APPLICATIONS OF HYDROLOGY TO IRRIGATION

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1. Introduction

Water is limited as to quantity, time and areal distribution. It is not always available in the amounts, at the time or location where needed for most advantageous use. However, unlike other natural resources, water is a renewable resource such that water used today will be replenished at some time in the future.

Water is essential in various areas of water resource development such as domestic and industrial water supply, irrigation, hydro-electric power, navigation, flood control, drainage and water shed management which includes soil erosion control and torrent control.

Agriculture in the Philippines depends much on water to sustain crop production. The water requirements of crops can be obtained from rainfall, surface water or groundwater. Where there is no rainfall or where it is not sufficient at the time it is needed, irrigation is resorted to by the application of water from streams, rivers, lakes and groundwater aquifers.

2. Hydrology and the Hydrologic Cycle

An understanding of hydrology which deals with the occurrence, circulation and distribution of water including its physical and chemical properties and its reaction with the environment is essential to the development of water as a natural resource.

The concept of the hydrologic cycle is the key to this understanding. Water can occur above the ground as atmospheric water, on the ground as surface water and below the ground surface as groundwater.

As shown in Fig. 1, the hydrologic cycle can be traced starting with water evaporating from bodies of water like streams, lakes and oceans and from the land coming from soil moisture evaporation and plant transpiration. The resulting water vapor is transported by moving air masses which under favorable conditions form into clouds and may condense further to result in pre-

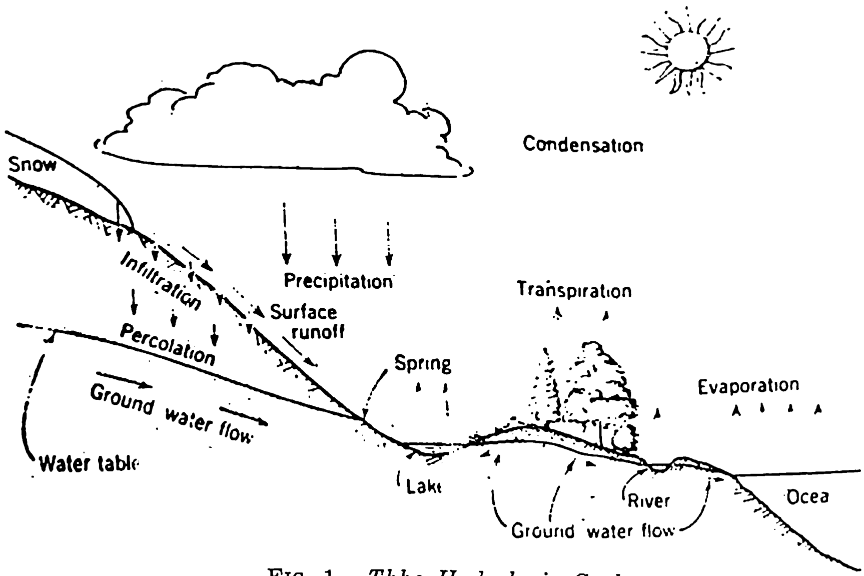


FIG. 1. *Thhe Hydrologic Cycle.*

cipitation in the form of rain, snow, hail or sleet. The usual form of precipitation in the Philippines is rain.

Precipitation may fall on bodies of water or on land. Part of the precipitation that falls on land infiltrates through the soil to replenish the soil moisture content needed by plants or goes down farther and percolates to replenish groundwater aquifers.

The portion of precipitation remaining on the ground surface either evaporates back to the atmosphere or flows to bodies of water as surface runoff. Under the influence of gravity, both both surface streamflow and groundwater, eventually discharge into the oceans as they move toward lower elevations.

The different routes that water may take in going through the cycle explain why there are differences in the occurrence and distribution of water as to time and location.

In the study of the availability of water, the four basic phases of interest to the hydrologist as can be seen in the hydrologic cycle are precipitation, evaporation and transpiration, surface streamflow and groundwater.

3. Water Need and Water Availability in Irrigation

Irrigation water is defined as the portion of the total water required by a crop to produce an optimum yield that is not directly supplied by rainfall. It can be obtained from surface water or groundwater sources or both.

The amount of water to be applied and the frequency of application of irrigation depend on soil properties, weather conditions and the particular crop to be irrigated.

The irrigation diversion requirement is the amount of water diverted from the source to compensate for the rest of the total water required by a crop not provided by rainfall. This amount will take care of evapotranspiration, percolation, farm waste, farm ditch loss and conveyance loss in the main canal and lateral.

Evapotranspiration or consumptive use includes the sum of the volumes of water used by vegetative growth in the area and that evaporated from adjacent soil. Farm waste include seepage, percolation and leakage in paddy dikes as well as over application of irrigation water and drainage. Farm ditch loss and conveyance losses are water lost due to seepage, percolation and leakage in the wetted perimeter of ditches and canals conveying water to the farms.

To the hydrologist, once the irrigation diversion requirement is determined, it is now his job to determine whether water is available from nearby sources at the time when it is needed.

To be able to evaluate the availability of water in the area, hydrological and meteorological data are required and these includes precipitation, evaporation, river stage, river discharge, groundwater, sediment and water quality.

Several government agencies are involved in data collection. PAGASA collects meteorological data such as rainfall, temperature, relative humidity, wind and solar radiation. NIA, BPW and NPC gather data on evapotranspiration, streamflow, sediments, groundwater and water quality.

The assessment of water availability require some of these data to be obtained from the source of water at the point of diversion or from nearby areas.

4. The Collection of Hydrological Data

a) *Measurement of Rainfall*

Rainfall data is normally expressed in depth (mm, cm, in) or in terms of intensity (mm/hr, cm/hr, in/hr). For irrigation requirements, daily rainfall data expressed in depth mportant. From the analysis of these data, precipitation during crop season, annual variations and minimum precipitation can be determined.

Rainfall is measured either with standard non-recording rain gages or with automatic recording rain gages. Non-recording rain gages are read twice a day and values given as rainfall depths. Recording rain gages give continuous readings and can give information on rainfall intensity, duration and the start and end of rain as well as depth.

b) *Measurement of Evaporation and Evapotranspiration*

Evaporation data is also expressed in depth (mm, cm, in) and measured daily with the use of evaporation pans. The data pertains to evaporation from a free water surface and is important in the study of reservoir sites.

More important for irrigation is the measurement of evapotranspiration. Actual measurements of evapotransipration are made in soil containers known as lysimeters. However, reliable observations are seldom attained since it is virtually impossible to attain soil moisture and vegetal cover conditions that will be similar to actual field condition.

One common method of determining evapotranspiration is by relating it to the so called potential evapotranspiration using the Penman equation based on meteorological factors like temperature, relative humidity, wind and solar radiation. This method will therefore require the measurement of these factors.

c) *Measurement of River Stage*

River stage is the elevation of the water surface of the stream relative to a given datum. Stage readings are given in terms of elevation such as meters or feet above the datum.

Stage is easier to measure than discharge and together with an established relationship between stage and discharge at a particular section of a stream where measurements are taken, it would then be sufficient to get the daily stage reading and the daily discharge can be determined.

The measurement of river stage is made with a staff gage or an automatic water stage recorded. The former is normally read twice a day while the latter gives a continuous record of water level fluctuations.

d) *Measurement of Discharge*

Discharge or flow is the volume of water that passes a section of a river or channel per unit time and it is normally expressed in cubic meters per second (CMS) or in liters per second (lps).

A discharge measurement requires the measurement of sufficient point velocities across a given cross-section to permit computation of an average velocity in the stream. Cross-sectional area of flow multiplied by average velocity gives the total discharge. Velocity measurements are usually made with current meters which have vanes or propellers that rotate with flow around them.

Unlike stage observations, discharge measurements are not normally done on a daily basis. These are done periodically and with simultaneous stage observations to provide data of paired observations for a calibration or rating curve that gives the stage-discharge relationship.

Other methods of discharge measurements are made with the use of weirs and flumes. Staff gage readings are also directly converted to discharge.

e) *Collection of Groundwater Data*

Groundwater information needed for the assessment of the availability of water include groundwater storage and yield and groundwater levels.

The appraisal of available groundwater is much more complicated than that of surface water. Groundwater aquifers can be treated as surface water reservoirs whose storage is determined by the rate of inflow or outflow.

The groundwater available is limited by the rate of recharge in the aquifer. Where groundwater is drawn from wells, the rate of groundwater supply may be determined by observing the change of groundwater level.

Measurements are usually taken at a number of wells and a series of contour maps of water level at successive dates are constructed from which it is possible to compute the volume of water bearing material that become saturated or drained for a given period.

In the case of a pumping test, if water levels in wells become stationary during a considerable period of pumping, it may be concluded that during the period the rate of withdrawal is equal to the rate of recharge. Pumping of water at a rate greater than the rate of recharge may result in an exhausted storage after continuous pumping.

Water levels are measured with automatic water level recorders similar to the stage recorder or with the use of steel or plastic measuring tapes weighted at one end which are lowered through the observation wells.

f) *Measurement of Sediment Transport*

Sediment carried by flow through streams are composed of smaller suspended sediments and the larger bedload sediments. Measurement of sediment loads is important since sediments can reduce the storage capacity of reservoirs and it can present operational and maintenance problems in irrigation works such as sitting in canals and ditches.

Suspended sediment samples are obtained with samplers that a normally wide necked bottles that allow water and Sediment discharge is normally expressed in terms of weight or volume of sediment per unit time. Sampling frequency should be such that it would represent sediment loads at all stages of streamflow with particular attention to periods of flood stages when the major part of the total annual sediment load may be transported.

g) *Water Quality Determination*

The quality of irrigation water will affect plant growth. Irrigation water must not contain objectionable salts, solids and other substances, dissolved and suspended beyond certain limits.

Of particular importance is the determination of the presence of sodium and chloride salts and the concentration of boron which all affect plant growth.

Irrigation water is recommended to be chemically analyzed at least once a year to be able to plan remedial measures in case of undesirable water quality.

5. Compilation and Analysis of Hydrological Data

Records of measurements of hydrological data such as precipitation, stage, discharge, sediment flow and others taken at various observation stations are compiled and analyzed for planning.

One analysis that is important in determining the availability of water from a river is the frequency or probability analysis of streamflow.

In most instances, the length of record of streamflow data in a station is short. The record of observations is just a small sample of the total population of streamflow values that have occurred and if the sample is too small, the reliability of the the derived probabilities may be questionable.

Probability analysis will determine the probability p(x) of a variable X like a streamflow value being equaled or exceeded in a given period like one year. Sometimes, instead of the probability p(x), return period or recurrence interval T_r is used where

$$p(x) = \frac{1}{T_r} \qquad \text{(Eq. 1)}$$

It is the average period within which a given streamflow value x will be equaled or exceeded.

For a short series or a small, sample, the probability p(x) is obtained using one of the formulas for plotting position p like Weibull's formula which is given as

$$p = \frac{m}{n + 1} \qquad \text{(Eq. 2)}$$

where n is the sample size or number of streamflow data, m is the rank of the streamflow value x with all the values arranged in decreasing order of magnitude such that the largest value of x has m = 1 and the smallest with m = n.

Table 1 shows the values of maximum daily discharges in m^3/sec of River Kymijoki, Finland from 1922 — 1964 already arranged in decreasing order of magnitude and with the corresponding values of the plotting positions in percent using Weibull's formula (Eq. 2).

TABLE 1. *Probability Analysis of Maximum Daily Discharges of River Kymijoki, Finland (1922-1964)*

Discharge X (m^3/s)	Order m	Plotting Position $p = \frac{m}{n+1} x\ 100$	Discharge X (m^3/s)	Order m	Plotting Position $p = \frac{m}{n+1} x\ 100$
658	1	2.27	445	23	52.27
644	2	4.55	436	24	54.55
616	3	6.82	415	25	56.82
614	4	9.09	412	26	59.09
584	5	11.36	406	27	61.36
574	6	13.64	391	28	63.64
558	7	15.91	388	29	65.91
547	8	18.18	385	30	68.18
546	9	20.45	366	31	70.45
540	10	22.73	357	32	72.73
535	11	25.00	357	33	75.00
527	12	27.27	343	34	77.27
520	13	29.55	342	35	79.55
512	14	31.82	342	36	81.82
508	15	34.09	338	37	84.09
507	16	36.36	290	38	86.36
494	17	38.64	263	39	88.64
474	18	40.91	233	40	90.91
471	19	43.18	183	41	93.18
471	20	45.45	159	42	95.45
463	21	47.73	138	43	97.73
458	22	50.00			

Sample Size	$n = 43$
Mean	$\log X = 2.6177$
Standard Deviation	$S_1 = 0.1551$
Skewness Coefficient	$C_s = 1.3198$

The empirical frequency or probability distribution is shown in Fig. 2 with the probabilities plotted against streamflow values of maximum daily discharges. An empirical distribution line may be fitted to the empirical distribution.

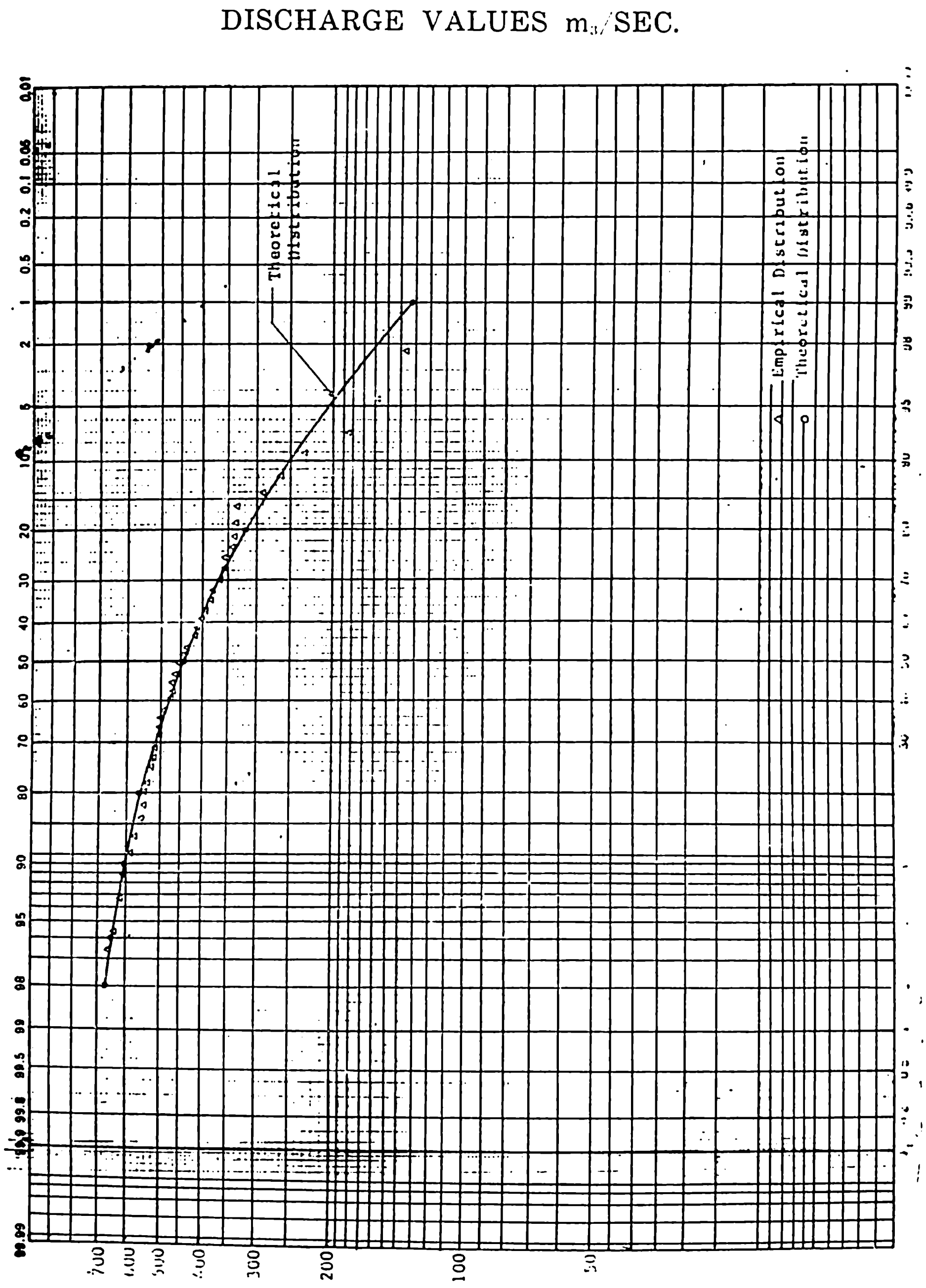
Using the statistical parameters of the data, a theoretical distribution that will closely fit the plotted data can be determined. For flood analysis or extreme value (maximum and minimum flows) analysis, the log-Pearson Type III and the Gumbel distributions are commonly used. The log-Pearson Type III distribution will be used in this paper.

The log-Pearson Type III distribution frequency or probability function is given as

$$\log X = \log X + KS_1 \qquad \text{(Eq. 3)}$$

where the data series of X values is converted to logarithms and the following parameters computed:

FIG. 2. *Plot of the Empirical and Theoretical Distributions for the Maximum Daily Discharges of River Kymijoki (Using the log-Pearson Type III Distribution.)*



Mean : $\log X = \frac{\Sigma \log X}{n}$ (Eq. 4)

Standard Deviation : $S_1 = \frac{\Sigma (\log X - \log X)^2}{n - 1}$ (Eq. 5)

Skewness Coefficient : $C_s = \frac{n \Sigma (\log X - \log X)^3}{(n-1)\ (n-2)\ (S_1)^3}$ (Eq 6)

In Eq. 3 K is a frequency factor and it is a function of skewness and the probability p(x). Table 2 gives the K values for the log-Pearson Type III distribution.

To plot the theoretical distribution line, several points on the line should be determined by using Eq. 3. In the example, the values of the parameters have been computed using Eq. 4, Eq. 5 and Eq. 6

TABLE 3. *Values of X*

Probability in % p(x)	*Frequency factor K*	*Discharge m³/sec X*
1	1.384	679.76
2	1.325	665.59
4	1.240	645.69
10	1.064	606.35
20	0.838	559.34
50	0.210	446.96
80	—0.719	320.76
99	—3.210	131.77

and are given in Table 1. For the value of skewness $C_s = 1.3198$, the different values of K corresponding to the different probabilities in Table 2 can be determined. The values of x corresponding to the probabilities are found by getting the antilog of the right side of Eq. 3. Table 3 below gives the values of x corresponding to different probabilities p(x) given in percent.

The theoretical distribution curve is also plotted in Fig. 2 for comparison with the empirical distribution. The plots were made on a special probability graph paper suited for the log-Pearson Type III distribution.

The purpose of using probability papers is to linearize the frequency distribution so that the theoretical probability curve appears as a straight line and extrapolation for values of x at high or low probabilities is made easier. For most probability distributions, linearization of the probability or frequency distribution on probability papers can be achieved. However, the log-Pearson Type III distribution has not yet been linearized in any known probability paper.

Frequency analysis will give us the probability of getting low flows from streams that we intend to tap for irrigation or other water development projects. It will give us a tool for assessing the availability of water for our needs.

TABLE *K Values for the Log-Pearson Type III Distribution*

	Recurrence interval, years							
Skew coefficient g	1.0101	1.2500	2	5	10	25	50	100
	Percent chance							
	99	80	50	20	10	4	2	1
3.0	–0.667	–0.636	–0.396	0.420	1.180	2.278	3.152	4.051
2.8	–0.714	–0.666	–0.384	0.460	1.210	2.275	3.114	3.973
2.6	0.769	–0.696	–0.368	0.499	1.238	2.267	3.071	3.889
2.4	–0.832	–0.725	–0.351	0.537	1.262	2.256	3.023	3.800
2.2	–0.905	–0.752	–0.330	0.574	1.284	2.240	2.970	3.705
2.0	–0.990	–0.777	–0.307	0.609	1.302	2.219	2.912	3.605
1.8	–1.087	–0.799	–0.282	0.643	1.318	2.193	2.848	3.499
1.6	–1.197	–0.817	–0.254	0.675	1.329	2.163	2.780	3.388
1.4	–1.318	–0.832	–0.225	0.705	1.357	2.128	2.706	3.271
1.2	–1.449	–0.844	–0.195	0.732	1.340	2.087	2.626	3.149
1.0	–1.588	–0.852	–0.164	0.758	1.340	2.043	2.542	3.022
0.8	–1.733	–0.856	–0.132	0.780	1.336	1.993	2.453	2.891
0.6	–1.880	–0.857	–0.099	0.800	1.328	1.939	2.359	2.755
0.4	–2.029	–0.855	–0.066	0.816	1.317	1.880	2.261	2.615
0.2	–2.178	–0.850	–0.033	0.830	1.301	1.813	2.159	2.472
0	–2.326	–0.842	0	0.842	1.282	1.751	2.054	2.326
–0.2	–2.472	–0.830	0.033	0.850	1.258	1.680	1.945	2.178
–0.4	–2.615	–0.816	0.066	0.855	1.231	1.606	1.834	2.029
–0.6	–2.755	–0.800	0.099	0.857	1.200	1.528	1.720	1.880
–0.8	–2.891	–0.780	0.132	0.856	1.166	1.448	1.606	1.733
–1.0	–3.022	–0.758	0.164	0.852	1.128	1.366	1.492	1.588
–1.2	–3.149	–0.732	0.195	0.844	1.086	1.282	1.379	1.449
–1.4	–3.271	–0.705	0.225	0.832	1.041	1.199	1.270	1.318
–1.6	–3.388	–0.675	0.254	0.817	0.994	1.110	1.166	1.197
–1.8	–3.499	–0.643	0.282	0.799	0.945	1.035	1.069	1.087
–2.0	–3.605	–0.609	0.307	0.777	0.045	0.959	0.980	0.990
–2.2	–3.705	–0.574	0.330	0.752	0.844	0.888	0.900	0.905
–2.4	–3.800	–0.537	0.351	0.725	0.795	0.823	0.830	0.832
–2.6	–3.889	–0.499	0.368	0.696	0.747	0.754	0.768	0.769
–2.8	–3.973	–0.460	0.384	0.666	0.702	0.712	0.714	0.714
–3.0	–4.051	–0.420	0.396	0.636	0.660	0.666	0.666	0.667