution of recharge for the period concerned as well. Figures 5 and 6 show the daily distribution of recharge for the study locations Angunakolapellessa and Maha Illuppallama respectively. As seen from Fig. 5 and 6, the distributions of estimates of recharge by the 4 different methods at a particular location appear to be very similar. Though not presented here, an analysis of variance test confirm that the difference of estimates of recharge in Fig. 5 and 6 are insignificant at 5% significance.

CONCLUSIONS

1. There is no significant difference between the estimates of recharge at a particular location arrived at using the four different models of estimating actual evapotranspiration used in the study.
2. Since the study locations are representative of the dry zone, it is likely that this result is true in general for the dry zone of Sri Lanka.

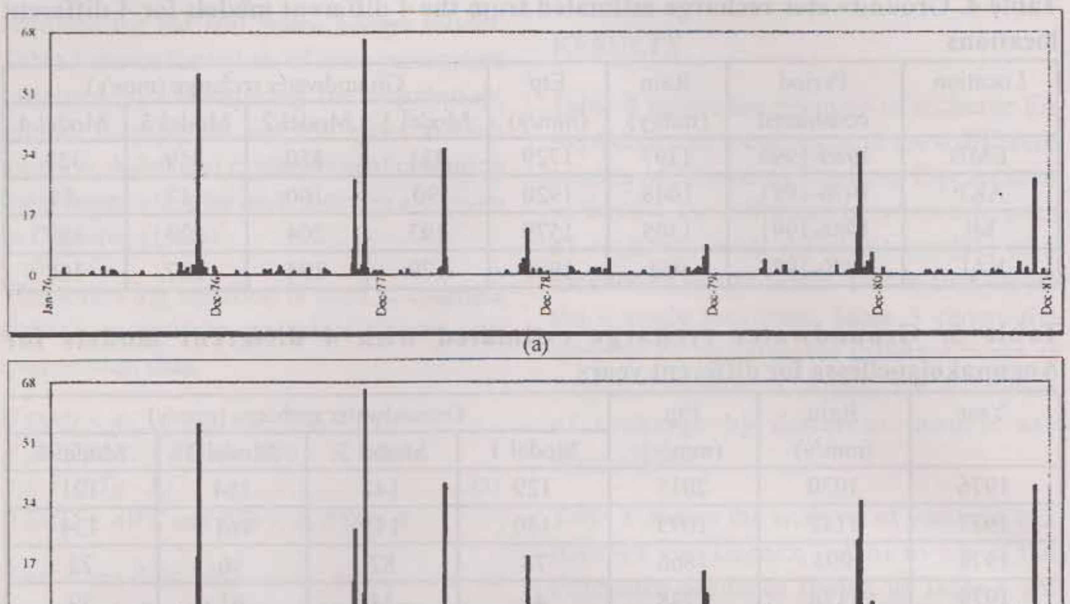

Fig. 4. (a), (b), (c) & (d) Groundwater recharge estimated with different models for Angunakolapellessa for the period 1986 - 1991 (Recharge values are in mm)

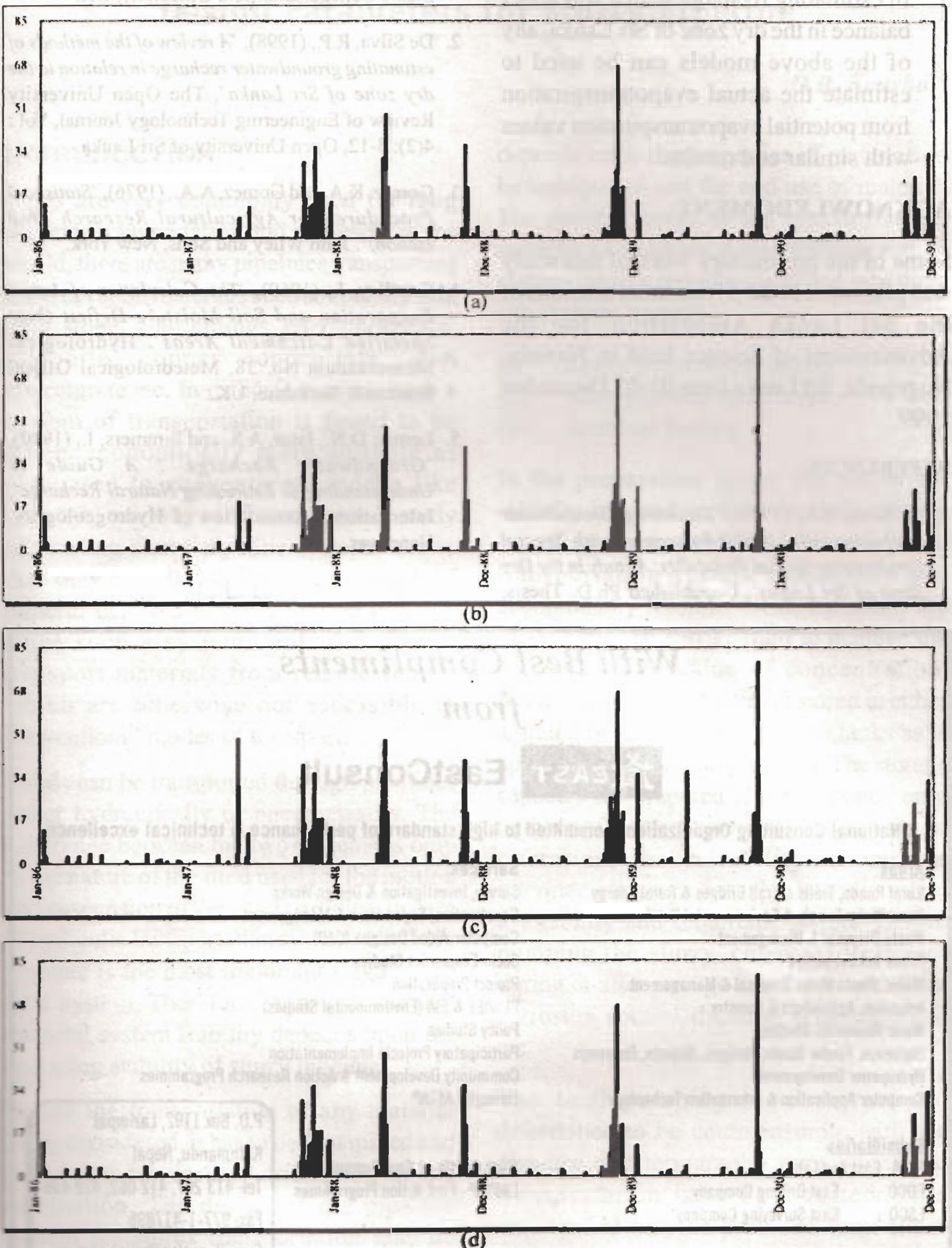

Fig. 5. (a), (b), (c) & (d) Groundwater recharge estimated with different models for Maha Illuppallama for the period 1986 - 1991 (Recharge values are in mm)

3. In estimating recharge with a soil water balance in the dry zone of Sri Lanka, any of the above models can be used to estimate the actual evapotranspiration from potential evapotranspiration values with similar end results.

ACKNOWLEDGMENT

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Design Parameters for Slurry Pipeline

D.R. Kaushal*

INTRODUCTION

Pipes are very commonly used for long distance transportation and at present in the world, there are many pipelines transporting different solid materials such as coal, fly ash, lime stone, zinc tailings, rock phosphate, gilsonite, copper concentrate, iron concentrate etc. In difficult terrains, such a system of transportation is found to be technoeçonomically more suitable as compared to conventional modes like railways, roadways and conveyors. A study of existing slurry pipeline systems shows that they broaden the economic reach of mineral deposits which could be utilized, since such a system could be used to transport materials from remotest areas which are otherwise not accessible to conventional modes of transport.

Solids can be transported through pipelines either hydraulically or pneumatically. The difference between the two systems is only in the nature of the fluid used for the motion and suspension of the solid particles. In case of hydraulic transportation system, the slurry pipeline is the most important stage of the total system. Therefore, it is also true that the total system stability depends upon the operating stability of slurry pipeline.

Before the transportation of any material being considered, it has to be first mixed and processed for further utilization at the destination. The design of the pipeline system for solids transportation may be different for different materials as the design depends upon the properties of materials to be transported and the end use of material. The general layout of the system remains same for all minerals. A slurry transportation system may be broadly classified into three sub systems namely :

(i) Slurry preparation facility
(ii) Main pipeline and pumps
(iii) Terminal facility

In the preparation stage, the solids are initially reduced to a convenient size by crushing and grinding to make the transportation system technically and economically feasible. Next, the solids are mixed with the carrier fluid to achieve the most optimum value of concentration. Finally the prepared slurry is stored in either agitated or non agitated storage tanks as is appropriate for each application. The storage capacity for prepared slurry depends on a number of factors, such as the continuity of operation, the reliability of various intermediate processes, the overall system availability and requirements, etc. Before pumping the slurry, chemical treatment during or after storage may be provided for corrosion, control, thinning, drag reduction, etc.

The total pumping requirements are determined to be commensurate with the distance and topography over which the transportation is to be effected. This requirement may be provided form either one or more locations along the length of the pipeline. If intermediate pumping is required, other additional facilities, like

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intermediate storage, corrosion and product quality control measures, may have to be provided at these intermediate stations, although to a much lesser extent than at the starting point.

At the utilization or terminal point, the slurry is received in storage tanks. It is then dewatered, filtered and dried in accordance with the requirements of end utilization of the solids. In some cases special processing, usually required for hydraulic transportation both at the staring and the terminal ends, can be avoided. For example, in some mineral processing plants, the solids are required to be finely ground and processed in wet form. In such cases, the particle size required for final processing is normally suitable for hydraulic transportation and, therefore, the additional costs of initial grinding and dewatering, purely to facilitate hydraulic transportation are avoided.

Slurry pipeline transportation has become more relevant in today's world due to emphasis of mankind on reduction in environmental pollution. Environmentalists all over the world are pressing the governments to frame rules for controlling the environmental pollution and other related features. Slurry pipeline system offers many such features which are attractive from an environmentalist point of view. Some of these features are :

- Traffic reduction
- Air pollution reduction
- Noise reduction
- Accident reduction
- Least ecological disturbance
- Saving on energy consumption

The other most important reason for the acceptance of long distance slurry pipeline transportation system as a viable mode of transportation is its attractive economics, which has been proved by Link *et al.* (1974) and Aude *et al.* (1974, 1975) in their economic analysis of comparison between different modes of transport. Besides these two points, there are many other attractive features in favour of a slurry pipeline transportation system and have been highlighted by Parida *et al.* (1996), Seshadri *et al.* (1996) and Condolias and Chapus (1963) as follows :

- tremendous economy of scale (operating costs are significantly reduced as the volume of transportation and distance increases).
- immune to escalation of prices.
- high degree of efficiency and reliability.
- simplicity of installation and small place requirements.
- ease of crossing both natural and artificial obstacles, such as roads, rivers, railways, etc.
- round the year availability, thus assuring continuous supply.
- extremely safe.
- reduced storage costs at the consumption point.
- leads to minimum environmental and ecological effects.
- can be readily automated.
- low manpower requirements for installation, operation and maintenance.
- easy to operate.

Technically, there are no limitations for adapting the slurry pipeline transportation system in a big way. However, to date, it has not gained high popularity because of some basic limitations, which are highlighted below :

- the initial capital cost is relatively high.

- the pipeline transportation system is solely dedicated to the transportation of solids, whereas a rail, road or a highway has multipurpose utility.
- the pipeline transportation system requires water or other liquids as the carrier fluid in large volume, which may not be easily available at all places and all the time.
- quality control has to be very stringent for efficient operation of the pipeline.

The attractive features of the slurry pipeline transportation system offer wide scope for future application for transporting minerals from inaccessible areas such as mountains, across seas and deep sea recovery of minerals.

WORLDWIDE SLURRY TRANSPORTATION PIPELINES

Table 1 shows some of the important slurry pipelines in operation throughout the world [Wasp (1977), etc.]

Table 1. Some important pipelines in the world

Material Transported	System Name, Location	Length (Miles)	Annual Throughput (MMTPY)	Initial Operation
Coal	Consolidation, Ohio	108	1.3	1957
	Black Mesa, Arizona	273	4.8	1970
Limestone	Calaveras, California	17	1.5	1971
	Rugby, England	57	1.7	1964
	Gladstone, Australia	15	2.0	1981
Copper	Bougainvillea, Chile	17	1.0	1972
Concentrate	West Iran	69	0.3	1972
	Escondida, Chile	103	0.8	1990
	KBI, Turkey	38	1.0	N/A
	Pinto Valley, Arizona	11	0.4	1974
Iron Concentrate	Savage River, Tasmania	53	2.3	1967
	Waipipi (Land), New Zealand	4	1.0	1971
	Waipipi (Offshore), New Zealand	1.8	1.0	1971
	Pena Colorada, Mexico	30	1.8	1974
	Las Truchas, Mexico	17	1.5	1976
	Sierra Grande, Argentina	20	2.1	1976
	Samarco, Brazil	245	12.0	1977
	Coahuila, Mexico	237	4.5	1983
	Kudremukh, India	44	7.5	1980
Gilsonite	American, Gilsonite	72	0.4	1957
	Valep, Brazil	74	2.0	1978
Phosphate	Goiasfertil, Brazil	9	0.9	1982

DESIGN PARAMETERS FOR SLURRY PIPELINE

The various design parameters that need to be well understood for design of pipelines for hydraulic transportation of solids are discussed briefly in following paragraphs :

Selection of the Carrier Fluid

The choice of the carrier fluid is primarily dictated by the availability and thus, generally water is used as the carrier fluid. However, depending on the end use of the solid material other carrier fluids can also be selected.

Optimum Particle Size

The flow of coarse slurry is always associated with high transportation velocities resulting in increased pressure drop and wear rate in the pipe. On the other hand flow of extremely fine slurries is also associated with higher pressure drop because fine particles change rheological properties of suspension drastically. Therefore, optimum particle size distribution is carefully decided according to pressure drop and end use requirement.

Optimum Concentration of Solids

The concentration of the solids in slurry form is often controlled by the upstream and downstream process (e.g. ash and tailing disposal, mineral processing). However, for long distance pipelines, it will be generally economical to transport the solids at the optimum concentration level for the particular size of pipeline. This avoids wasteful expenditure of energy on the transportation of carrier fluid. The upper limit for the concentration is governed by the fact that at high concentrations nearing the static settled value, the pressure drop increases very steeply. Normally, the optimum concentration for hydraulic transportation is selected on the basis of the lowest specific energy consumption (i.e. energy spent per ton of dry solids through one kilometer of pipeline). A good guide for the selection of concentration can be obtained from the viscosity data. The viscosity of the slurry increases very steeply after a certain value of concentration. The optimum concentration of solids usually taken to be 10% to 20% lower than the static settled concentration and it should be high enough to satisfy the thruput requirement of the solids.

Minimum Operating Velocity

The minimum operating velocity should ensure complete and stable suspension of solids in the pipeline during the flow of slurry being transported. It is a function of properties of solids, concentration level and pipe diameter. The upper limit of operating velocity is governed by the fact that at higher velocities both the abrasion rate and power requirements increase very rapidly. At lower operating velocities the possibility of choking and excessive uneven wear will cause problem in the operation of a slurry pipeline. The operating velocity is normally chosen in the asymmetric flow regime and is kept about 0.5 to 1.0 m/s above the deposition velocity. The critical velocity at which a bed of particles beings to form is known as the deposition velocity. Since the usual carrier fluid employed is water, and flow is turbulent under normal pipe flow conditions, the deposition velocity of a heterogeneous suspension is almost invariably a turbulent flow phenomenon. It is directly related to the fall velocity of the particles and to the degree of turbulence existing in the system. It is found to increase with increasing particle size, particle density and solid concentration. Deposition velocity also increases with increasing pipe diameter.

Pipe Diameter

The pipe diameter should be sufficient to transport the required throughput of solids at the optimum concentration and velocity. In practice all three of the above parameters namely, velocity, solid concentration and pipe diameter are interdependent and it becomes necessary for a designer to optimize all of them simultaneously, subject to the constraints on the energy consumption and wear rate.

Pressure Drop

For designing a pipeline slurry transportation system, one of the most important technical parameters to be evaluated by the designer is the estimation of the head loss and thus the power requirement under various operating conditions. It is this parameter which dictates the selection of pump capacity. The power requirements of a slurry pipeline should include allowances for pressure drop in pipes, pipe bends, fittings and potential head. Further additional allowance has to be included for the increased power requirement for starting the flow after a shutdown.

Additives Required for Flow Improvement

Additives are added to the slurry for a variety of reasons. The important ones are for shear thinning and dispersing, for drag reduction and for corrosion/erosion control. For thick slurries (high concentration and fine particles) shear thinning materials or dispersants such as lignin compounds / polyphosphates are used. These additives break up the agglomerates and increase the slurry fluidity by releasing the trapped fluid. The presence of coarser particles also helps to reduce the apparent viscosity of slurry. Long chain polymers which results in drag reduction in pure liquid flows are usually not effective for slurry system. This is because, these additives are effective only above a threshold value of Reynolds number whereas slurry system mostly operate near the region of laminar - turbulent transition. Corrosion of the pipe surface can be controlled by reducing the mount of dissolved oxygen through the addition of agents like sodium sulphite. Also, one may add other agents like sodium dichromate which maintain protective layers on the pipe surface in spite of continuous abrasion by the solid particles. In general, the pH value of slurry is kept in the range of 9 to 10 in order to make the pipe material passive. For the above purpose, additives like lime can be used to keep the slurry basic.

Metal Allowance

A knowledge of the extent of corrosion and erosion, enables the designer to estimate the metal allowance for given system life. This depends on various parameters like particle size, velocity of flow, etc. The choice of pipe material is also important. Materials like high density polyethylene (HDPE) are very wear resistant, but can not withstand high pressures. Thus, they are suited only for short distance pipelines. In long distance pipelines, sometimes provision is made for rotation of the pipeline in order to ensure uniform wear over the perimeter of the pipe. Normally carbon steel pipes are used for long distance slurry pipelines.

Water Hammer

It might be thought that a slurry which is denser than water would enable pressure waves to be transmitted more rapidly than in water and that in consequence the severity of hydraulic shock caused by a pressure disturbance would be enhanced. In practice, however, this does not occur: the presence of solid particles has been known to cause attenuation of the pressure wave as observed by Walker (1962). It would be dangerous, however, to rely upon the presence of solids to damp out pressure waves, as cases are on record [Henderson (1962)] of water hammer occurring in slurry pipelines. It is therefore recommended that similar provisions for the avoidance of water hammer are made in the design and operation of solids pipelines as would be made for pipelines carrying water, e.g. the fitting of air vessels and means to prevent the rapid closure of valves.

Maximum Allowable Slope

This can be decided on the basis of laboratory tests and it should be small enough to ensure trouble free start up. Settling solids should not slide down and block the lower end. The critical slope depends on various parameters like particle size, shape density and concentration.

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"Nothing in the world can take the place of persistence; Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated failures. Persistence and determination alone are omnipotent."

– Calvin Coolidge

Hydrological Study of Tukucha Khola at Tripureshor in Kathmandu

*Hari K. Shrestha**

ABSTRACT

The existing bridge on Tukucha Khola at Tripureshor, Kathmandu, suffered a major damage due to scouring in 1998. The superstructure part of the bridge was temporarily repaired, but the bridge needs to be reconstructed for safe passage of traffic. A hydrological study of Tukucha Khola was conducted to obtain necessary parameters required for a detailed design of reconstruction of the bridge over the Khola at Tripureshor, Kathmandu. This article deals with the hydrological part of the study.

INTRODUCTION

The Tukucha Khola is a tributary of Bagmati river which flows from north to south and meets the Bagmati River at Tripureshor, about two hundred meters downstream of the bridges connecting Kathmandu and Lalitpur cities. The Tukucha Khola, which originates from local depressions at south of Maharajgunj, Kathmandu, has no tributaries. The Tukucha Khola used to be rain-fed in the wet season and an effluent river in the dry season. But due to the rapid urbanization of basin area of this Khola, the base flow has become negligible in the winter. The only sources of flow in Tukucha in the dry season are the urban sewage and drainage water. Since this Khola flows right through the heart of Kathmandu city, the rain water infiltration is negligible in this area, and hence the base flow part of Tukucha is very low, even in summer season. Major part of the dry season flow in Tukucha is sewage water from residential part of Kathmandu.

The geomorphological characteristics of Tukucha Khola at Tripureshor are basically governed by the physical restraints put up by human activities. The river flows mostly between the brick or stone walls put up all along its pathway. The sinuosity of the Khola is very low; the river essentially flows straight. The slope of the river in the vicinity of the bridge site is 0.005.

The bed of Tukucha Khola consists mostly of fine sand and clay. The upper surface of the Khola mostly contains waste materials thrown on the riverbanks by local people. At the bridge site, the water way has reduced to less than half of what it used to be, as indicated by the heaps of garbage on both sides of the river. The maximum water way in the upstream site of the bridge site is about 12m, whereas the current width of the bridge at the site is only about 7 m. There are constructions on both sides of the bridge and hence, the bridge length cannot be increased.

The vertical masonry walls on both sides of the river at the bridge site help to contain the river in its course, but the obstruction of flow from debris constricts the waterway and causes scouring. The severe restriction in the flow of water causes higher velocity of flow during flooding. This higher velocity, in turn,

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causes deeper scouring of the riverbed. This scouring phenomenon probably caused part of the bridge to collapse in 1998.

BASIN CHARACTERISTICS

Basin Divide, Basin Slope and Catchment Area

For drawing basin divide and obtaining basin slope and catchment area of Tukucha Khola at bridge site, topographical map of scale 1:25000 was used. The bridge site was located on the map and the basin boundary for the bridge site was drawn. The basin boundary of the bridge site of Tukucha Khola is given in Fig. 1. The catchment area of the basin is 6.6 km^2 and the basin slope in the plains is 0.005.

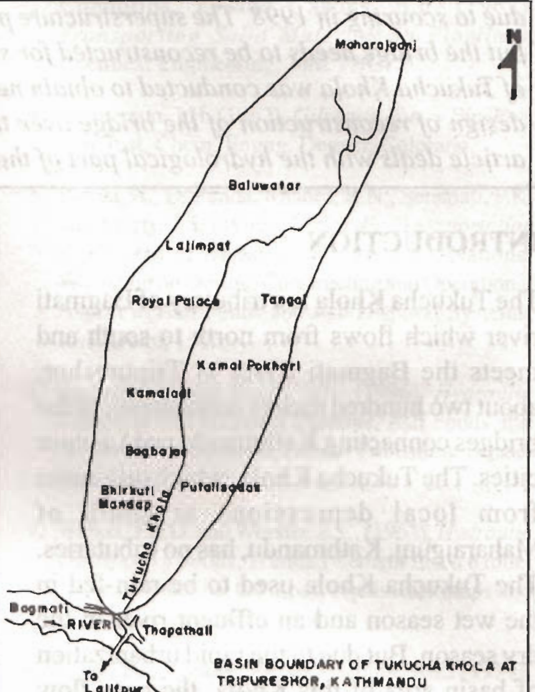
The length of the Tukucha Khola basin is approximately 5.75 km. The basin is elongated in the North-South direction. The maximum width of the basin is 1.56 km at the middle of the basin. The average width of the basin is 1.15 km.

The Tukucha basin is covered with developed lands. The approximate land use pattern of this basin is as follows :

- Private built up land : 60%
- Public built up land : 20%
- Cultivated land : 20%

RIVER CHARACTERISTICS

The pertinent river characteristics of the khola up to the proposed bridge site of Tukucha Khola are summarized in Table 1.



BASIN BOUNDARY OF TUKUCHA KHOLA AT TRIPURESHOR, KATHMANDU

FIG. 1

Table 1. River characteristics of Tukucha Khola at Tripureshor, Kathmandu

Bridge Site	Tripureshor
River Name	Tukucha Khola
Tributaries	None
River Length (up to bridge site)	6 km
Elevation Difference	1343 m – 1285 m
Average River Slope	0.009 (taking maximum length)
Average bed slope in the vicinity of bridge	0.005
Bed Material	Sandy silt, clay
Nature of Flow	Perennial
River Gauging Station	None

HYDROLOGICAL ANALYSIS

Rainfall

The Department of Hydrology and Meteorology under the Ministry of Science and Technology, HMG/N, has established several meteorological stations inside Kathmandu Valley. The meteorological stations that lie at the vicinity of the catchment area of Tukucha Khola (at bridge site) are the Tribhuvan International (Kathmandu Airport (TIA), Budhanilkantha, and Panipokhari. Hence, to obtain 24-hour maximum rainfall and to associate that with maximum discharge, meteorological data were collected from those stations. Additional 24-hours maximum rainfall data were obtained from the records of the Indian Embassy at Kathmandu. The location and elevations of TIA, Budhanilkantha and Panipokhari, stations are given in Table 2.

Rainfall Frequency Studies

Using the values of 24-hours maximum rainfall from the catchment area for a number of successive years, 24-hours maximum rainfall frequency analysis can be carried out. The three generally used techniques of frequency studies are the Gumbel Distribution Method, the Log-Pearson Type III method, and the Log Normal method.

A. The Gumbel's Method

The gumbel method (Gumbel's Distribution) is the most widely used probability-distribution function for extreme values in hydrologic and meteorologic studies for prediction of flood peaks and maximum rainfalls. In this method, the variate X (maximum rainfall or flood peak discharge) with a recurrence interval T is given by

$$X_T = X_{avg} + K\,\sigma_{n-1}$$

where,

X_T = maximum rainfall or flood peak discharge

X_{avg} = average value of X

σ_{n-1} = standard deviation of the sample of size N = $\sqrt{\dfrac{\sum(x - x_{avg})^2}{N-1}}$

K = frequency factor expressed as

$$K = \frac{y_T - y_n}{S_n}$$

y_T = reduced variate, a function of T and is given by $y_T = -\left[\ln . \ln \dfrac{T}{T-1}\right]$

y_n = reduced mean, a function of sample size N

S_n = reduced standard deviation, a function of sample size N.

B. The Log-Pearson Type III method

In this method, the variate is first transformed into logarithmic from (base 10) and the transformed data is then analysed. If X is the variate of a random hydrologic or meteorologic series, then the series of Z variates where Z = log x are first obtained.

Table 2. Location and elevation of meteorological stations

Station Name	Station No.	Latitude	Longitude	Elevation (m)
TIA	1030	27°42'	85°22'	1336
Budhanilkantha	1071	27°47'	85°22'	1350
Panipokhari	1039	27°44'	85°20'	1335

For this z series, for any recurrence interval T, z_T - z_{avg} + K_z σ_z where, z_{avg} = arithmetic mean of z values, K_z is a frequency factor which is a function of recurrence interval T and the coefficient of skew C_s. For N - number of sample = number of years of record, σ_z = standard deviation of the Z variate sample = $\sqrt{\frac{\sum(z - z_{avg})^2}{N-1}}$ and

C_s= coefficient of skew of variate

$$Z = \frac{N \sum_i (z - z_{avg})^3}{(N-1)\,(N-2)\,(\sigma_z)^3}$$

The corresponding value of x_T = antilog (z_T)

C. The Log Normal Method

This method is basically same as the Log-Person Type III method except that the skewness coefficient C_s is taken as zero. The log-normal distribution plots as a straight line on logarithmic probability paper.

The results of Gumbel's method, Log-Pearson Type III method and the Log Normal method to estimate the 24-hours maximum rainfall (mm) in Tukucha Khola basin are summarized in Table 3.

River Stage and Discharge

There are no records of stage or discharge data of Tukucha Khola. There are numerous domestic, industrial, and agricultural drainages that discharge wastewater into this river along its way upstream of the bridge. This khola being an urban river, the catchment area ratio cannot be used to estimate the discharge and the associated river stage at the bridge sites from data of nearby river system. Also, the nature of variation in flow in Tukucha during dry season is caused mainly by operation schedule of outlet gates of industries and irrigated lands upstream of the bridge. Hence, the variation in discharge in Tukucha is rather sudden and arbitrary in nature.

Measured Discharge

River discharge was measured by float method on Tukucha Khola on January 24, 1999. The discharge was about 0.05m³/s. However, since the discharge was measured during the dry season, all the flow in the Khola can be considered to be sewage and / or waste water drainage flow. Hence, this discharge value does not reflect the actual water discharge, and has very little use for predicting the summer flow. Due to development activities on the river basin, the rain water infiltration capacity of the land is extremely low, and any major rainfall can cause extremely high flow for a short duration in this Khola.

Sediment Data

No sediment data is available for the Tukucha Khola. Also, since the study was conducted in the dry season, no useful

Table 3. Results of rainfall frequency analysis for Tukucha Khola basin at Tripureshor

Method		
Gumbel's	Log-Pearson Type III	Log-Normal

purpose would have been served had water sample been taken for sediment analysis. Because, as previously mentioned, the flow during the dry season is mostly sewage water.

Flood Flows

The bridges are particularly susceptible to flood flows. As such, flood flow analysis is a primary requirement for determining parameters necessary for reconstruction of the bridges. Flood flow on the river was estimated using the following generally used methods.

A. Rational Method

This method has been developed by taking the rainfall and the catchment characteristics into consideration. According to this method, the peak discharge, Q_p of a river can be calculated as :

$$Qp = 0.56\ p.\ f.\ I_c.\ A$$

where, A = catchment area in km^2

p = percentage coeff. of runoff for the catchment characteristics

f = a factor to correct for the variation of rainfall intensity over catchment area

I_c = critical hourly intensity of rainfall in

$$\text{mm/hr} = \frac{F(T+1)}{T(t_c+1)}$$

F = Maximum 24-hr rainfall in mm; (for Tukucha Khola at Tripureshor, F_{100} = 190, F_{50} = 171, F_{25} = 152)

T = Number of hours = 24 hours

t_c = time of concentration in hours

$$= \left(0.88\ \frac{L^3}{H}\right)^{0.385}$$

L = distance from the critical point to the bridge site in km.

H = difference in elevation between critical point and the bridge site in meters.

The various parameters for the use of Rational Method for Tukucha Khola, for 25-years, 50-years, and 100-years return period, are tabulated in Table 4. The T = 24 hours and the F values for various return periods as stated above are used to calculate I_c.

The peak discharge for various return period T for the rivers at the bridge sites under study by the Rational method are summarized in Table 5.

B. Dicken's Method

One of the empirical formulas widely used

Table 4. Parameters for rational method for Tukucha Khola at Tripureshor

p	f	L	H	t_c	I_c		
		(km)	(m)	(hr)	25 yr.	50 yr.	100 yr.
0.55	0.97	6	55	1.612	60.6	68.2	75.8

Table 5. Peak discharge for various return periods from rational method

River Name	Q_{p25} (m^3/s)	Q_{p50} (m^3/s)	Q_{p100} (m^3/s)
Tukucha Khola at Tripureshor	45	51	57

in northern India and Nepal is Dicken's formula. The original Dicken's formula has been modified by the Irrigation Research Institute, Roorkee, in 1976, by conducting frequency studies (Varshney, 1986). As per this modified formula,

$$Q_p = C_T \cdot A^{3/4}$$

where, A = total catchment area (km^2)

C_T = Dicken's modified constant for a desired return period,

$T = 2.342 \log(0.6\,T) \log(1185 / P) + 4$

$P = 100\,(A_s + 6) / A$

A_s = snow covered area in the catchment

Since $A_s = 0$ for Tukucha Khola, P = 600/A. Therefore, for a specific return period, the only variable in the calculation of Q_p is the catchment area A.

The peak discharge for various return period T for the rivers under study by the Dicken's method are summarized in Table 6.

C. Water and Energy commission Secretariat / Department of Hydrology and Meteorology (WECS/DHM) Method

As per the recommendation of the Water and Energy Commission Secretariat / Department of Hydrology and Meteorology (WECS/DHM) of Nepal, the flood flows of any river of catchment area A (km^2) lying below 3000 m elevation are given by :

Instantaneous Peak flood for a return period of 2 years, $Q_2 = 1.8767\,(A + 1)^{0.8783}$

Instantaneous Peak flood for a return period of 100 years, $Q_{100} = 14.63\,(A + 1)^{0.7342}$

The flood flow for any other return period, T years, can be found as :

$$Q_T = \exp(\ln Q_2 + s\,\sigma)$$

Where, σ = standard deviation of natural logarithms of annual floods

$= \ln(Q_{100} / Q_2) / 2.326$

s = Standardized normal variate from a particular return period = 0, 0.842, 1.282, 1.645, 2.054, 2.326, and 2.576 for T = 2, 5, 10, 20, 50, 100, and 200 years, respectively.

The catchment area of Tukucha Khola lies below the elevation of 3000m. Therefore, the WECS/DHM method is applicable for this study. However, it should be noted that the WECS/DHM method is recommended only for pre-feasibility study. The peak discharge for various return periods (T = 2, 20, 50, and 100 years) for the khola by WECS/DHM method, along with the σ value, are summarized in Table 7.

Design Discharge

The proposed bridge is a major bridge in the heart of the capital city of Nepal. This bridge

Table 6. Peak discharge for various return periods from Dicken's method

River Name	Q_{p25} (m^3/s)	Q_{p50} (m^3/s)	Q_{p100} (m^3/s)
Tukucha Khola at Tripureshor	29.12	32.35	35.60

Table 7. Peak discharge for various return periods for WECS/DHM method

River Name	σ	Q_{p2} (m^3/s)	Q_{p20} (m^3/s)	Q_{p50} (m^3/s)	Q_{p100} (m^3/s)
Tukucha Khola at Tripureshor	0.757	11.1	38.7	52.8	64.8

site lies very close to the intersection connecting Lalitpur Municipality to Kathmandu Metropolitan area. It is usual to take at least 25 years flood as design discharge for major bridges, although the peak flow of 100-years return period can also be taken as design flood. The peak flood flow (Q_p) for various return periods (years) from various methods are summarized in Table 8.

The rational method is recommended for rivers with catchment area up to a maximum of 50 km^2 because of its inherent assumption of uniformity in rainfall intensity in the catchment. For catchment larger than 50 km^2 in area the Rational method generally gives very high value. The catchment area of Tukucha Khola at Tripureshor is below 50 km^2; the results of the Rational method, hence, applies in this case. The WECS/DHM method does not consider the urbanization factor; this method is recommended for pre-feasibility study only. So, taking a conservative approach due to lack of adequate hydro-meteorological data for analysis, the results obtained by the Rational method or the Dicken's method, whichever gives the higher value, are used as the design discharge value for further calculations.

Taking design discharge as 25-years return period flood from the Rational method, the design discharge for Tukucha Khola at the bridge site is 45 m^3/s.

Water Way

Where river training works are to be used to establish desirable approach conditions to a major structure such as a bridge or a barrage, it is necessary to establish a width for the waterway opening. The Lacey's empirical equation for estimating waterway width is

$$W = KQ^{1/2}$$

where, W - effective linear waterway under regime condition (m); K = coefficient, varies from 4 to 6 depending on local site conditions; Q = design discharge (m^3/s)

For the following unrestricted waterway calculation, the value of K is taken as 4. The resulting unrestricted waterway width required for Tukucha Khola is 4 x $(45)^{1/2}$ = 26.8 m. This length of the waterway cannot be provided because of the realities of the Tukucha Khola at the bridge site. The maximum length of the bridge that is logical at the site is 7m. So, the waterway is fixed to be 7m for the bridge. This restriction in waterway causes higher scour depth, which should be considered during detailed design of the bridge foundation. Based on this length of the waterway, other calculations are performed.

High Flood Level (HFL) and Freeboard

For calculating the HFL of the rivers at the bridge sites, a rating curve (stage-discharge

Table 8. Peak discharge (m^3/s) from various methods for various return periods at Tukucha Khola

Return period (yrs.)	Method		
	Rational	Dicken's	WECS/DHM
25	45	29.12	38.7*
50	51	32.35	52.8
100	57	35.6	64.8

relationship curve) is needed. Since no specific hydrometric stations are established near the bridge site, the cross sections and bed slope were surveyed. The rugosity coefficient (also called Manning's n) was estimated by observing the bed materials. By using Manning's equation the rating curve for the river at the bridge site was developed. It should, however, be noted that the bed material constituent changes drastically from the dry to the wet season in Tukucha Khola. The flow from a sudden burst of rain can carry the debris thrown on its bank and can block the river flow or dump the debris where the river flow relatively slowly, thus changing the upper bed material composition.

By Manning's equation :

$$\text{Discharge } Q = V\,A = \left(\frac{1}{n} R^{2/3} S^{1/2}\right) A$$

where, Q = discharge (m^3/s); n = Manning's roughness coefficient (indicates resistance to flow, depends upon surface roughness, amount of vegetation, channel irregularity, stage, scour and deposition); A = cross-sectional area of flow (m^2); R = hydraulic radius = A/P; P = wetted perimeter (m); S = bed slope.

For the Tukucha Khola, the Manning's n is taken as 0.065 (bottom consists of sand and clay, banks are rough and loaded with debris and vegetation). The cross-sectional area during flood and the bed slope is obtained from cross-sectional survey.

The rating table and the associated rating curves for Tukucha at the bridge site were developed. From the rating tables, the HFL for the design discharge for Tukucha Khola at the bridge site can be found. The difference between the elevation of the lowest part of the bridge superstructure and the HFL is the freeboard. The freeboard in a bridge allows the safe passage of flowing debris during flooding. The Tukucha Khola at Tripureshor, due to vegetation and garbage dumps on the riverbanks, is particularly susceptible to debris flow. The debris flow tends to block the flood flow and causes over flow of water during floods. The HFL for the design discharge, the bed level, water depth, and freeboard for Tukucha Khola at the bridge site are tabulated in Table 9. The elevation of HFL, bed level, and superstructure is taken with reference to the site survey data. The HFL at the bridge site and the bridge section are presented in Fig. 2.

Scour Depth

Scour of stream bed occurs during the passage of flood discharge, when the velocity of the stream exceeds the limiting velocity that can be withstood by the particles of the bed materials. The scour is aggravated at the nose of the piers and at the bends. The maximum scour depth has to be determined to calculate the depth of foundation of the bridge. The scour depth for a particular design discharge depends on local geology and the water way width. As per IRC 78/1983, the mean scour depth (d_{sm})

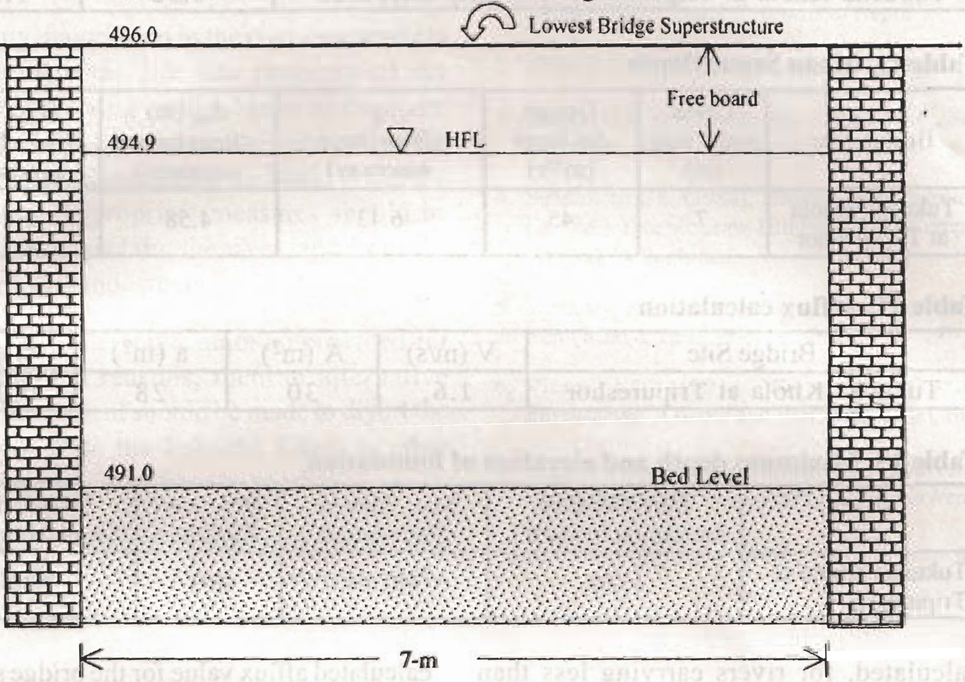
Table 9. HFL, bed level, water depth, and freeboard

River Name	HFL (m)	Bed Level (m)	Water Depth (m)	Elecation of Lowest Part of Bridge Superstructure (m)	Freeboard (m)
Tukucha Khola at Tripureshor	494.9	491	3.9	496	1.1

Fig. 2

Tukucha Khola at Tripureshor

HFL, Free Board, Bed Level at Bridge Site



below the highest flood level (HFL) may be calculated form the equation

$$d_{sm} = 1.34\,(q^2/f)^{1/3}$$

where, q = design specific discharge (m^3/sec/m); f = silt factor of a representative sample in the bed = $1.76\sqrt{d_m}$; d_m = weighted mean diameter of bed material in mm ≈ d_{50}; d_{50} = average particle size in mm.

The average particle size (d_{50}) of the river bed were collected to estimate scour depth. The restriction to flow due to river bank encroachment and obliquity of flow were considered in calculating scour depth. The bed material and the average particle size (d_{50}) of the Khola at the bridge site, according to the laboratory analysis, are given in Table 10. Also included in the table are the corresponding values of d_{sm}.

Table 11 is the summary of mean scour depth calculation using the effective linear water way and the actual water way available. The q in Table 11 represents specific design discharge for linear waterway. Similarly, the d_{sm} represents mean scour depth below the HFL, considering linear waterway. The maximum scour depth D_{max} is taken as $1.5d_{sm}$ near the bridge abutments.

Afflux

The afflux is the heading up of flood water on the up stream of a bridge and is measured by the difference in levels between the up stream and down stream water surface of the bridge. The reduction of water way due to construction of bridge and other reasons that obstructs the smooth flow of the water are the reasons for the afflux. The afflux is

Table 10. Bed material and d_{50} for various rivers at the bridge site

Bridge Site	Bed Material	d50 (mm)	f
Tukucha Khola at Tripureshor	Silty clay, sand	0.32	1.00

Table 11. Mean Scour Depth

Bridge Site	Linear water way (m)	Design discharge (m^3/s)	q (from linear waterway)	d_{sm} (m) (from linear waterway)	D_{max} (m) (from linear waterway)
Tukucha Khola at Tripureshor	7	45	6.43	4.58	6.86

Table 12. Afflux calculation

Bridge Site	V (m/s)	A (m^2)	a (m^2)	H (m)
Tukucha Khola at Tripureshor	1.6	30	28	0.023

Table 13. Minimum depth and elevation of foundation

River	Min. Depth of foundation from HFL	Max. Elev. of Foundation	Bed Level Elevation	Foundation Depth below BL
Tukucha Khola at Tripureshor	13.06	481.84	491	9.16

calculated, for rivers carrying less than $3000 m^3/sec$ flow, using Molesworth's formula as given below :

Afflux, H in meters

$= [V^2/17.88 + 0.015] [((A/a)^2) - 11]$

where, V = average velocity of river up stream of the bridge prior to restriction (in meters/sec); A = unrestricted sectional area of the river (in m^2); a = restricted sectional area of the river (in m^2).

For calculation of A, the unrestricted waterway width (10-m) is multiplied by Dmax from unrestricted waterway width. Similarly, the restricted area is calculated by multiplying actual waterway width (7-m) by the Dmax from restricted waterway. The velocity V is obtained from linear interpolation of velocity values for the design discharge from rating table calculations. The calculated afflux value for the bridge site for the design discharge is tabulated in Table 12.

Depth of Foundation

The minimum depth of foundation below high flood level is kept at 2 d_{sm} for erodible strata. The minimum depth and elevation of foundation at the bridge site are summarized in Table 13.

CONCLUSIONS

The following conclusions were drawn from the hydrologic study of Tukucha Khola at Tripureshor, Kathmandu :

1. The waterway width of the river has been overly restricted. At the bridge site, the waterway width is less than one third of what it should be for unobstructed flow of the river during flood.

2. The flow in the river in the dry season is mostly wastewater from different sources.

3. Any major flood in the river can severely damage the life and property of the people living on the banks of the river. The Nepal government should inform the local residents along the banks about the risks. Appropriate measures should be taken to reclaim the river land from the private landowners.

4. If the waterway cannot be provided for practical reasons, then an alternative arrangement should be made to divert the river from the Tukucha Khola to other rivers in case of heavy rainfall.

5. The foundation of the bridge at the site should be very deep to withstand the effect of scouring during major flooding.

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Operation of Banganga Irrigation Project, Nepal

*Lakshmi Narayan Choudhari**

ABSTRACT

To overcome the operation problem of Banganga irrigation project, a simulation model has been developed with deterministic crop water demand and stochastic inflow for the operation of diversion canal and reservoir system. Several alternatives have been tested in simulation runs by varying the main canal capacity (off-taking from reservoir) and the reservoir capacity. The standard operating rule that has been developed, if applied to this project, would help in improving the performance of the system thereby increasing the crop yields and improving the living standards of the people.

INTRODUCTION

The Banganga Irrigation Project is located in the Kapilvastu district of western Terai region of Nepal. During the Rana regime, the depressed area in Jagdishpur was converted to a reservoir. The project has a gross command area of 7500 hectares with culturable command area of 6215 hectares. Out of 6215 ha, 343 ha lies ahead of the Jagdishpur reservoir (connected by diversion canal) and the balance 5872 ha lies downstream of the reservoir. The main canal fed by the reservoir is about 20.5 km long and has a design capacity of $5.66 m^3/s$. There are 3 major branch canals : (a) Taulihawa Branch (b) Laxminagar Branch (c) Hathihawa Branch and 32 minor distributaries off-taking from the main and secondary canals. This project was constructed by DIHM (Department of Hydrology and Meteorology) in 1978 and operated by DoI (Department of Irrigation).

The reservoir capacity has been increased from $1.5 Mm^3$ to $4.75 Mm^3$ with a minimum storage capacity of $0.1 Mm^3$ by increasing the area from 97 ha to 157 ha after the project was included in Command Area Development Project (CADP) during 1982 to 1989 to improve the efficiency of the irrigation system. The reservoir is man made earthen embankment all round with five kilometers of peripheral gravel road and directly fed by the diversion canal (4.75 km long) that draws water from Banganga river. The Banganga, a small river, originates from the mid hills of Nepal and flow from north to south. The river is almost dry during the dry months (March to May) and is as low as $0.65 m^3/s$ during April (ADB, 1981). Its discharge is highly dependent on the rainfall of its catchment area (1315 sq. km).

As per the "Provisional Impact Evaluation Study of the Project" carried out by GEOCE Consultant (1990), there is high shortage of water, due to inadequate water management, especially in the tail end part of the command area. Farmers of this command area would not show up their readiness for cultivation till they get rain in their fields. This indicates that farmers have no faith in the management operation of the irrigation system. What they need is some form of guarantee in water

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supply because they do not want to take the risk of crop failure. The management operation, therefore, has to be improved to provide the guarantee of water supply.

Sound planning and operation are therefore required for the irrigation system management i.e. the operation of the reservoir and the canal. This apparently demands to formulate efficient operating policies both for the reservoir and the diversion canal to improve the irrigation system as a whole.

If the irrigation system can not supply right quantities of water in right time and place, the efficiency of the system will suffer and crop yields will naturally decrease. In developed countries, the water resource problems have been solved or being solved by systematic water resource planning and operation whereas in the developing countries, due to lack of technology, missing data or economy, the undertaking of such a system analysis is still a great problem. The problem is more so in a country like Nepal. In this study, an attempt has been made to address the case with deterministic demand and the transformed stochastic inflow (synthetic flow) to the reservoir for the operation of the diversion canal and the reservoir system

The main objective of this study is to determine efficient operating policies through operation of diversion canal and a single multipurpose reservoir. The focus is on the efficient management and operation of the irrigation system consisting of the reservoir and the canal. To achieve the objective, iterative simulation model for the reservoir and the diversion canal was formulated to determine the decade-wise release of water from the reservoir to meet the target demand and standard operating polices were found for longer time horizon.

PROJECT AREA AND AVAILABLE DATA

The Banganga Irrigation Project is located in the western Terai in Kapilvastu district, Lumbini zone of Nepal (Fig. 1). The climate of the project is sub-tropical monsoon. The command area gets heavy rainfall from June to October, generally brought about by south-east monsoon. The average rainfall ranges from 1300-1600mm [ADB, NEP AP - Report No. 28 (1981)]. The mean monthly temperature ranges from 15.5°C Jan. to 32°C in June. The average evaporation rate is 5.5mm/month.

The runoff of the Banganga river is dependent on the rainfall pattern of the catchment area. Water is abundant during wet season (June-Oct.) but critical during dry season. Kaila Khola, a tributary of the Banganga river immediately upstream of the headworks, contributes the base flow during the dry season months. Figure 2 shows the reservoir characteristics of Jagdishpur reservoir.

Paddy is the dominant crop in the command area. Apart from paddy, other crops in the command area are: wheat, pulses and vegetables. The total cropping intensity (Fig. 3) is 145% [ADB, Report No. NEP: AP-28 (1981)].

METHODOLOGY AND MODEL DEVELOPMENT

The irrigation water requirements of each crop are calculated based on recommendations given by Doorenbos and Pruitt (1977). Sequential generations of non-

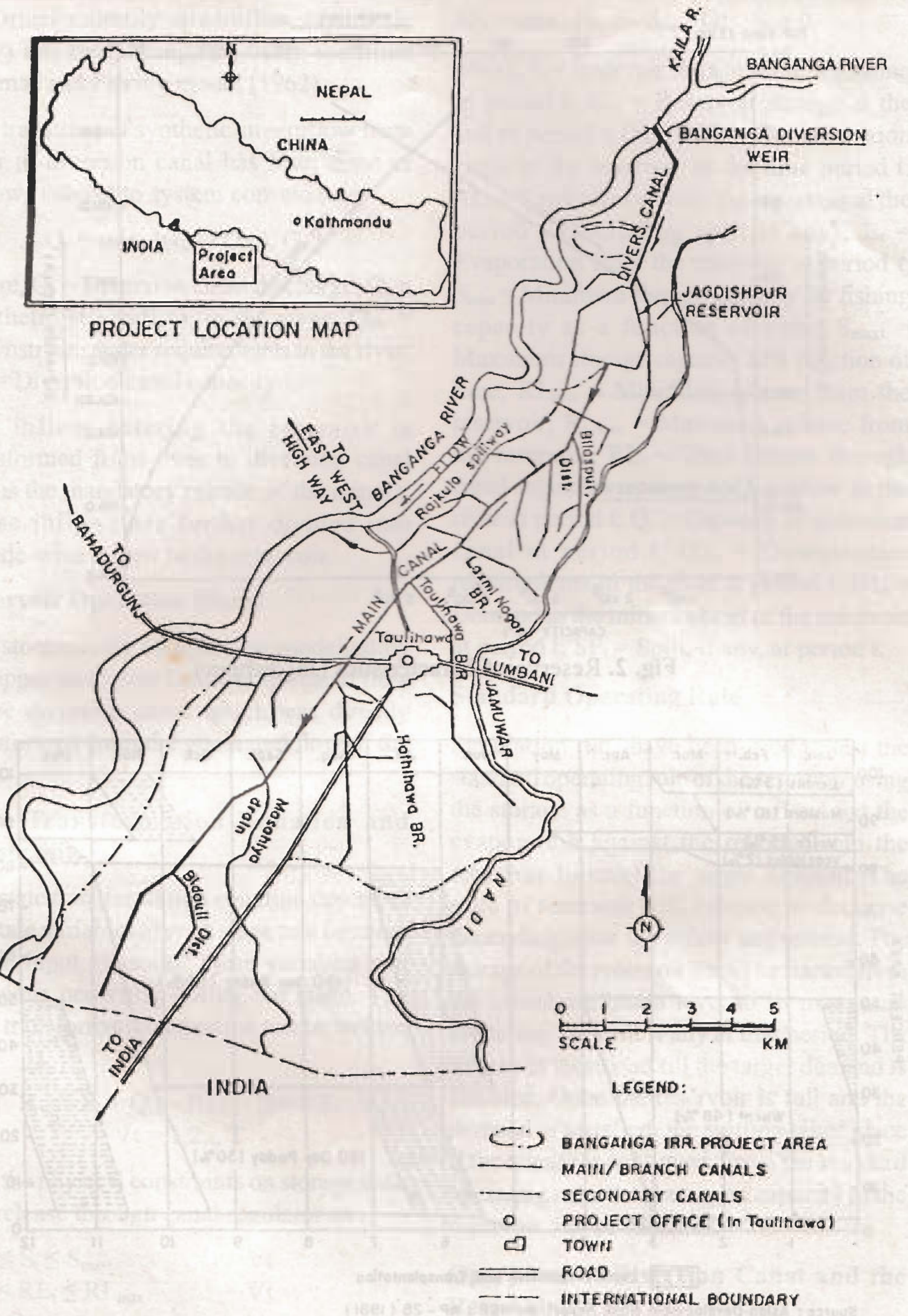

Fig. 1. Existing Banganga Irrigation System (Nepal)

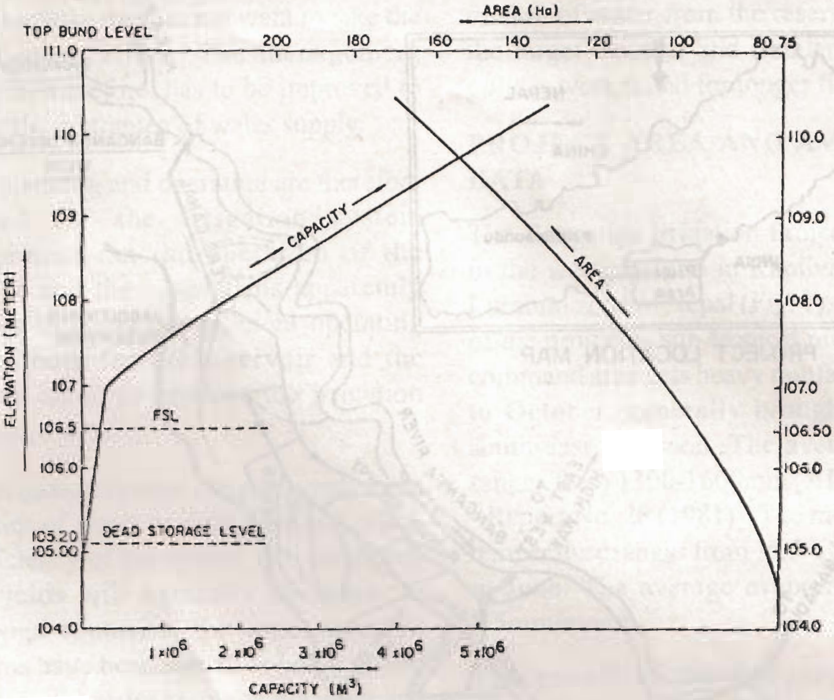

Fig. 2. Reservoir Characteristics (Jagdishpur)

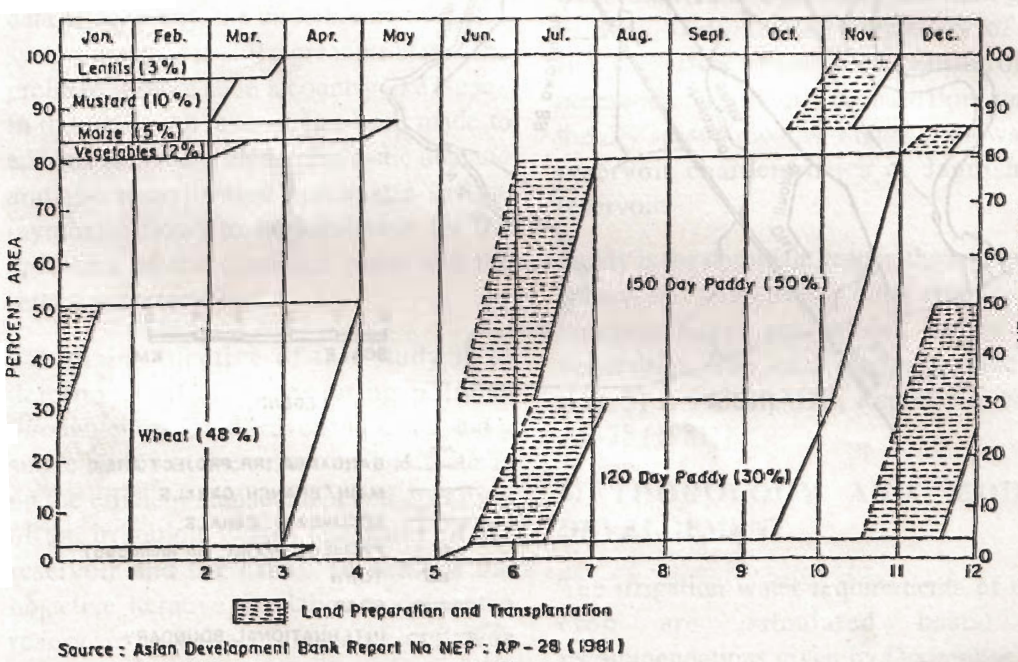

Fig. 3. Existing Cropping Pattern Banganga (6215 Ha)

historical monthly streamflow (synthetic flow) has been computed using modified Thomas and Fiering model (1962).

The transition of synthetic streamflow from river to diversion canal has been done as follows subject to system constraints :

$$Q_c = \min. [(Q_r - Q_{d/s}), Q_{cs}]$$

where, Q_c = Diversion canal discharge; Q_r = Synthetic streamflow in the river; $Q_{d/s}$ = Downstream water requirements in the river; Q_{cs} = Diversion canal capacity.

The inflow entering the reservoir is transformed from river to diversion canal minus the mandatory release of the minors. These inflows are further divided into decade-wise inflow to the reservoir.

Reservoir Operation Model

The stochasticity of inflow is modelled by the upper and lower limits of the canal flow in the diversion canal which was directly transformed from the generated flow of the river.

State Transformation Equation and Constraints

The state transformation equation describes the state variables at each stage as a function of the input values of these variables and decisions occurring during the stage. The state transformation equation can be written as:

$$S_{t+1} = S_t + Q_{ct} - RL_t - D1_t - E_t$$
$$\forall t = 1,2,.. T$$

with the physical constraints on storage state and release through canal regulator as :

$$S_{mint} \leq S_t \leq S_{maxt} \quad \forall t$$
$$R_{min} \leq RL_t \leq RL_{max} \quad \forall t$$
$$Q_{ct} \leq Q_{rt} \quad \forall t$$
$$Q_{ct} \leq Q_{rt} \leq Q_{rdis} \quad \forall t$$

$$SP_t = \min. \{S_{t+1} - S_{max}, O\} \quad S_t > 0$$

where, S_t = reservoir storage at the beginning of period t; S_{t+1} = Reservoir storage at the end of period t; Q_{ct} = Inflow from diversion canal to the reservoir at the time period t; RL_t = Total release from the reservoir at the period t (including spill if any); E_t = Evaporation from the reservoir at period t; S_{mint} = Minimum storage capacity for fishing capacity as a function of time; S_{maxt} = Maximum storage capacity as a function of time; RL_{min} = Minimum release from the reservoir; RL_{max} = Maximum release from the reservoir; RL_t = Total release through canal regulator as stage t; Q_r = Flow in the river at period t; Q_c = Capacity of diversion canal at period t; $Q_{d/s}$ = Downstream requirements in the river at period t; $D1_t$ = Demand in the minors ahead of the reservoir at period t; SP_t = Spill, if any, at period t.

Standard Operating Rule

Simulation runs have been used to test the standard operating rule of the reservoir using the storage as a function of inflow and the evaporation against the release from the reservoir to meet the target demand. The state of reservoir will increase or decrease depending upon the inflow and release. The storage of the reservoir has to be started from the initial minimum level to its maximum including the spill if any at that period. The release is increased till the target demand is fulfilled. Once the reservoir is full and the demand is satisfied, the spilling takes place if the release is continued. From the standard operating rule, the maximum capacity of the reservoir can be obtained.

Operation of Diversion Canal and the Reservoir

The state of reservoir is highly dependent on the inflow from the diversion canal because of the limited capacity. The reservoir is small and cannot store water for interyears or intermonths. The capacity of the diversion canal is another constraint of the system. It is not possible to divert as much water as needed through the diversion canal and store in the reservoir. For the efficient operation of the system, simultaneous operation of the reservoir and the diversion canal under the systems' constraints is highly essential.

Objective Function

The objective function is to minimize the annual one-sided squared deviation between the reservoir release and the irrigation water requirement at the reservoir. Mathematically :

$$\text{Minimize } Z = \sum_{t=1}^{T} [min.(RL_t - DT_t, 0)]^2$$

where, Z = Objective function to be minimized; RL_t = Total release from the reservoir in stage t (including spill if any); DT_t = Total irrigation demand.

Reliability of the System

The reliability of the system gives the measure of the systems performance as how many times the system does fail to meet the irrigation demand during a given time interval of operations. The reliability is given as :

Reliability = {1-Ndf / TOTOP}* 100%

where, Ndf = Total number of failures to meet target demand; TOTOP = Total number of operation periods.

RESULTS AND DISCUSSION

In the present study, the irrigation demands as deterministic on decade basis with stochastic inflow time series from the historical record of 14 years have been computed. The input variables such as precipitation, evaporation, inflow are kept with same accuracy in finding the better irrigation operating policy of the system. The time series of the gross irrigation demand has been calculated for the synthetic flow of 50 years as historical record were available for short duration (14 years only). The model uses the method based on FAO-24 and modified by Doorenbos and Pruitt (1977). The ET_o computed using FAO-24 (1977) for this project in ADB (NEP Report No. 8) have been used to calculate the ET_c in this case.

In this case, 80% probability of rainfall is taken into consideration to compute NIR (Net Irrigation Requirements). It is under the assumption that the water diverted for irrigation is not just meeting the supplementary irrigation demand rather once there is water in canal the farmers will not wait the rain which is uncertain to fall and, then divert water from the canal and irrigate first to the ponding depth. The rain falling after this will go as spill from the fields. Furthermore, rice is not sensitive to excess water and usually, it is the tendency of the farmers to over-irrigate their fields. This will provide an extra reliability to farmers.

The generated 50 years synthetic flow was tested for the mean, standard deviation and skewness values. The test results showed the generated flow satisfy the LN3 parameters of the historical flow and K-S tests. Figure 4 between average historical flow and the

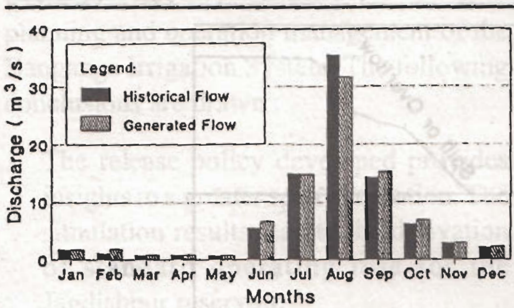

Fig. 4. Comparison of synthetic flow and historical flow (Banganga Irrigation Project, Nepal)

synthetic flow shows the comparison between them.

Diversion Canal Operation

The transformation of diversion canal flow calculation showed that there is a serious lack of inflow into the reservoir during the months of March to May. Also, the reservoir capacity is small, it cannot hold inter-year storage or even inter-months storage, the crops during these periods are automatically put in stress condition. The case arises during the first one decade period of June when the demand is very high, however, this happens for a short and initial period of the paddy crops and will not adversely effect the crop yield. During the rest of the decades, the demands are well within the reservoir capacity plus the inflow of the diversion canal capacity.

Reservoir Operation and Simulation Model

The simulation model of the diversion canal and reservoir system gives decade-wise release to the main canal off-taking from the reservoir. Various options have been tested to improve the operating policies of the system. In the first case, the RC (reservoir capacity) and the main CC (canal capacity) are kept same as existing in the field condition i.e. 4.75 Mm^3 and 4.89 Mm^3 respectively and simulation have been carried out by decreasing the demand by decreasing the command area by 10%, 20%, 30% and 40% respectively. On the other scenario, the reservoir capacity and the main canal capacity have been increased to 7.13 Mm^3 (50%) and 5.38 Mm^3 (10%) respectively. Similarly, in the third scenario, the reservoir capacity and the canal capacity are increased to 6.90 Mm^3 (45%) and 5.9 Mm^3 (20%) respectively (Fig. 5a). The crop water demands have been decreased in the same way as mentioned above. Simulation for each scenario has been carried out for the synthetic flow of 50 years each. To derive the standard operating rule for the reservoir

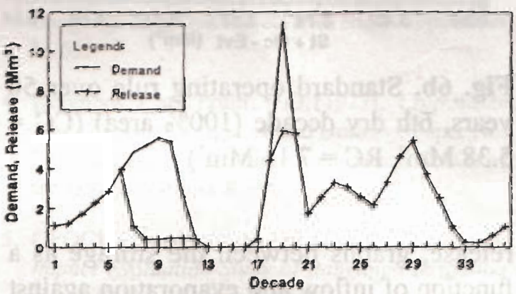

Fig. 5. Demand and release for dry year (CC = 5.90 Mm^3, RC = 6.98 Mm^3) (100% area)

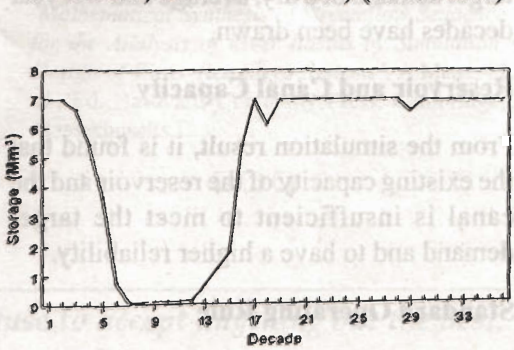

Fig. 5a. Sotrage variation in dry year (CC = 5.90 Mm^3, RC = 6.98 Mm^3) (100% area)

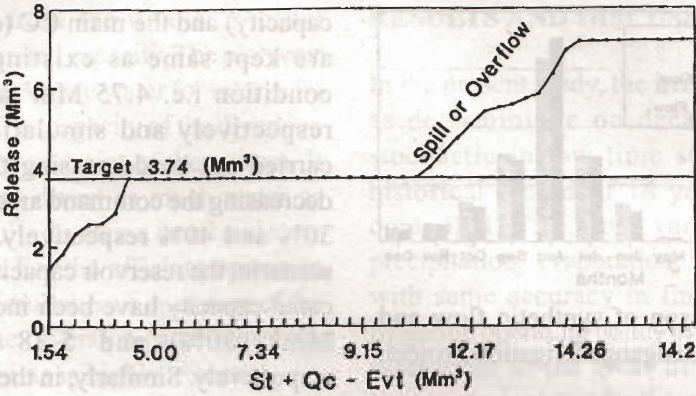

Fig. 6a. Standard operating rule over 50 years, 30th wet decade (100% area) (CC = 5.38 Mm^3, RC = 7.13 Mm^3)

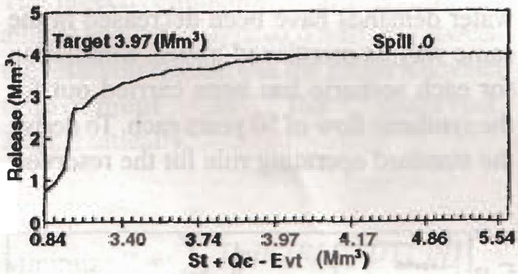

Fig. 6b. Standard operating rule over 50 years, 6th dry decade (100% area) (CC = 5.38 Mm^3, RC = 7.13 Mm^3)

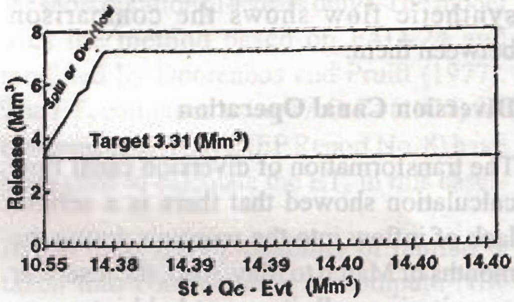

Fig. 6c. Standard operating rule over 50 years, 27th wet decade (100% area) (CC = 5.38 Mm^3, RC = 7.13 Mm^3)

release, graphs between the storage as a function of inflow and evaporation against the release and the target, considering the target demand of a dry, average and wet year decades have been drawn.

Reservoir and Canal Capacity

From the simulation result, it is found that the existing capacity of the reservoir and the canal is insufficient to meet the target demand and to have a higher reliability.

Standard Operating Rule

A glance at Figures 6 a, b, c shows the operating rule for the reservoir. From the Figure, it is found that the reservoir cannot store water for intermonths or even for the interdecades to meet the demand. Once the target demand is fulfilled, the spilling starts. To maintain the target demand and release at constant level and spill to be zero the inflow from the diversion canal needs to be adjusted suitably.

CONCLUSIONS

An attempt has been made to address the deterministic demand and the transformed stochastic inflow (synthetic flow) for the operation of the diversion canal and the reservoir system. The focus is on the planning and operation management of the Banganga Irrigation System. The following conclusions are drawn :

1. The release policy developed provides insights to a greater span of duration. The simulation results lead to the derivation of standard operating rule for the Jagdishpur reservoir.

2. The diversion canal in the Banganga irrigation system plays a major role in supplying the required inflow to the reservoir. The existing design capacity of the diversion canal is sufficient. However, to maintain its design capacity, it should be kept clean off the siltation of bed and weeds.

3. The existing main canal off-taking from the reservoir and the reservoir itself are of insufficient capacities to meet the dry season demands and need to be increased by 10% and 50% respectively. The topography and the geology will not pose any problem for this expansion. There are a lot of undulations and bushes in the reservoir which should be cleared for effective use of the reservoir.

4. The bed of the diversion canal is not lined. Side slopes are lined with dry stone riprap. The weed problem can be overcome by lining the bed of the canal.

5. Due to short length of the diversion canal, weeds and siltation, there is some backwater effect. Hence a study may be made considering the backwater flow and the effect of siltation in the discharge capacity of the diversion canal.

6. The study may be made for the stochastic demand by generating the optimal cropping pattern because this study has been made under a fixed cropping pattern.

7. A study may be made by incorporating ground water especially during dry season months to augment the reservoir storage or main canal flow.

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"It's a funny thing about life; if you refuse to accept anything but the best, you very often get it."

– Somerset Maugham

Energy Dissipation Over Stepped Spillways

*Nishikant Padhy**

ABSTRACT

A spillway is a structure for effectively disposing of the surplus water from the dam. The water flowing over the spillway acquires a lot of kinetic energy by the time ti reaches near the toe. If arrangement are not made to dissipate this huge kinetic energy of the water, large scale scour can take place on the downstream side near the toe of the dam and away from it.

In a stepped spillway, the spillway face is provided with a series of steps, from near the crest to the toe. Hence energy is continuously dissipated over the length of spillway by jet impact and mixing on the steps and jet break up in air. Due to provision of numbers of steps much air is entrained in the flow and spray action becomes significant. The energy dissipation caused by the steps reduces the size of the energy dissipater, generally provided at the toe of the spillway. Stepped spillways have been built on the past but there appears to be renewed interest on them because of significant cost savings.

INTRODUCTION

Energy dissipation below hydraulic structures like dams, barrages, across rivers and control weirs on canal is accomplished conventionally by single fall hydraulic jump type stilling basins, roller buckets or trajectory buckets. However, in case of high head dams, the kinetic energy at the toe of the spillways will be very high, and the tail water depths available in the river are often inadequate for the former two devices. Narrow and curved gorges consisting of fractured rock prohibit the adoption of the last. In such situations, a system of falls cascading down the side of a valley with a stilling basin below can be used as an alternative spillways.

Stepped spillways have another advantage that these can be adopted for any type of dam irrespective of the material of construction. Convenience of adopting these in concrete dams is obvious. Even in case of earth and rock fill dams, a system of falls with a stilling basin below each fall can be used. But one has to take care of the protective cover on the earth-fill. For this purpose, a common construction material like Gabions has been successfully utilised in various countries.

LITERATURE REVIEW

Rajaratnam (1990) studied the energy dissipation for a stepped spillway of constant slope of sinθ, with a large number of identical steps. He assumed the flow to be fully developed after the first few steps. For such a fully developed flow, with a constant mean velocity V and normal depth y, energy at the toe E_t, can be represented as

$$Et = y + \frac{V^2}{2g}$$

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[redacted]

q = unit discharge

Nishikant *et al.* (1997) attempted to predict the scour depth below stepped spillways.

If y' and V' are the corresponding depth and velocity at the toe of a smooth spillway without steps then

$$E_o = y' + \frac{V'^2}{2g}$$

and $\Delta E = E_o - E_t$

If the relative loss is defined as $\frac{\Delta E}{E_o}$, it can be shown that

$$\frac{\Delta E}{E_o} = \frac{(1-A) + \frac{F^2}{2}\left(\frac{A^2-1}{A^2}\right)}{1+\frac{F^2}{2}} \quad \text{............ (1)}$$

where, F = Froude number at the toe of smooth spillway

$$A = \left(\frac{C_f}{C_f}\right)^{1/3}$$

C_f = coefficient skin friction for stepped spillway

C_f = coefficient skin friction for smooth spillway

Taking $C_f \approx 0.18$, $C_f \approx 0.0065$, $A \approx 3$ and for a relatively large value of F', Rajaratnam (1990) showed that

$$\frac{\Delta E}{E_o} \approx \frac{A^2-1}{A^2} = \frac{8}{9}$$

This indicates considerable amount of energy loss due to steps, or in other words only 10 percent of energy needs to be dissipated at the toe of stepped spillway.

Stephenson (1991) presented an empirical relation for the relative energy dissipation $\Delta E/H$ where H = Height of spillway

$$\frac{\Delta E}{H} = \frac{0.84}{\theta^{0.25}} \cdot \left[\frac{q}{(gH^3)^{1/2}}\right]^{-1/3} \quad \text{............. (2)}$$

q = unit discharge

The energy dissipation is high in the height of spillway is large or if the discharge is small the effect of slope (θ) is not very significant.

Christodoulou (1993) conducted experiments on a stepped spillway, whose step tips followed the standard crest shape to the tangency point. The step shape parameter height/length was 0.7. In total, the spillway has 15 steps, each 25mm high. He was able to determine an effect of step number N on the rate of energy dissipation. It depends upon the modified parameter h_c

$= \frac{y_c}{Nh}$ where $y_c = \left(\frac{q^2}{g}\right)^{1/3}$ is the critical depth and h is the height of steps. The result of Christodoulou, for his and the data of Sorensen for $h_c < 25$ is

$$\frac{\Delta E}{E_o} = \exp(-30\, h_c^2) \quad \text{.................... (3)}$$

Increasing the number of steps strongly increases the energy dissipation.

Tatewar and Ingle (1996) derived the expression for energy loss by regression analysis using the experimental data of Sorensen (1985) and Christodoulou

$$\frac{\Delta E}{E_o} = 0.000457\,D^2 - 1.078\frac{h}{l} - 1.99\frac{y_c}{H} + 2.339 \quad \text{................................ (4)}$$

where D = Drop number (dimensionless)

$$= \frac{q}{\sqrt{gh^3}}$$

h and l = height and length of each step.

PRESENT WORK

Nishikant *et al.* (1997) attempted to predict the scour depth below stepped spillways.

They prepared three models, the first being the smooth one, the second having 11 steps of 10cm high and third one having 6 steps of 20cm high. They observed that for a particular discharge,

$$\frac{\text{scour depth for model I}}{E_t \text{ for model I}} = \frac{\text{scour depth for model II}}{E_t \text{ for model II}} = \frac{\text{scour depth for model III}}{E_t \text{ for model III}}$$

In other words, the scour depth is proportional to the kinetic energy at the toe.

To predict scour depth, they proposed the relationship,

$$\frac{d}{y} = C_1 \ln \frac{q^2}{gH^3} + C2 \text{ .... } (5)$$

where, d = scour depth; y = flow depth at the toe of spillway; q = unit discharge; H = height of spillway.

C_1 and C_2 are constants and their values depend upon the type of bed materials, number of steps and the tail water depth maintained beyond toe.

CONCLUSIONS

According to Rajaratnam (1990), for a large number of identical steps and for a high Froude number, the theoretical energy loss at the spillway toe is 89% of the energy present without the steps. Sorensen (1985) reported 84% of kinetic energy dissipation upto the toe for a model spillway of 59 steps. However, Christodoulou (1993) got slightly lower energy losses due to smaller number of steps.

When such huge amount of kinetic energy is lost on the steps, only a part of the kinetic energy is required to be dissipated below the toe. In such cases, the length of stilling basin becomes significantly less, thus resulting in highly economical projects. The only thing to be kept in mind is, to design the shape and number of steps properly, taking into account the height of spillway and the amount of discharge.

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Climate Disaster Awareness

*Naresh Chandra Saxena**

ABSTRACT

Climate change has devastating effects on the lives of people. The climate is changing fast, frequently, abruptly, aggressively and continuously. Within the last decade of this century, the usual patterns and cycles of rain, cloudy or sunshine, heat or cold, humidity and wind flow have turned unusual and erratic. Slow could be controllable but rapid is not. Diurnal thermal differences have become more than 25°C and both maxima and minima have been pushed up during summer, drastically changing life styles in a single life span. Energy use and costs have soared. Untimely rains have caused heavy landslides and flooding every where. Standing crops and harvested and heaped grains have been destroyed and pre and post harvest losses are extremely high. Industry, agriculture and forestry sectors are in chaos and are the worst affected.

A beautiful, healthy and systematic climate, till now, has failed miserably, adversely affecting human beings, environment and everything related to life of all kinds. The vicious circle of climatic change is very complicated.

It is, therefore, necessary to create public awareness on climate change issues. The government could also take initiative (i) to formulate suitable policies (ii) coordinate with the concerned UN authorities and (iii) establish regional and international cooperation.

INTRODUCTION

The co-existence of people with nature and natural disasters is well known from time immemorial. In the olden times, natural disasters were not that many and frequency and severity were not very high. The overall damages were minimum. But the modernity in life has introduced exponentially increasing needs and demands/desires so much so that there seems to be no end. Machines and hence their production almost in all countries of the world has become the need of the hour. The consumer has become the testing ground on one side and dumping site on the other for all varieties of equipments and machines irrespective of their impact on environment or climate. The rising middle class and the neo rich have joined the bandwagon without any consideration for ecology. The poor are left with no choice. They are getting poorer and poorer and in order to survive, have to destroy the environment – after all cooking can be only by firewood from forest and no other means like electricity and gas or even kerosene.

The affluent class have refrigerators, air conditioners (O_3 depleting CFC), cars and other means of transport (GHG – green house gas emissions), and other luxury items manufactured in specific factories and locations. Human activities, in modern times, like tremendous industrial activity,

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extensive deforestation, rapid urbanization and huge population growth have mainly been responsible for horrors and distress due to disasters. Both frequency and severity of natural disasters are increasing uncontrollably thanks to modernity.

Nepal is one of the major disaster-prone countries in South East Asia. Every year, excessive/untimely rains or no rains, famines and strangely hot or cold waves strike almost all parts of the country. Landslides, erosion and flood havoc are traced to high rainfall causing random runoff. Human sufferings, village after village being washed out, disruptions in urban settings, huge damage to property, industry, agriculture and the cattle loss is beyond description.

AIMS

1. The aim should, therefore, be to create awareness among all people, all countries, intellectuals/researches and the institutions. The natural disasters could concern everyone, every country and better be not left in isolation. A committed coordination before, during and after the disaster is a must for survival.
2. The various types of natural disasters are all inter-related, interconnected and inter-dependent. For example change of climate could trigger rise of sea level, flooding and erosion and landslides. The aim should be to deal with anyone or more with extreme caution and concern.

   The usual types are climate change, floods, erosion, landslides, earthquake, storms, draughts, cyclones etc.
3. Scientific techniques including remote sensing should be used to predict the natural disasters. The necessary technology should be available to both the have and have-nots. A collective initiative or UN efforts can be very effective for the sake of humanity.

THE U.N. CONCERN

On December 22, 1989, UN General Assembly adopted a resolution to designate the decade (1990 to 1999) as the International Decade for Natural Disaster Reduction (IDNDR). The UN General Assembly had also designated the second Wednesday of October as International day for natural Disaster Reduction to be observed annually during the said decade. What prompted the UN Assembly to adopt the resolution was the increasing numbers of natural calamities over the years in almost all parts of the world affecting adversely the lives of millions of people and causing considerable damage in infrastructure and property. Hardly a day passes without one part of the world or the other being hit by natural disasters.

The first major international meeting on climate change – one of the natural disasters – held in Geneva in 1979, discussed climate variability and how changes might affect human activities. In 1985, The Villach Symposium in Austria concluded that the increase in green house gases (GHG) could induce global warming and produce serious seal level rise. This led to the presentation of the UNFCCC at the EARTH SUMMIT in Rio (Brazil) in 1992.

Awareness of UNFCCC (United Nations Frame work Convention on Climate Change) is necessary in the context of its EXISTENCE, INTERNATIONAL ROLE AND about opportunities it provides for "MITIGATION AND ADAPTATION TO

CLIMATE CHANGE".

The important conclusion of UNFCCC had been that climate change is a global phenomenon, which requires all nations to seek mitigation measures at all levels.

Under the UNFCCC, every country is required to develop a climate response programme that integrates climate change activities into all relevant sectors including energy, transport, industry, agriculture, forestry and waste management. Any action taken to reduce the potential impacts due to climate change disaster should seriously consider social, economic and political problems.

VICIOUS CIRCLE

The climate change disaster does affect several sectors of human activity and to combat at any or every stage is not easy, rather complicated. Solution of one creates a new problem and tackling this converts into another one. It constitutes a vicious circle moving round and round without satisfactory settlement. Sometimes, it is back to square one.

The Vicious Circle of Climatic – Change is :

- Developing and poor countries have a PRIORITY of Human NEEDS.
- Careless, casual and criminal harnessing of natural resources result.
- Involving seven sectors, agriculture, forestry, river system, energy, transport, industry and waste management.
- GHG (green house gases) emissions into atmosphere increase (due to burning of biomass, use of fossil fuels and energy use and production).
- Increase in GHG induces global warming and sea level rise.
- Climate changes.
- Action taken to reduce its impact gives rise to serious problems (SEP problems of social, economic and political dimensions).
- But priority of human needs prevails over every activity.
- Reduce EMISSIONS (GHG) → increase problems (SEP).
- Reduce/Control Problems (SEP) → Increase Emissions (GHG).
- Priority shall not be given to "GHG mitigation options" if there is "Conflict between GHG effects and human needs".

Climate disaster cannot be prevented and mitigation is the only solution in pre, during and post havoc situations. As soon as meteorological forecast of the impending danger is available, IMMEDIATE, RELIABLE AND FIRM actions should be taken. During and after, planned actions/help in and from all should be switched on with electrifying speed to reduce human/animal sufferings and other life and property/ environment losses to the minimum if not completely eliminated.

This was not followed in India (Orissa's 29 Oct. 1999 super cyclone, the worst in the last century) unfortunately due to negligence, corruption, lack of coordination, bureaucracy and red tapism at all levels – pre, during and post disaster. The result was, more than 10,000 human deaths, thousands of cattle losses, crores of rupees worth of property/environment losses and unparalleled human misery. Months after the hurricane, dead bodies and carcasses littered all around, people were not able to reach food/shelter and nothing seemed to move in any direction by way of help. Humanity had stopped.

Israel is an example in contrast. It had already been bracing for a violent snow storm sweeping much of the country during last week of January 2000, with weather forecasters predicting it could be the worst in eight years. They say upto 30cm of snow had fallen, where minimum temperatures were – 2°C. At least 200 emergency centers had been set up across the country where Israelis could obtain supplies such as beds and medicines, while police and civil volunteers were out on patrol round the clock.

Unexpected low temperature and snowfall had killed 7 U.S. astronauts during nineteen eighties indicating worst in US space history. The rocket carrying them was to be launched but could not make it because it had snowed whole night and temperature fallen to 2°C. Usually there used to be no snowfall and temperature no less than 4°C on the day of the launch. The bottom of the rocket had, therefore, frozen and fuel leaked causing it to explode in flight. Enquiry had been set up and with the help of recovered cameras and material it was proved beyond doubt that climate change was mostly responsible for the ghastly tragedy.

Even now, Jan. 2000 started with unusually frigid weather in Washington (USA) and people had to suffer it out with winter storm without alternatives.

In various parts of Nepal, drought (September – October 1999) had damaged paddy crop upto 75% and wheat crop 55% before paddy. There was shortage of food grain, the people might have to leave their homes and go out to earn their living due to two successive crop failures. On the contrary, the incessant rainfall in Parsa had ruined the rice production equivalent to Rs. 9.03 million in the current year according to reports from Agricultural Development Office Parsa (ADOP).

In October 1999, a small hole had been detected in the ozone (O_3) layer above the Mountain Lake of Titicaca, which straddles Bolivia and Peru. The phenomenon is climate dependent and possibly caused by unusually strong mountain winds. It is producing a larger amount of ultraviolet rays in the area and might become dangerous in the near future.

Some of the countries are sensing hazards and are coming together to think about it and do some thing about it. A $45 million plan for storm surge disaster reduction in the northern part of the Indian Ocean has been finalized in 1999 by the countries of the region. They have also set themselves pre-project targets. The countries are India, Bangladesh, Iran, Maldives, Mauritius, Myanmar, Pakistan and Sri Lanka, which have witnessed some of the world's worst natural disasters. An action plan was being prepared to develop infrastructure for effective and timely storm surge forecasts, warnings and management.

A storm surge is defined as "abnormal rise of sea level associated with the movement of tropical cyclones". Experts say the devastation caused by a storm surge can be mitigated substantially if the height and time of peak water level along the coast and the area likely to be inundated can be reliably forecast.

A complete awareness of the natural disaster problems and a sensible and planned approach by the people and the countries would control the disastrous effects. It is the urgency and top priority now before it is too late.

CONCLUSIONS

1. If not impossibility even difficulty develops into disaster and disaster is difficult to deal with.

2. Timely treatment – preventive, curative and maintaining status quo perhaps could help.

3. Climate change crisis is every nation's concern.

4. Five GHG (green house gases) emissions viz CO_2, CO, CH_4 (methane), N_2O and NO_x are the most damaging and responsible for vicious circle of climate change.

5. The modern living conditions and extreme demands and necessities have aggravated the balance of ecology resulting in increase in severity and frequency of natural disasters.

6. Natural disasters know no political boundaries and hence all countries are vulnerable because of one or the other.

7. 'Adversity never comes alone' is true with natural disasters. Recently (29 Oct. 1999) in Orissa (India), the supercyclone (Century's worst) was accompanied by excessive rains, sea water rise and flooding every where.

8. GHG emissions are higher as industrialization proceeds further and it is unfortunate that under industrialized countries do suffer due to changed climate irrespective of their own low or negligible GHG emissions.

9. Climate is changing, why aren't we ? We must show our anxiety through any/all possible ways to reduce emissions of all kinds (GHG, CFC etc.) on a global scale.

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"Choose a job you love, and you will never have to work a day in your life."
– Confucius

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Energy from Municipal Solid Waste

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ABSTRACT

With increased urbanization and the 'throw-away' culture being rampant, the problem of solid waste management has increased manifold. On the other hand, resources are depleting at a fast rate, hampering the sustainable development. Also, the energy requirements of the world have increased enormously with the depletion of fossil fuel resources. In such circumstances, the energy recovery from the solid waste may be the best answer to the existing problems, and also environmentally and economically acceptable to developing countries. Various options available to utilize the organic contents of municipal solid waste for energy recovery are discussed herein.

INTRODUCTION

Over the long expanse of man's history and prehistory, the principal source of readily available and utilizable energy was the renewable resource-wood. Energy availability has been probably the most important factor in limiting population increase.

It appears inescapable that while the world reserves of fossil fuel are still large, we have reached such high levels and growth rates in energy use that continuation of the present trend threatens to exhaust our resources within a comparatively short time.

Recycling of metals, glass, paper etc. and the efficient utilization of carbonaceous waste to produce fuels represent important and technically feasible methods of conserving energy. Such improvements may not, in themselves, offer a total solution to our energy problems, but they can make significant and economic contribution. In the case of waste utilization, environmental problems are, in many cases, simultaneously resolved.

The availability of fossil fuel has adversely affected the lives of all of us, and there is no reason to believe that situation will get better for the future generations. Indeed, for the finite natural resources that continue to be consumed at high rates, such as natural gas, oil and coal, the problem cannot be solved over the long term simply by discovering new reserves; depletion will ultimately take its toll.

The shortage of fossil fuel is only one of the reasons why non-fossil carbon to energy processes are being developed. Pollution problems caused by the need to dispose waste in an environmentally acceptable manner have demanded improved disposal methods.

The shortage and high cost of mineral supplies have also prompted the developments of recovery processes,

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specially using urban refuse, so that valuable metals and other energy intensive products such as paper and glass can be recycled back into the economy. The production of synthetic fuel from waste offers the opportunity to combine improved waste disposal and economical energy recovery technologies into one processing system, in a more economical manner so that the cost of waste disposal is reduced. The purpose of this paper is to summarize the important processes for the recovery of energy from the municipal solid waste and to review the state of the art.

The municipal solid waste from household, commercial and some industrial sources contains, as a major portion, the combustible material (paper, cardboard, plastics, rags, wood, grass, leaves etc.) and as a minor portion, glass, metals and other non-combustible materials. The combustible materials can be processed to provide a new source of fuel and the non-combustible material can be processed to separate and prepare the metals and glass in a form and to a specification for reuse. Both the use of new fuels from the municipal waste and the use of recovered material conserve energy.

METHODS

There are six general methods of converting municipal solid waste to energy:

(i) Use as a supplementary solid fuel in either suspension or stoker fired boilers,

(ii) Burning the "as received" material in water wall incinerators,

(iii) Gasification by pyrolysis,

(iv) Conversion to oil by pyrolysis,

(v) Biological conversion to methane

(vi) Wet oxidation

When municipal solid waste is processed to produce a solid, liquid or gaseous fuel, the heat of combustion of the product fuel is always greater than that of the input waste. The upgrading of fuel quality is one of the major reasons for processing the raw municipal solid waste.

Energy conservation through resource recovery of municipal solid waste can be realized through :

(a) the utilization of the organic fractions as a fuel or as a feed stock for conversion to fuel, and

(b) the utilization of recovered materials (metals and glass) in the manufacture of "new materials" with the consequent savings in the energy during processing.

SUPPLEMENTARY SOLID FUEL

Solid waste fuel produced by physical processing started in 1970. Such a fuel is termed RDF (Refuse Derived Fuel) or WDF (Waste Derived Fuel). In most cases, RDF is used as a supplementary fuel to replace coal in conventional, industrial or power station boilers. An attractive use of RDF as a supplementary fuel in a cement kiln is a positive advantage as it forms a part of the final product. The methods used for separation of municipal solid waste into inorganic and organic fraction for the preparation of RDF, are:

(i) Wet pulverization process,

(ii) Wet pulping, and

(iii) Dry separation

The simplest process for production of RDF is dry separation. It involves solids pulverization of the waste in a hammer mill and the separation of the ferrous metal by magnetic extraction. The product is screened and the oversize material is pulverized again to give finer particles. The product is then upgraded before being used as a fuel. The methods of upgrading RDF are:

(a) Secondary shredding to a size 15 mm - 30 mm for suspension firing in boilers-known as Fluff-RDF
(b) Boiling of RDF to avoid decompositioning of organic fraction
(c) Fuel pellets or briquettes
(d) Powder RDF with particle size less than 1 mm. It is claimed to be both stable in storage and suitable for co-firing with heavy fuel oil.

BURNING THE "AS RECEIVED" MATERIAL IN WATER WALL INCINERATORS

Heat contained in the gases produced from the incineration of the solid waste "as received" can be recovered by conversion to steam. The low level heat remaining in the gases after heat recovery can also be used to preheat the combustion air, boiler makeup water, or solid waste fuel.

In water wall incinerators, the internal walls of the combustion chamber are lined with boiler tubes that are arranged vertically and welded together in continuous sections. When water walls are used in place of refractory materials, they are not only useful for the recovery of steam, but also extremely effective in controlling furnace temperature without introducing excess air.

The steam generated from the municipal solid waste "as received" in water wall incinerators is used to run the steam turbines, which rotates the generators to produce electricity. With mass fired units having the "as received" municipal solid waste as fuel, auxiliary fuels may be required.

GASIFICATION BY PYROLYSIS

Gasification is sometimes used to describe the reaction of organic compounds with less oxygen or air that would be required for complete combustion, when some pyrolysis also occurs. Waste as such can also be converted into Synthetic Natural Gas (SNG) by pyrolysis. The process consists of thermal decomposition of the shredded municipal solid waste at low pressure in the range of 900°-1700°F range. However, the initial product gas is a low calorific value gas that contains low concentration of methane and higher concentration of CO, CO_2 and H_2. The gas composition and yield depends upon the process conditions. Optimum yield of CO, H_2 and CH_4 occurs at about 1000°C and its calorific value varies between 4 and 20 MJ/m^3 for SNG depending upon the extent of product dilution with combustion gas or with nitrogen with circulation air.

For production of pipe gas by pyrolysis, the SNG is first adjusted in composition by shifting the molar ratio of hydrogen to carbon monoxide in a shift converter to about 3:1, which corresponds to the stoichiometric ratio needed to convert CO to methane in the methanator. The gas is then scrubbed to remove CO and the resulting gas, which contains CO, and hydrogen is methanated to yield pipe gas.

In the hydrogasification process, part of the feed is first converted to hydrogen by partial oxidation or steamed reforming followed by shifting to increase the hydrogen content as high as possible. The hydrogen rich gas is then reacted with remaining feed at 500°-1500°F and 500-2500 psi to be hydrogenated and yield a product gas having high ethane content. Shifting, scrubbing and methanating as in the pyrolytic process then upgrade the gas.

CONVERSION TO OIL BY PYROLYSIS

The production of liquid fuels or synthetic crudes from municipal solid waste is direct hydrogenation. The process is similar to hydrogasification except that the liquefaction process is conducted under less rigorous condition so that all C-C bonds are not broken and high yields of intermediate liquid product are formed.

The municipal solid waste can also be converted to liquid fuels by first converting the feed to synthetic gas by pyrolysis. This synthetic gas can then be converted to liquid hydrocarbons by Fischer Tropsch chemistry, in which, in the presence of certain type of catalyst, carbon monoxide can be hydrogenated to afford a complex mixture of aliphatic hydrocarbons similar to high paraffin crude as shown below:

$$NCO + (2n + 1) H_2 \text{ --------- } C_nH_{2n+2} + nH_2O$$

$$NCO + 2n\ H_2 \text{ --------------- } C_nH_{2n} + nH_2O$$

The process was used in 1936 in Germany with coal derived synthesis gas. Hydrogen was added to this mixture to increase the molar ratio of hydrogen to carbon monoxide. The mixture was then treated in an iron oxide catalyst to remove the sulfur and passed over cobalt or nickel catalyst at about 400°F.

BIOLOGICAL CONVERSION TO METHANE

Digestion is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressure and at temperature of 95°-105°F. The organic fraction is separated from the municipal solid waste and the particle size is reduced. This is made in the form of a water slurry and the anaerobic digestion leads to an intermediate calorific value gas, that is essentially a two component gas containing methane and CO_2. This product is easily upgraded to pipeline gas (SNG) by removal of CO_2 in conventional amine scrubber or by other methods.

WET OXIDATION

Although this method has been used for sewage, sludge, it is now being pioneered for solid waste. It comprises of breaking down of the organic fraction of the municipal solid waste with atmospheric oxygen at high temperature (300°C) and high pressure (1500 psi).

THE ENERGY RECOVERY EFFICIENCY

The various systems of energy recovery from municipal solid waste have varying efficiencies depending upon the characteristics of the waste, the process adopted and the energy utilization. Table 1 gives the energy recovery of the various systems:

Table 1. Energy Recovery Efficiencies

System	% efficiency
Water wall incinerator	57-67
Solid RDF	66-70
Pyrolysis to oil	35-40
Pyrolysis to gas	45-65
Anaerobic digestion to Ch_4	25-42

From the above discussion, it is clear that there is a great potential for energy recovery from municipal solid waste and if the above discussed procedures are put into practice, several million liters of petrol and coal can be saved. This will not only solve the problem of energy requirement but will also be able to save many environmental problems connected with municipal solid waste disposal.

Major "waste-as-fuel" technologies are being pursued to determine their environmental and energy benefits, to develop technologies to control undesirable environmental impacts.

CONCLUSIONS

The environmental benefits to be derived from the use of "waste as fuel" include:

(i) Lessening of the potential for land and water potential from landfill operations to energy/resource recovery operations i.e. less pollution associated with landfills.

(ii) Minimizing the amount of the air pollution that is otherwise inherent with the solid waste disposal options of uncontrolled, non-heart-recovering incineration i.e. less pollution associated with incinerators.

(iii) Reducing the overall pollution load by replacing primary fossil fuel with fuel derived from waste whose disposal otherwise represents an environmental problem i.e. less overall pollution conservation of primary fuels.

Certainly, one of the best municipal solid waste disposal options available (potentially the best environmentally and economically) is to treat the waste in such a fashion that its energy and material resource values are recovered. The developing countries can opt for these processes with the following conditions :

(i) To assure that environmentally acceptable process and control technology is available for tapping waste as a potential resource to help meet their energy requirements.

(ii) To allow the attainment of a more cost-effective system of solid waste management through resource recovery.

(iii) To achieve an incremental reduction of pollutant generation and energy consumption from the traditional practices of using virgin resources for fuels and materials production through the substitution of waste-derived fuels and the recycling of resources recovered from waste stream.

If these objectives could be achieved sufficiently well, to spur widespread implementation of the technologies involved, not only would the mounting solid waste disposal problem be alleviated but also part of the nation's energy conservation goal (of saving prime conventional fuels) would be met.

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Is Our Technical Education Socially Relevant ?

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ABSTRACT

Technical education, as it is practiced today, has failed to inculcate in our students an appreciation for ethical, moral and social issues. The paper highlights certain corrective measures that can help remedy this situation. The none-too-bright image of engineers in the eyes of the public will also receive a boost from adopting these methods.

INTRODUCTION

The caption of this paper is in the form of a rhetorical question. Most rhetorical questions have an implicit answer. The answer in this case is 'no', not if the present day technical education curriculum and teaching methods are any indication.

The author's association of over 36 years with the University of Roorkee, one of the premier technical centres of learning in India, gave him an opportunity to study first hand the strengths and weaknesses of the Roorkee pattern. When the Roorkee system was compared with what prevails in most other technical institutions, certain ideas got crystallized and it was possible to come up with some definitive conclusions. It is proposed to dwell upon some of those ideas in this paper. The pattern of technical education in Nepal is not much different from what exists in India and therefore, what is true for those colleges in India, will, in most part, be true for those in Nepal too.

OBJECTIVE OF A 'TRUE' TECHNICAL EDUCATION

The objectives of a good technical education can be identified as follows:

1. To enable the alumnus to enter into professional practice, with a capability for early productivity and potential for continuing development
2. To develop in him/her appreciation for ethical, moral, social and humanistic implications of engineering projects.
3. To develop the skills required to effectively communicate decisions and ideas to opinion makers and the public.
4. To prepare a solid base for graduate study and research.

While objectives at 1 and 4 can be achieved by a suitable structuring of courses, inculcation of a humanistic approach and the art of communication skills can be nurtured only by conscious efforts of teachers and administrators of technical education. These aspects are discussed in some detail in the following paragraphs.

THE SOCIAL ISSUES

Professional ethics, moral issues, aspects of safety are often marginalized in the present day technical education scheme. This is unfortunate. Real engineering does not merely consist of arriving at 'cut and dried' solutions by carrying out a purely technical analysis using available inputs. What we do

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must not only make technical sense, but at the same time be ethical in practice, morally right and should contribute towards the larger good of the society. What may be perfect engineering in theory, may, in fact, be indefensible in practice. But still engineers often stubbornly and self-righteously try and justify their own solutions, ignoring questions of morals and ethics. They work in splendid isolation. Social consciousness is certainly not the forte of most engineers. The social implications of engineering projects are often not factored at all in project reports. Let me cite an example. The furore about the Sardar Sarovar-Narmada Project and the Tehri project could perhaps have been contained if the problem of rehabilitation of the dam-displacees had been carefully sorted out during the initial stage itself. Again, sometimes, a relatively inferior site for a project purely from a technical point of view, may have to be preferred to a better one, if only to preclude social conflict. But engineers somehow seem unable to make this kind of social adjustment.

How do we then inculcate social values in professional training ? Including formal courses like professional issues and ethics can be somewhat limited in scope. Giving a more liberal education to technical students is a more effective option. Courses in Humanities and Social Sciences have often been downgraded in an effort to push in as many technical courses as possible. This is a shortsighted approach. Our curriculum must be broad-based, with at least 12-15% weightage being earmarked for H&SS courses. This will surely broaden the horizon of impressionable minds.

Eminent public persons must be invited to campuses to speak on social issues. Seminars, panel discussions etc. must be a regular feature of colleges. Students must be provided with forums for debates, group discussions and opportunities to come into contact with the public. If students are encouraged to take part in activities like Shramdan, National Service Scheme (NSS), they would imbibe the precept of the dignity of labour. All these, would help engineers eschew the ivory-tower attitude.

Roorkee University has been fairly successful in providing opportunities for the students to develop a well-rounded personality through its well established extracurricular activities, but when it comes to framing curriculum, it has shown too much of rigidity, with far too many engineering core courses and too little of the liberal arts.

COMMUNICATION SKILLS - THE BUGBEAR OF ENGINEERS

Engineers have often been accused, quite justifiably, in my opinion, of being poor communicators. This has often resulted in a poor appreciation among the public of even excellent technical projects. On the other hand, technocrats say that bureaucrats often get their way even in technical matters where they are supposed to be far less knowledgeable. In recent years, the NGOs and the self-styled environmentalists have also joined issue with engineers and have succeeded in stalling many important engineering projects by propagating technical untruths. Instead of blaming others for this state of affairs, engineering administrators must look inwards and address this question dispassionately to remedy the situation.

In the author's opinion, firstly, there is a need to strengthen formal courses on communication skills in our technical education curriculum instead of trying to downsize them, which is what most curriculum development cells are doing.

Group discussion classes must be incorporated in the technical curriculum. Debating societies and student professional societies need to be strengthened. Writing skills can be honed by incorporating them into laboratory reports and perhaps into a few suitable engineering courses too.

To brighten the perception of engineering in the eyes of the public, engineering education needs some "drumbeating". Production of audiovisual programs on attention-catching engineering aspects, highlighting spectacular achievements of engineers through the medium of TV, publishing semi-technical articles on engineering in magazines popular among the youth, publishing innovative applications such as designing for earthquake resistance, mass housing etc. can improve the image of the profession, which is suffering through a lack of communication.

To illustrate the damage that negative publicity can cause, one can cite the example of pseudo-specialists propagating the myth that high dams are unsound and their height can be brought down with little harm. Now, anyone with a rudimentary knowledge of engineering can see that most of the storage capacity in a dam is generated at higher elevations and there is therefore an optimal height of a dam where the benefits are the maximum. Reducing the height will only result in a high cost-benefit ratio. Similarly, run-of-the-river dams are routinely trotted out as an alternative to high dams. Engineers have failed to counter this kind of ill-informed propaganda because of their inability to get their ideas across to opinion makers and the public. Worse, they seem to think that it is not even necessary to do this. All the while, it is the profession on the whole which suffers.

It must be said that in spite of some efforts in recent years to overcome the deficiency of communication skills among students of Roorkee University, the situation is not yet satisfactory, by any standard. Too much of engineering bias with too little attention to speaking and writing skills have together contributed to this state of affairs.

CONCLUSIONS

The present model of technical education obtaining in a majority of technical institutions has failed to develop in our students an appreciation for ethical, moral and social issues. A more liberal education, coupled with opportunities to develop a well-rounded personality, would be helpful.

Technocrats suffer from an image problem. There is a need to strengthen the communication skills within our technical curriculum and also through promotion of extracurricular activities. Some amount of 'drumbeating' is necessary.

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