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METHODS FOR VERIFICATION OF HYDROLOGICAL FORECASTS

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Secretariat of the World Meteorological Organization - Geneva - Switzerland
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EVALUATION REPORT ON METHODS FOR VERIFICATION OF HYDROLOGICAL FORECAST

1. Introduction

In recent years, many verification criteria and methods of hydrological forecasting, including the graphical and numerical, have been used in the project on intercomparison of hydrological models by WMO and some countries. Just as the WMO secretariat pointed out:

1) The set of criteria which is appropriate for one project may not be at all appropriate for another project, even if the two project are quite similar;

2) Many of the criteria proposed in the planning stage of each project proved meaningless or impractical in the execution phase, and had to be revised or eliminated, and when the numerical and graphical results became available it was clear that many criteria provided the same information or no information.

However, it is not necessary for us to develop more verification criteria and methods, but to select a few reasonable verification criteria and methods.

The verification of hydrological forecasting can be divided into three items:

1) Evaluation of accuracy and reliability of each forecasting model and method.
2)Determination of degree of success of an individual operation forecast.
3) Benefit and effectiveness analysis for hydrological forecast

The first item is to evaluate the practicability and reliability of newly developed model and method before it is applied operationally. The second item is to determine the effectiveness of the model and method in actual practice when it is used in conjunction with operational data. The third item is to obtain social and economic benefits through hydrological forecasts. All these are needed to further improve hydrological forecasting system.

This report emphatically estimates the methods of evaluating surface water forecasting. Some methods can be also used for evaluation of ground water or water quality forecasting. But we have not much experience in this respect.

2. Evaluation of accuracy and reliability of each forecasting model and methods

2.1 Principle of verification criteria

The following requirements should be satisfied when forecasting models and methods are evaluated:

1) Objectivity of evaluation criteria
2) Comparability of evaluations.

The latter factor is important if a large number of rivers and elements are covered by hydrological forecast.

The model and method used in forecasting any hydrological phenomena can be regarded as effective and its practical use justified only when the forecast error of a given probability is less than the equal probable deviation of the forecast variable from its mean. If this is not the case, then the model and method has no advantage over the use of hydrologic or climatic long-term means. In other words, a forecasting model and method can be held to be effective , its application justified only if the forecasting errors are substantially less than those which may result from a "naive" forecast.

2.2 Graphical verification

There are many methods of graphical verification. The methods mostly used are as follows:

(a) A linear scale plot of simulated and observed hydrography; (b) A double mass plot of simulated versus observed volumes; (c) A flow duration curve of both simulated and observed daily discharges; (d) A scatter diagram of simulated versus observed monthly maximum discharges; and etc..

Being audio-visual and figurative, graphical verification is easier to be accepted. The method is also advantageous in that it can eliminate the error of observing and simulating the periods of rise and fall , high water and low water, peak and valley, great flood and small flood. It can also be conveniently improved and calibrated. The disadvantages of the method are that it can not make quantitative indication and comparison among the large and small rivers and the rivers in mountainous region and plain region, and it occupy large space in document. Therefore, graphical verification can be taken as a qualitative method, not as the one for objective comparison. In evaluating hydrological forecasting model and method, graphical verification can serve as a reference. The item (a) ——→a linear scale plot of simulated and observed hydrography——is very important.

2.3 Permissible error verification

Some countries use the method of permissible error (δ) verification. Permissible error is a permitting range determined on the basis of the statistic and analysis of the available hydrological error data, according to the hydrological level, data condition and users' requirement, which is taken as verification standard.

Various forecasting factors and forecasting methods have different permissible errors. Permissible errors can be determined as forecasting variables or the square-root deviation (or percentage) of the variable (or amplitude) in leadtime. Permissible errors will appear as linear (non-linear) change with variable or amplitude and we can also determine a value as upper limit or lower limit (the permissible errors set in the hydrological Information and Forecasting Standard in China are shown in ANNEX 1).

After determining permissible error, you can calculate percentage of the numbers equal to or less than permissible error in all the examined numbers (N), which is qualified rate or guaranteed rate. It is considered that it is excellent if the guaranteed rate is more than 85% and forecasts can be issued if guaranteed rate is more than 65%. However, it must be pointed out that the examined number (N) should be more than 25 (N>25), which is more important for the forecasting of flood events and single value factors (flood peak level, discharge, the time of flood peak appearing or flood volume) with corresponding method.

The permissible error verification is advantageous in that it can indicate the relationship between δ and P of forecasting model and method, which is convenient to users. It can determined the quality of single forecasting with and can meet the need of users. The disadvantages are that it is complicated to determine permissible error, as the artificial factor is greater. Objectivity is short and it is inconvenient to calculate in the use of continuous model because it is difficult to compare programs. It is good in forecasting single factor with corresponding forecasting method.

2.4 Numerical verification

There are many numerical verification criteria. The criteria usually used are as follows:

$$CO = \sqrt{\frac{(Y_c - \overline{Y_c})^2}{(Y_o - \overline{Y_o})^2}}$$

$$NTD = 1 \quad \frac{\sum(Y_c - Y_o)^2}{\sum(Y_o - \overline{Y_o})^2}$$

$$NTM = \frac{\sum(Y_o - \overline{Y_o})^2 - \sum(Y_c - Y_o)^2}{\sum(Y_o - \overline{Y_o})^2}$$

$$S = \sqrt{\frac{\sum(Y_c - Y_o)^2 / n}{Y_o}}$$

$$R = \frac{\sum(Y_c - Y_o)}{n\overline{Y_o}}$$

$$A = \frac{\sum |Y_c - Y_o|}{n\bar{Y}_o}$$

In the above equations:

Y_o =observed discharge
Y_c =computed discharge
$\underline{n}$ =total number of observation
$\bar{Y}_o$ =mean observed discharge
$\bar{Y}_c$ =mean computed discharge

The conditions from various countries show no sign of verification criteria suitable to all the forecasting methods and rivers. Comparing with the other criteria, however, NTD criterion is better in terms of objectivity and comparability. The reason is that a forecasting method can be held to be effective and its application justified only if the forecasting errors are substantially less than those which may result from a "naive" forecast. The mean value is perhaps the simplest so-called "naive" forecast. NTD criterion is established in comparison with "naive" forecast. Other methods can be certainly used, such as assuming that the forecast variable will remain the same as observed at the initial moment of the forecast (termed initial forecast), or a trend will continue into the immediate future.

NTD criterion is suitable not only to continuity models and medium- or long term forecasting methods, but also to single factor and short-term forecasting. However, the expression should be changed a little.

$$NTD_{\Delta} = 1 - \frac{\sum(\Delta Y_c - \Delta Y_o)^2}{\sum(\Delta Y_o - \Delta\bar{Y}_o)^2}$$

in which Y and Y indicate change of forecast variable during the forecast leadtime. Y is the mean change.

The NTD and NTD_{Δ} coefficients are fully reliable statistical characteristics of both variable and error in the case of a normal distribution.

According to the analysis by Prof. G. Gavadias:

$$(1-NTD) = \frac{(\bar{Y}_o-\bar{Y}_c)^2}{\sum(Y_o-\bar{Y}_o)^2} + (1-b)^2 \frac{\sum(Y_c-\bar{Y}_c)^2}{\sum(Y_o-\bar{Y}_o)^2} + (1-r^2)$$

(BIAS) (SLOPE) (RESIDUALS)

In which: $b = r\frac{(So)}{(Sc)}$ $So = \sqrt{\frac{\sum(Yo-\bar{Y}o)^2}{n-1}}$ $Sc = \sqrt{\frac{\sum(Yc-\bar{Y}c)^2}{n-1}}$

The error can be divided into three terms by criterion. The three terms represent respectively the contribution of the overall bias ($\bar{Y}o-\bar{Y}c$) of the difference if the slope from unity and of the residuals.

Actually, NTD coefficient is r^2 the square of the correlation coefficient between Yc and Yo under the condition of $\bar{Y}o-\bar{Y}c=0$, for expressing the close extent between Yc and Yo.

Therefore,NTD criterion has been widely used and listed in technical specification and manuals by many countries.

In using NTD, some points should paid attention to as follows:

1) Enough samples should be available(great n)
2)NTD criterion only gives an overall verification. If you want to obtain effectiveness in great flood or low water period, making statistical analysis on the basis of a discharge criterion of a period is necessary.
3) Statistics should be made for various NTD in various leadtime.

The shortcoming of NTD criterion are as follows:

1) In term of comparability, NTD is effective with various methods in the same river but not with the same methods in various river. It is because the NTD values are quite different with the different rivers in size and flood at level. For rivers with flood slowly rising and falling, more effective NTD value can be obtained in terms of inertial forecast.

2) Lacking concept of permissible error and guarantee ratio, there will be no persisted relation with every evaluation of operational forecasting.

2.5 Mean forecast lead time (MFLT) verification

A recently introduced concept permit the expression of the timeliness of forecast and their accuracy as a single numerical score, expressed as units of time, and termed "mean forecast lead time"(MFLT). The score enables the effect of a particular combination of timeliness and accuracy on the recipient of the forecast to be examined. The concept of MFLT gives a measure of forecast effectiveness which is physically meaningful and which is more closely related to economic benefit that are the verification criteria given earlier.

But, the biggest drawback to MFLT, is that it combines forecast lead time with crest hit or miss into one number, a value in hours. It does not have a communicable meaning to anyone not intimately familiar with MFLT. For example, we have a flood and are asked "How did you do?". Answer "Well real good, our MFLT was N hours", or "......not, so good our MFLT was almost zero.". Therefore, it is difficult to use MFLT verification widely.

3. Determination of degree of success of an individual operational forecast

The calculation of errors of each forecast is essential for the accumulation of statistical data and for checking the stability of previous evaluations of the accuracy and effectiveness of a forecast method. This is particularly true when the method is of the type which might be developed from a relatively small amount of hydrological data.

Strictly speaking, statistical estimation of the success of an individual forecast is impossible, since the forecasting method itself only enables us to determine the confidence interval within which the appearance of the variable is expected with a given probability.

In order to show the uses of a direct understanding and overall efficiency of the hydrological forecasting, services can be appraised on the basis of there data. Therefore, it is necessary to evaluate each operational forecasting.

3.1 The method of permissible error

It is convenient to determine the level of single operational forecasting and the concept is clear in the condition of permissible error, there are 4 levels that can be divided as follows:

A. The forecasting error is under 25% of permissible error.
B. the forecasting error is within 25-50% of permissible error.
C. The forecasting error is within 50-100% of permissible error
D. the forecasting error is above permissible error.

3.2 Other methods

When evaluation is made with the standard of graphical and numerical examinations (as NTD), there are no concept of permissible error. So, permissible error can be calculated using standard deviation of the forecast variable (So). The expression is

$$\delta = \pm\ 0.674 So$$

The levels can be divided according to the standard shown in Section 3.1, under the condition of permissible error.

3.3 Categorical, event oriented, flood forecast verification

It is the method offered by the Office of Hydrology, NWS, 1988, which is similar to the permissible error method. It is suggested whereby a river rise is viewed as an event, or series of events, each of which is categorized according to magnitude. The event is classified by stage, on a scale of one to six, ranging from one flood or record major flood. An event may pass through more than one classification before recession takes place. If the event is not correctly predicted, an error , measured in feet, is computed. It is an event error, not a stage or crest error. The site specific flash flood event is similarly analized, but on a scale of one to four. The resulting data obtained over time permit a variety of simple statistics to be computed that should prove highly useful in evaluating flood prediction capability. Also available would be a comprehensive tabulation of forecast and observed lead time for each event, number of rises nationwide in each category, average prediction error by category, and a fair comparison of demonstrated forecast skill (See ANNEX 2).

The merits of this method are as follows:

1) With classification, it is suitable for all the forecasting variables, stations and river basins. So it has comparability.
2) Being clear in concept and direct in perception, it can be easily accepted.
3) The permissible error in forecasting is considered by combining hydrology with meteorology.
4) It is clear and definite in evaluation of every operational forecasting.

The demerits of this method are as follows:

1) It seems complicated because of classifying all station;
2) Now, the precision of hydrological forecasting is much higher than that of weather forecasting. Using this method, the forecasting results are very rough, which can not meet the requirement in policy-making of flood control and operation of water projects. The policy-making of flood control given based on a water level(or discharge), and operation of some water projects needs the forecasting of discharge process.
3) It is difficult to make a comprehensive evaluation of hydrological forecasting model and method with this methods.

4. Benefit and effectiveness analysis for hydrological forecasts

The benefits and effectiveness of hydrological forecasting is very important. For example, flood and ice forecasting is playing important role in avoiding injuries and deaths and ensuring a stable society.

4.2 Economical benefit and effectiveness

The economical benefit and effectiveness of hydrological forecasting can be divided into preventing calamity (flood, ice and drought etc.) and promoting what is beneficial (electricity generation, irrigation and shipping etc.). The benefit of hydrological forecasting in calamity prevention is a part of comprehensive measures (structure and non-structure) benefit. It is difficult to make analysis.

Before making benefit and effectiveness analysis for hydrological forecasts, social investigation should be undertaken. One is to make investigation of economical benefit after the occurrence of flood. The practice shows that obvious economical benefit will be obtained if correct forecasting is made. Another is to investigate the range of the loss avoided in household, trade, industry and agriculture and the range of benefit gained in hydro-electricity generating, irrigation and shipping. It would be best to investigate the benefit obtained in various leadtimes and then make the total benefit and water level probability diagram as well as the various leadtimes and total benefit diagram.

4.3 Benefit cost and cost effectiveness analysis

To establish a new hydrological forecasting system or improve an old one, the analysis of investment and benefit must be made for obtaining the most economical benefit.

5. Conclusion

1) The evaluation of hydrological forecasting should be divided into three parts: A. The evaluation of forecasting method; B. The evaluation of single operational forecasting; and C. The analysis of forecasting benefit. All the three parts can not be neglected.

2) In the evaluation of forecasting method, not only calibration period, but also verification period should be evaluated with the result in verification period as the main base.

3) The linear scale plots of simulated and observed hydrography in the graphical criterion can be taken as one of the audio-visual and important referent criteria.

4) NTD criterion is a better one in all the numerical criteria and can be continuously improved in practice, which is expected to be the general criterion in the world.

5) People usually do no understand the benefit of hydrological forecasting , so that investigation and propaganda should be strengthened. Compilation and publication of examples of hydrological forecasting results should be considered.

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10) Standards for Hydrological Information and Forecasting , Ministry of Water Resources and Electric Power, PRC 1985

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ANNEX 1

Permissible Errors Verification in China

The following regulation should be made for permissible errors because of the difference between forecasting elements and forecasting methods:

1. Forecasting of river stage (discharge): The permissible error of the maximum changing range in predicting period is adopted as mean square deviation δ_{Δ}. When changing range is zero, the permissible error will be $0.3\delta_{\Delta}$. The other permissible errors can be obtained with straight line insert method. For example, when stage permissible error δ_{Δ} > 1.0 m, 1.0 m will be the upper limit; when $0.3\delta_{\Delta}$<0.1m, 0.1m will be the lower limit; when discharge permissible error is less than measuring error , the measuring error will be the lower limit.

20% of observed changing range within predicting period will be taken as permissible error, 5 cm be taken as lower limit of stage and measuring error will be the lower limit of discharge.

The permissible error of the forecasting flood peak time is taken as 30% of duration between forecast based on time and the observed flood peak time with 3 hours as lower limit.

2. Rainfall-runoff forecasting : The permissible error of net rainfall depth is taken as 20% of observed value. The permissible error is more than 20mm with 20 mm as upper limit,

while permissible error is less than 3 mm, with 3 mm as lower limit.

The permissible error of flood peak discharge is 20% with measuring error being taken as the lower limit. The permissible error of flood peak occurrence time is taken 30% of the duration between forecasting based on time and the observed peak time, taking 3 hours or one calculating time interval as lower limit.

3. The forecasting of spring flood and ice information

The permissible errors of the factors in the forecasting of spring flood and ice information are taken as the percent of changing range. If the predicting period is above 10 days, the forecasting factor will be taken as 30% of changing range of observation.

The permissible errors of the predicting period for forecasting factors are as follows:

Predicting period(day)	1-3	4-5	6-9	10-13	14-15
Permissible errors(day)	1	2	3	4	5

4. Forecasting stage of the Typhoon Surge

As for forecasting maximum stage of Typhoon Surge, the permissible errors are taken as 15% of changing range of the observed values in predicting period with 20 cm as lower limit.

5. Forecasting of runoff volume in month and season

As for the forecasting of runoff volume in month and season in arid region, the permissible errors are taken as 20% of the observed values, while permissible errors of monthly runoff in dry season are taken as 30% of the observed values.

6. Criterion or verification according to permissible error standard. Qualification rate must be calculated and forecasting plan be divided into three degrees:

A: qualification rate >85%
B: 85%>qualification rate>70%
C: 70%>qualification rate>60%

All the forecasting plans which reach degree A and B can be used for operation; the plans reach degree C for reference; and the plans under degree C only for estimation.

ANNEX 2

A Categorical, Event Oriented, Flood Forecast Verification in the United States

1) Abstract

In the flood forecast service of NWS in the United States, a system of compiling information over time that permits the agency to judge and track its flood prediction capability has never been established due to complexity of the verification problem. In particular, the historic relevance on observed versus forecast crest difference as the primary means of determining flood forecast accuracy has prevented agreement within the profession as to the best method of compiling verification data.

A categorical event oriented flood forecast system is a different approach in which a river rise is viewed as an event or series of events, each of which is categorized according to magnitude. The event is classified by stage, on a scale of one to six, ranging from one flood to record major flood. An event may pass through more than one classification before recession takes place. If the event is not correctly predicted, an error, measured in feet, is computed. It is an event error, not a stage or crest error. The site-specific flash flood event is similarly analyzed, but on a scale of one to four. The resulting data obtained over time permit a variety of simple statistics to be computed that should prove highly useful in evaluating flood prediction capability. Also available would be a comprehensive tabulation of forecast and observed lead time for each event, number of rises nationwide in each category, average prediction error by category.

2) Verification procedure and examples

By way of definition and rule, illustrated in some example, the flood forecast verification program gets driven this way:

a) A flood is an event classified by stage, with a significance categorized by magnitude of rise, for example:

Table 1 Categorical Flood Event

CAT.	DEGREE	GENERAL DESCRIPTION
1	NO FLOODING	NO FLOOD EXPECTED
2	MINOR FLOODING	NEAR FLOOD STAGE--ONLY MINIMAL DAMAGE EXPECTED
3	MODERATE FLOODING	SECONDARY ROADS BLOCKED--TRANSFER TO HIGHER ELEVATION NECESSARY TO SAVE PROPERTY, SOME EVALUATION MAY BE REQUIRED
4	MAJOR FLOODING	EXTENSIVE INUNDATION AND DAMAGE--,MANY PRIMARY ROADS AND BRIDGES CLOSED--MANY PEOPLE MAY BE EVACUATED
5	NEAR RECORD FLOODING	MAJOR FLOODING WHICH IS EXPECTED TO APPROACH THE RECORD FLOOD

6	RECORD FLOODING	MAJOR FLOODING WHICH IS EXPECTED TO EQUAL OR EXCEED FLOOD OF RECORD

Table 2 Example of Stage Assignment for Flood Categories, the Trinity River at Dallas

Stage (FT)	Flood Event	Flood Category	Stage Range
	No Flood	1	00.0---29.9
30 FS	Minor Flood	2	30.0---31.9
32	Moderate Flood	3	32.0---39.9
40	Major Flood	4	40.0
50	Near Record Flood	4,5	50---52.5
52.6 FOR	Record Major Flood	4.6	52.6

FS---Flood Stage FOR---Flood Of Record

b) A flood forecast event error is the difference between forecast crest and the observed event, whereby the error represents the minimum stage plus or minus, required to change the forecast such that the event would have been correctly predicted.

c) Either forecast river stage or forecast crest is a suitable measure of the degree or magnitude of flooding predicted.

d) A verification event occurs whenever the river rises from one flood category into another. If, during the course of a rise, a river passes through one or more levels of flood for which no forecast was issued, only the highest degree of flood will be subject to verification , whether a final crest prediction is made or not.

e) Only the initial(first) forecast of the category of flood anticipated counts for verification. Subsequent river forecast for stage within this same category are ignored until the river recedes to a lower level, lesser degree (category) of flood.

f) Every forecast that predicts a new (higher) level (category) of flood is verified, even if subsequent forecasts downgrade the earlier prediction and even if the flood occurs earlier or later than predicted.

g) River forecasts that to predict rivers to rise to some range of stage (a bracket) are called bracket forecast, such kind of forecast reflect the uncertainty inherent in river prediction under some circumstance. Typically, the bracket forecast is issued early on in a developing rise, and then narrowed to a specific value during later public updates. In the case of a bracket forecast, the highest or lowest stage values, whichever is appropriate specified by the bracket, will be used to computed flood event error.

h) River forecast that only calls for some degree of flood, but no specific stage or range of stage is mentioned is call non-stage specific categorical forecast. These kind of forecasts will not be verified.

i) Any river rise, regardless of small, that brings river level into a new category of flood, will be verified.

j) A flash flood is a flood in which the inundation follows the observable causative event by less than six hours. By " observable causative event", for example, we distinguish between, say, a dam failure causing flash flood (a less than six hour event) and the copious rain leading to failure, which may occur for many hours prior to failure of the structure. Site-specific flash flood warning will be verified similarly to flood warning for the larger rivers.

k) Credit will be given for site-specific flash flood warning based on area warnings, according to the stipulations outlined herein, if the agency desires so.

l) A river already at the warning flood level (category) when the "forecast" is issued, is a "zero lead time warning", and will be verified as an event with no forecast issued.

m) A verified flood event is one in which there occurs during the forecast period, an observed or estimated stage or crest in the same category of flood as predicted.

n)Categorical forecast lead time for verified events is the difference, in hours, between time of forecast issuance and the time the event occurred.

3) The statistics and verification summaries

The above procedure generates raw data in the following form: (a) A flood—no;yes. (b) Was the flood predicted—no;yes. (c) If no, the stage error for the missed event. (d)If yes, the forecast and observed warning times for the predicted event. (e) The number and kind of flood event for which no forecast was issued. A lot of tabulation and verification scores can be derived from these data that measure service. For example, Table 3.

Table 3. SUMMARY OF REGIONAL AND NATIONAL STATISTICS FOR <u>MAJOR FLOOD</u> (CAT. 4) EVENTS, ONE YEAR. OBSERVED LEAD TIME TOP VALUE: FORECAST LEAD TIME BENEATH.

REGION	NUMBER OF EVENTS	PERCENT FORECAST	PERCENT MISSED	EVENT AVG. STAGE ERROR (FT)	PERCENTAGE DISTRIBUTION LEAD TIME IN HOURS: 0	0<6	>6≤12	>12≤18	>18≤24	>24≤36	>36≤48	AVERAGE (HRS) LEAD TIME
					5	15	21	20	10	15	14	11.6
EAST	285	73	27	3.1	5	12	18	23	16	20	6	17.3
					14	24	20	18	13	9	2	9.1
SOUTH	390	61	39	4.9	14	18	23	25	12	6	2	11.5
					9	8	20	14	33	9	9	18.2
CENTRAL	362	52	48	2.0	9	14	17	20	29	7	4	14.8
					15	11	21	40	8	4	1	13.5
WEST	154	83	17	1.6	15	21	28	33	2	1	0	8.8
					0	2	1	20	17	29	31	24.3
ALASKA	96	81	19	2.7	0	0	2	18	20	24	36	29.4
					8.6	12.0	16.6	22.4	16.2	13.0	11.2	15.3
NATIONAL	1287	70	30	2.9	8.6	13.0	17.6	23.8	15.8	11.6	9.6	16.4

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