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Model Documentation Report: Short-Term Hydroelectric Generation Model

August 1993

**Energy Information Administration
Office of Coal, Nuclear, Electric, and Alternate Fuels
U.S. Department of Energy
Washington, DC 20585**

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Model Documentation Report: Short-Term Hydroelectric Generation Model

Introduction

Purpose of the Report

The purpose of this report is to define the objectives of the Short-Term Hydroelectric Generation Model (STHGM), describe its basic approach, and to provide details on the model structure. This report is intended as a reference document for model analysts, users, and the general public. Documentation of the model is in accordance with the Energy Information Administration's (EIA) legal obligation to provide adequate documentation in support of its models (Public Law 94-385, Section 57.b.2).

Model Summary

The STHGM performs a short-term (18 to 27-month) forecast of hydroelectric generation in the United States using an autoregressive integrated moving average (ARIMA) time series model with precipitation as an explanatory variable. The model results are used as input for the *Short-Term Energy Outlook*.

Model Archival Citation

The STHGM is archived on the Energy Information Administration mainframe system and is available through the sponsoring office. The model contact is:

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Report Organization

The remainder of this report is organized in the following manner: (1) model purpose, (2) model rationale, (3) model structure, (4) properties of the mathematical solution, (5) calibration and sensitivity analysis, (6) documentation of technical detail on the model data and equations, and (7) appendices.

Model Purpose

Model Objectives

The STHGM is used to provide quarterly projections of national hydroelectric generation for the *Short-Term Energy Outlook*. The model uses an ARIMA time series model with explanatory variables, otherwise known as a transfer function model,¹ as the basis for its forecasting. The model is based on 23 years of monthly historic data from 1970

¹George E. Box and Gwilym Jenkins, *Time Series Analysis, Forecasting and Control* (1976).

to 1992. The model also incorporates variations in precipitation as an explanatory variable.

Model Input\Output

The STHGM uses both DOE and non-DOE data input sources. The DOE data are national totals of the plant-level net hydroelectric generation data reported monthly on the Form EIA-759, "Monthly Power Plant Report," and its predecessors. The non-DOE data are monthly precipitation data from the National Climatic Data Center.²

Forecasts of precipitation data are also required for the model, due to the modelling assumption of "normal" precipitation. The 57-year monthly averages from the National Climatic Data Center are used as the forecasted "normal" precipitation.³

The output data is an 18 to 27-month forecast of net hydroelectric generation.

Relationship to Other Models

The STHGM does not directly interface with other EIA models; however, its forecast is utilized as input in the Short-Term Integrated Forecasting System (STIFS). The hydroelectric forecast is independent of other renewable and nuclear generation forecasts, but it does have an impact on the fossil fuel generation forecasts as an input to STIFS.

Model Rationale

The Time Series Approach

Time series models predict future generation as a function of past generation and account for trends and seasonality. No use is made of engineering knowledge or economic concepts in these models. Since a seasonal pattern is observed in historical monthly net hydroelectric generation data and the level of generation is affected by the availability of water, the STHGM is designed as an ARIMA time series model with the addition of one explanatory variable, precipitation.

Assumptions

The STHGM uses an ARIMA time series model with precipitation as an explanatory variable. The model is based on normal ARIMA modelling assumptions. That is, the data are assumed to follow a model which is linear and time invariant with constant coefficients. Fixed monthly values are used to describe seasonality. Precipitation is assumed to be "normal" from the last month of available data forward. A 57-year average for precipitation in the given calendar month is the assumed "normal" precipitation for that month.

Alternative Approaches

The previous approach for forecasting hydroelectric generation used by the Energy Information Administration was to use a purposive sample. For each month during the current water year, which ends September 30, or a nine-month period from presently available data if longer, hydroelectric generation projections were based upon information obtained by phone from 10 utilities/organizations representing eight U.S. geographic regions (Table 1). Generation in each region was projected to change by the same percentage as generation for the sample. That is, estimations for each of the forecast months was determined by calculating a monthly ratio of each utility's projected generation

²1970-1987: National Climatic Data Center, *State, Regional, and National Monthly and Annual Precipitation Weighted by Area for the Contiguous United States January 1931 - December 1987* (Asheville, NC, August 1988), p. 66. 1988-1992: National Climatic Data Center, *Monthly State, Regional and National Heating Degree Days Weighted by Population* (Asheville, NC, March, 1989 through 1993), Table 3.3, "Regional and National Average Precipitation."

³National Climatic Data Center, *State, Regional, and National Monthly and Annual Precipitation Weighted by Area for the Contiguous United States January 1931 - December 1987* (Asheville, NC, August 1988), p. 66.

Table 1. Hydroelectric Generating Regions

Region	State
1	Connecticut, Delaware, District of Columbia, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
2	Alabama, Florida, Georgia, Kentucky, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia, Alaska, Hawaii.
3	California.
4	Arizona, Colorado, Nevada, New Mexico, Utah.
5	Idaho, Oregon, Washington.
6	Arkansas, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Missouri, Ohio, Oklahoma, Texas, Wisconsin.
7	Montana, Wyoming.
8	Nebraska, North Dakota, South Dakota.

to its actual generation in the past year. This ratio was applied to the region's generation for the previous year to arrive at a projected value for the corresponding month of the current year. The regional projections were aggregated to obtain a national projection for generation.

Hydroelectric generation in the succeeding years was assumed to be normal. Normal generation was calculated for conventional and pumped storage units by using capacity information from the Form EIA-860, "Annual Electric Generator Report," and historical monthly capacity factors averaged over ten years.

This methodology included a considerable amount of analyst judgement: the assessment of patterns and other factors, such as precipitation, weather, demand, or market conditions. Another shortcoming of this method was that different methodologies were used by the different sampled organizations.

In the development of the STHGM, the specific form of the model used for forecasting was selected from among reasonable alternatives of the same form including the use of regular and seasonal differencing. Additionally, an alternative to the use of monthly dummies to explain seasonality was considered. First the periodogram of the generation data was examined and the seasonal frequencies having the greatest impact were selected. The seasonal mean was defined to be the sum of estimated coefficients multiplying the sine and cosine functions having these selected periodicities. The monthly dummy variable approach was adopted because it gave smaller root mean square error forecasts in the out of sample forecast evaluations (described in Calibration and Sensitivity Analysis, p. 7).

Another approach that was examined included the effects of trading day variations. The historic hydroelectric generation data were tested for trading day variation using the procedure X11 in SAS. The purpose of this test was to determine if the data needed to be adjusted for trading days, i.e. do hydroelectric facilities generate more on a Monday than on a Sunday. Any month can be looked at as having 28 days plus 0 to 3 extra different days of the week. Depending upon which days are extra, i.e. Monday and Tuesday or Saturday and Sunday, the net hydroelectric generation in a month could be affected. Tests at the 5 percent level indicated some trading day effect with the lowest generation on Sundays and the largest on Mondays and Tuesdays (Table 2). Tests of regional trading day variation using hydroelectric generation data for the ten Census Divisions (Appendix C) indicated that while some trading day effect was noticeable, it was negligible. Therefore, the national data were not adjusted for trading day variation.

Another approach which has not yet been examined is to use knowledge of current precipitation conditions instead of assuming normal precipitation throughout the forecast period. That is, the model could be modified to use average precipitation for low years or high years for sensitivity analysis.

Table 2. National Trading Day Variation Output

C15 FINAL TRADING DAY REGRESSION

	COMBINED WEIGHT	PRIOR WEIGHT	REG. COEFF.	ST.ERR. COMB.WT.	T (1)	T PR.WT.
MONDAY	99.478	*****	99.478	113.47	0.877	*****
TUESDAY	104.71	*****	104.71	111.63	0.938	*****
WEDNESDAY	79.931	*****	79.931	113.42	0.705	*****
THURSDAY	-44.29	*****	-44.29	115.28	-0.384	*****
FRIDAY	-38.61	*****	-38.61	113.89	-0.339	*****
SATURDAY	76.899	*****	76.899	112.77	0.682	*****
SUNDAY	-278.1	*****	-278.1	113.94	-2.441	*****

* COMB. WT. DIFFERS FROM 1 AT 1 PER CENT LEVEL
 ** COMB. WT. DIFFERS FROM PRIOR WT. AT 1 PER CENT LEVEL

SOURCE OF VARIANCE	SUM OF SQUARES	DGRS.OF FREEDOM	MEAN SQUARE	F
REGRESSION	5792155	6	965359.145	2.146
ERROR	116067925	258	449875.677	
TOTAL	121860080	264		

PROBABILITY OF A LARGER F IS .0487498

STD. ERRORS OF TRADING DAY ADJUSTMENT FACTORS

31-DAY-MONTH	337.877
30-DAY-MONTH	357.280
29-DAY-MONTH	391.275
28-DAY-MONTH	0.000

Model Structure

Flow Diagram

The initial step of the STHGM is reading in the historical net hydroelectric generation and precipitation data. The data are divided by the number of days in each month in order to account for the different lengths of the months. Next the first ARIMA procedure is run to estimate coefficients for the monthly dummy variables and the correlated lags of the precipitation data. The generation data are then adjusted using these coefficients to account for seasonality and the effects of precipitation. The ARIMA procedure is then run with the adjusted data which outputs the forecast. The forecast is multiplied by the number of days in each month and readjusted for seasonality and the effects of precipitation (Figure 1).

List of Computations and Equations

The time series models considered for this project come from the ARIMA family of models with explanatory variables. Model identification and estimation were done using PROC ARIMA in SAS version 6.07. In particular the model structure is of the form

$$\Phi(B)(NATIONAL_t - \sum_{k=1}^{12} NUM_{k-1} DUM_{t,k} - v(B)RAINNAT_t) = \Theta(B)a_t \quad (1)$$

where,

NATIONAL_t is the national daily average hydro generation in month t;
DUM_{t,k} is a seasonal dummy variable which is zero unless observation t is in month k, in which case it is one;
RAINNAT_t is the national daily average precipitation in month t;
φ(B) is the autoregressive part of the model (Equation 6);
θ(B) is the moving average part of the model (Equation 7);
v(B) is the transfer function part of the model (Equation 3); and
NUM_{k,1} are the coefficients of the seasonal mean, where k=1 is the coefficient for January.

Specific model structure was selected from this family of models based on standard diagnostics: the autocorrelation function, partial autocorrelation function, and inverse autocorrelation function of both the generation data and the model residuals, significant t-statistics for estimated parameters, the Portmanteau goodness of fit Chi square test for departures from model assumptions, the Akaike Information Criterion (AIC) to select the best from competing models, and comparisons of the model forecasts to actual data otherwise known as out-of-sample testing.⁴

The specific estimated parameters are shown in Table 3.

This model includes two functions which explain the time varying mean of the generation data: the first is the mean due to seasonal variation, the second is the mean due to the impact of precipitation. In particular, the average seasonal effect in month t is given by

$$MEANS_t = \sum_{k=1}^{12} NUM_{k,1} DUM_{t,k} \quad (2)$$

Where NUM_{k,1} is the estimated parameter (Table 3) and DUM_{t,k} is unchanged. The variance of the estimated seasonal mean in a month, VARS_t, is the square of the approximate standard error of the appropriate estimated coefficient (Table 3).

The transfer function part of the model describes the impact of precipitation on hydroelectric generation. This relationship is given formally by

$$MEANR_t = v(B)RAINNAT_t \quad (3)$$

Using the estimated coefficients (Table 3) it is written specifically

$$\begin{aligned} MEANR_t = & 896.22 RAINNAT_t - 834.26 RAINNAT_{t-1} - 526.13 RAINNAT_{t-2} - \\ & 262.03 RAINNAT_{t-8} - 171.29 RAINNAT_{t-9}. \end{aligned} \quad (4)$$

The variance of the estimated mean of the changes in precipitation is given by

$$\begin{aligned} VARR_t = & (140.39 RAINNAT_t)^2 + (145.49 RAINNAT_{t-1})^2 + (139.87 RAINNAT_{t-2})^2 \\ & + (130.23 RAINNAT_{t-8})^2 + (131.45 RAINNAT_{t-9})^2. \end{aligned} \quad (5)$$

where the approximate standard errors of the estimated coefficients come from Table 3.

⁴For more information, see: Sas Institute Inc., *SAS/ETS User's Guide*, Version 6 (Cary, NC, January 1989).

Table 3. ARIMA Output Containing Estimated Dummy Variable and Precipitation Lag Parameters

ARIMA Procedure

Maximum Likelihood Estimation

Parameter	Estimate	Approx. Std Error	T Ratio	Lag	Variable	Shift
MA1,1	-0.29039	0.07168	-4.05	13	NATIONAL	0
MA2,1	-0.13117	0.07594	-1.73	12	NATIONAL	0
AR1,1	0.85116	0.03234	26.32	1	NATIONAL	0
AR1,2	-0.09212	0.04206	-2.19	11	NATIONAL	0
NUM1	896.22200	140.38903	6.38	0	RAINNAT	0
NUM1,1	-834.25619	145.49253	-5.73	1	RAINNAT	0
NUM1,2	-526.13090	139.86515	-3.76	2	RAINNAT	0
NUM1,3	-262.02553	130.23461	-2.01	8	RAINNAT	0
NUM1,4	-171.28814	131.44949	-1.30	9	RAINNAT	0
NUM2	595.29831	35.24633	16.89	0	DUM1	0
NUM3	600.13781	35.31950	16.99	0	DUM2	0
NUM4	605.04081	35.52695	17.03	0	DUM3	0
NUM5	600.80657	36.09334	16.65	0	DUM4	0
NUM6	610.64743	38.26016	15.96	0	DUM5	0
NUM7	589.90960	38.65004	15.26	0	DUM6	0
NUM8	511.49184	39.02628	13.11	0	DUM7	0
NUM9	453.11518	38.12019	11.89	0	DUM8	0
NUM10	404.01621	37.03964	10.91	0	DUM9	0
NUM11	404.01113	35.34626	11.43	0	DUM10	0
NUM12	478.45024	35.54321	13.46	0	DUM11	0
NUM13	560.71792	35.08532	15.98	0	DUM12	0

Variance Estimate = 1688.87656
 Std Error Estimate = 41.0959434
 AIC = 2764.43375
 SBC = 2839.76597
 Number of Residuals = 267

Autocorrelation Check of Residuals

To Lag	Chi Square	DF	Prob	Autocorrelations						
6	4.31	2	0.116	0.029	-0.002	-0.058	0.029	0.060	0.084	
12	7.77	8	0.456	0.030	0.001	-0.066	0.025	-0.078	0.018	
18	14.07	14	0.444	0.018	0.080	-0.099	-0.054	0.010	0.049	
24	20.55	20	0.424	0.043	0.024	0.074	-0.005	-0.011	0.118	
30	22.18	26	0.679	-0.032	0.041	-0.004	-0.030	-0.037	0.022	
36	27.30	32	0.703	-0.004	0.065	-0.017	-0.023	-0.085	-0.065	
42	36.22	38	0.552	0.010	-0.093	-0.011	-0.136	-0.009	-0.028	

For purposes of forecasting generation, these two mean functions are subtracted from the past generation data, the autoregressive and moving average parts of the model (Table 3) are reestimated, and used to forecast 13 to 27 months ahead. MEANS, the seasonal effects on the generation, is calculated for the forecasts using the known dummy variables each representing a month. MEANR, the impact of precipitation on the generation, is calculated for the forecasts using the actual precipitation for past months which is still affecting generation in the forecast period and a 57-year average monthly precipitation as the monthly forecasts. These impacts are then added to the forecasts from ARIMA. The estimated forecast variance from ARIMA is added to VARS, and VARR, the variances of the estimated seasonal and precipitation effects, and is used to calculate 95 percent confidence intervals for the forecasts.

The autoregressive part of the model using coefficients given by AR (Table 3) is

$$\Phi(B) = (1 - 0.85B + 0.09B^{11}) \quad (6)$$

The moving average part of the model using coefficients given by MA (Table 3) is

$$\theta(B) = (1 + 0.29B^{13})(1 + 0.13B^{12}) \quad (7)$$

After specifying the model for the ARIMA procedure, the procedure automatically makes use of these formulas in calculating the forecasts.

Properties of the Mathematical Solution

Theoretical Considerations

See Assumptions, Alternative Approaches, and List of Computations and Equations.

Subject-Matter Considerations

Because the hydroelectric generation data exhibits seasonality, the STHGM uses dummy variables each representing a month to account for seasonality. Seasonality needs to be accounted for in the raw data in order for the time series model to reflect it in the forecasts.

Precipitation is an explanatory variable to the time series model because of the dependency of hydroelectric generation on precipitation historically. Precipitation levels determine the availability of water in reservoirs for electricity generation, as well as the effects of recent rain or snow on run-of-river hydroelectric facilities. Average precipitation is used during the forecast period for hydroelectric generation which is consistent with the assumption of normal weather for the *STEO* forecasts.

Calibration and Sensitivity Analysis

Results of Calibration

Evaluation of the model was performed using out-of-sample tests. That is, several different periods of actual data were deleted from the input data, the parameters in the model were reestimated, and forecasts made as described above for a 24-month period. These forecasts were compared to actual data and past forecasts for the *Short-Term Energy Outlook* based on the same historical data.

The first comparison was to graph the out-of-sample results (Figures 2, 3, and 4). From the graphs, the following conclusions are illustrated: (1) the STHGM forecast is in general closer to the actual generation than the previous *STEO* forecasts; (2) the 1990 and 1991 actual data are close to the long run average hydroelectric generation and the STHGM forecasts for these years is generally within 1 to 2 billion kilowatthours of the actual generation; (3) for 1992, an unusually low year for hydroelectric generation, both forecasts are not as good as for 1990 and 1991, which can be explained by the forecast assumption of normal precipitation and the fact that precipitation was below normal in 1992; (4) in 1992, with the below normal hydroelectric generation, the STHGM still provides a closer forecast than used in the *STEO*; and (5) as the input data gets closer to 1992, the STHGM forecasts improved for 1992.

The second comparison was with the Root Mean Square Errors (RMSE) of the model runs (Table 4), where n is the number of months of the forecast included in the calculation and

$$RMSE = \sqrt{\sum_{i=1}^n \frac{(FORECAST_i - ACTUAL)^2}{n}}$$

In all cases the RMSE of the STHGM is smaller than the RMSE of the *STEO* forecasts. The RMSEs show the improvement of both forecasts for a particular year as the input data gets closer to that year.

Figure 2. Out of Sample and STEO Forecasts Using Actual Data through 1989 Compared to Actual Data, 1990 and 1991.

Notes: •All forecasts are based on actual generation and precipitation data through the indicated year.
 •All forecasts assume normal precipitation during the forecast period. •Data shown in Table C1.
 Source: **STEO Forecasts:** Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memo to Office of Energy Markets and End Use dated March 13, 1990. **STHGM Forecasts:** Energy Information Administration, STHGM run using HYDRO.TIME.SERIES.FINAL.D060193. **Actual:** Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

Figure 3. Out of Sample and STEO Forecasts Using Actual Data through 1990 Compared to Actual Data, 1991 and 1992.

Notes: •All forecasts are based on actual generation and precipitation data through the indicated year.
 •All forecasts assume normal precipitation during the forecast period. •Data shown in Table C2.

Source: **STEO Forecasts:** Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memo to Office of Energy Markets and End Use dated March 19, 1991. **STHGM Forecasts:** Energy Information Administration, STHGM run using HYDRO.TIME.SERIES.FINAL.D060193. **Actual:** Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

Figure 4. Out of Sample and STEO Forecasts Using Actual Data through 1991 Compared to Actual Data, 1992 and 1993.

Notes: •All forecasts are based on actual generation and precipitation data through the indicated year.
 •All forecasts assume normal precipitation during the forecast period. •Data shown in Table C3.
 Source: **STEO Forecasts:** Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memo to Office of Energy Markets and End Use dated March 6, 1992. **STHGGM Forecasts:** Energy Information Administration, STHGM run using HYDRO.TIME.SERIES.FINAL.D060193. **Actual:** Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

Table 4. Comparison of Root Mean Square Errors.

Using Historical Data through:	Year(s) of Forecast Included in the RMSE	RMSE	
		STHGM	STEO
1989:	1990	1,267	2,289
	1991	1,367	1,923
	1990 and 1991	1,318	2,114
1990:	1991	1,363	2,040
	1992	3,280	5,092
	1991 and 1992	2,511	3,879
1991:	1992	2,597	3,749

Notes: •All forecasts are based on actual generation and precipitation data through the indicated year. •All forecasts assume normal precipitation during the forecast period.

Source: **STEO Forecasts:** Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memos to Office of Energy Markets and End Use dated March 13, 1990, March 19, 1991, and March 6, 1992. **STHGM Forecasts:** Energy Information Administration, STHGM runs using HYDRO.TIME.SERIES.FINAL.D060193.

Documentation of Technical Detail on the Model Data and Equations

Description of Input Data

Input hydroelectric generation data for the STHGM is from archived databases of the Form EIA-759, "Monthly Power Plant Report," from 1970 through 1992. Data prior to 1978 may differ from published data due to unreturned forms that were estimated in the published data. The differences in the published data and the database is generally less than 0.1 percent; and, therefore, the database was used.

Once the model has read in the generation data, the data are divided by the number of days in each month in order to account for the different lengths of the months. Once the time series procedure is completed, the forecast of average daily generation is multiplied by the number of days in each month to produce estimates of monthly generation.

The monthly input precipitation data from 1970 to 1992 and the 57-year average precipitation data are from the National Climatic Data Center. These numbers were hand typed into the needed format. Forecasted precipitation data are the monthly averages for the 57-year period from 1931 to 1987 from the National Climatic Data Center.⁵ The precipitation data, like the generation data, was adjusted to account for the number of days in the month.

Non-DOE Input Sources

- **1970-1987 and Average:** National Climatic Data Center, *State, Regional, and National Monthly and Annual Precipitation Weighted by Area for the Contiguous United States January 1931 - December 1987* (Asheville, NC, August 1988), p.66. **1988-1992:** *Monthly State, Regional and National Heating Degree Days Weighted by Population* (Asheville, NC, March, 1989 through 1993), Table 3.3, "Regional and National Average Precipitation."
- National precipitation data.

DOE Data Input Sources

- Energy Information Administration, Databases for Form EIA-759, "Monthly Power Plant Report," and predecessors.
- Hydroelectric generation data.

ARIMA Output Providing Coefficient Estimates

The coefficient estimates and a number of statistics related to the goodness-of-fit of the equations estimated by the STHGM are listed in Table 3.

⁵National Climatic Data Center, *State, Regional, and National Monthly and Annual Precipitation Weighted by Area for the Contiguous United States January 1931 - December 1987* (Asheville, NC, August 1988), p. 66.

Appendix A. Model Abstract

Model Name: Short-Term Hydroelectric Generation Model

Model Acronym: STHGM

Model Description: The STHGM performs a short-term (18 to 27-month) forecast of hydroelectric generation in the United States using an autoregressive integrated moving average (ARIMA) time series model with precipitation as an explanatory variable. The model results are used as input for the *Short-Term Energy Outlook*.

Last Model Update: May 1993

Part of Another Model: None.

Model Interfaces: None. Results used as independent input into the Short-Term Integrated Forecasting System (STIFS).

Sponsor:

- Office: Office of Coal, Nuclear, Electric and Alternate Fuels.
- Division: Analysis and Systems Division.
- Branch: Supply Analysis Branch, EI-532.
- Model Contact: Robin Reichenbach.
- Telephone: 202-254-5353.

Documentation: Energy Information Administration, "Model Documentation Report: Short-Term Hydroelectric Generation Model."

Archive Media and Installation Guides: Archived on Energy Information Administration mainframe system under the name "HYDRO.TIME.SERIES.FINAL.D060193" on account RR56434. The model is written in SAS version 6.07.

Purpose: The STHGM is to be used for general forecasting purposes to provide quarterly projections of monthly national hydroelectric generation for the *Short-Term Energy Outlook*.

Energy Systems Described by Model: National hydroelectric generation.

Coverage:

- Geographic: National.
- Time Unit/Frequency: Monthly.
- Products: Hydroelectric Generation.

Modelling Features:

- **Model Structure:** Autoregressive integrated moving average (ARIMA) time series model with an explanatory variable.
- **Modelling Technique:** Time series analysis.
- **Special Features:** None.

Non-DOE Input Sources

- **1970-1987 and Average:** National Climatic Data Center, *State, Regional, and National Monthly and Annual Precipitation Weighted by Area for the Contiguous United States January 1931 - December 1987* (Asheville, NC, August 1988), p.66. **1988-1992:** *Monthly State, Regional and National Heating Degree Days Weighted by Population* (Asheville, NC, March, 1989 through 1993), Table 3.3, "Regional and National Average Precipitation."
 - National precipitation data.

DOE Data Input Sources

- Energy Information Administration, Databases for Form EIA-759, "Monthly Power Plant Report," and predecessors.
 - Hydroelectric generation data.

General Output Descriptions: STHGM is used to generate short-term (18 to 27-month), monthly forecasts of U.S. hydroelectric generation.

Computing Environment:

- **Hardware Used:** Energy Information Administration Mainframe System (Model Number IBM 3090).
- **Operating System:** MVS.
- **Software Used:** SAS version 6.07.
- **Estimated Run Time:** Approximately 15 seconds computer time on EIA Mainframe System.
- **Special Features:** None.

Independent Expert Reviews: None.

Status of Evaluations by Sponsor: On-going.

Bibliography:

- George E. Box and Gwilym Jenkins, *Time Series Analysis, Forecasting and Control* (1976).
- Sas Institute Inc., *SAS/ETS User's Guide*, Version 6 (Cary, NC, January 1989).

Appendix B. Source Code

```
//RR5UTIMD JOB (6434,HST,,80),'HYDRO.TIME',TIME=(,15)
//STEP1 EXEC SAS607,OPTIONS='MACRO',REGION=4024K,TIME=(,15)
//FORM1 DD DSN=CN6434.RR5.HYDRO.HISTORY.DATA.Y70T92,
//          DISP=SHR,LABEL=(,,,IN)
//PREC DD DSN=CN6434.RR5.PRECIP,
//          DISP=SHR,LABEL=(,,,IN)
//*
*OPTIONS MPRINT NONOTES NOSOURCE NOCENTER;
OPTIONS MPRINT NOCENTER;

*-----*
| THIS JOB PERFORMS A TIME SERIES FOR HYDRO |
*-----*

***** MACROS *****;

*---- CALCULATE THE NUMBER OF DAYS IN EACH MONTH ----*;

%MACRO NUMDAYS;
  IF MONTH < 12 THEN NEXTMON=MONTH+1; ELSE NEXTMON=1;
  IF MONTH < 12 THEN NEXTYR=YR; ELSE NEXTYR=YR+1;
  DAYS=MDY(NEXTMON,1,NEXTYR)-MDY(MONTH,1,YR);
  DROP NEXTYR NEXTMON;
%MEND;

*---- MULTIPLY THE FORECAST BY THE NUMBER OF DAYS IN EACH MONTH --*;

%MACRO FOREDAYS;
  F= (FORECAST + MEANS+MEANR)*DAYS;
  STDF=SQRT(STD**2 + VARS +VARR)*DAYS;

  U95=F+1.96*STDF;
  L95=F-1.96*STDF;
%MEND;

*---- PLOT THE FORECAST ----*;

%MACRO FOREPLOT(REGION,N);

PROC SORT DATA=_LAST_; BY YR MONTH;

PROC TIMEPLOT DATA=_LAST_;
  CLASS YR MONTH;
  PLOT F="&N"
       U95='U'
       L95='L'/OVERLAY HILOC;
  TITLE "&REGION FORECAST";

DATA OUTPLOT; SET _LAST_;
YEAR=YR+(MONTH-1)/12;

PROC PLOT DATA=OUTPLOT;
PLOT F*YEAR="&N";
XMEND;
```

```

*****
***** MAIN PROGRAM *****
*****;

```

```

**** READ IN NATIONAL GENERATION DATA ****
**** AND ADJUST FOR # OF DAYS PER MONTH ****;

```

```

DATA AA;
  INFILE FORM1;
  INPUT YR 3-4 MONTH 9-10
    @12 (NATIONAL) (9.1);

```

```

DATA AA (DROP=I DAYS);
  SET AA NOBS=NUM;
  NUMAA=NUM;

```

```

  %NUMDAYS

```

```

  NATIONAL=NATIONAL/DAYS;

```

```

PROC SORT DATA=AA;
  BY YR MONTH;

```

```

**** READ IN NATIONAL PRECIPITATION DATA ****
**** AND ADJUST FOR # OF DAYS PER MONTH ****;

```

```

DATA RR;
  INFILE PREC;
  INPUT YR 11-12 MONTH 17-18
    RAINNAT 27-30;

```

```

DATA RR (DROP=I DAYS);
  SET RR NOBS=NUM;
  NUMRR=NUM;

```

```

  %NUMDAYS

```

```

  RAINNAT=RAINNAT/DAYS;

```

```

**** MERGE DATASETS ****;

```

```

PROC SORT DATA=RR;
  BY YR MONTH;

```

```

DATA ONE;

```

```

  MERGE AA (IN=A) RR (IN=B);
  BY YR MONTH;

```

```

  IF (A OR B) THEN OUTPUT;

```

```

**** ESTABLISH DUMMY VARIABLES ****;

```

```

DATA ONE; SET ONE;
  ARRAY DUM(*) DUM1-DUM12;

```

```

DO I=1 TO 12;
  DUM(I)=0;
  IF MONTH=I THEN DUM(I)=1;

```

END;
DROP I;

**** USE PORTION OF MERGED DATASET THAT INCLUDES ****
**** ACTUAL VALUES OF GENERATION AND PRECIPITATION ****;

DATA ONES; SET ONE;
IF _N_ LE NUMAA;

**** FIRST ARIMA PROCEDURE ****;
**** COEFFECIENTS OF PARAMTERS USED FROM OUTPUT ****;

PROC ARIMA DATA=ONES;

IDENTIFY VAR=RAINNAT NLAG=48;
ESTIMATE P=(1,11,17)(12) ML PLOT;
TITLE1 'PRECIPITATION DATA';

IDENTIFY VAR=NATIONAL CROSSCORR=(RAINNAT DUM1 DUM2 DUM3
DUM4 DUM5 DUM6 DUM7 DUM8 DUM9 DUM10 DUM11 DUM12) NLAG=48;
ESTIMATE P=(1,11) Q=(13)(12) ML PLOT NOINT INPUT=((1,2,8,9)
RAINNAT DUM1 DUM2
DUM3 DUM4 DUM5 DUM6 DUM7 DUM8 DUM9 DUM10 DUM11 DUM12);

**** ADJUST DATA FOR SEASONALITY AND PRECIPITATION CORRELATION **;

DATA NAT; SET ONE;
MEANS=595.298*DUM1+ 600.138*DUM2 + 605.041*DUM3 + 600.807* DUM4 +
610.647*DUM5+ 589.910*DUM6 +511.492*DUM7+453.115* DUM8+
404.016*DUM9+404.011*DUM10+478.450*DUM11+560.718*DUM12;

MEANR=896.222*RAINNAT+834.256*LAG(RAINNAT)+526.131*LAG2(RAINNAT)+
262.026*LAG8(RAINNAT)+171.288*LAG9(RAINNAT);

VAR= (36**2);

VARR= (140.389**2)*(RAINNAT**2) +
(145.493**2)*LAG(RAINNAT)**2 +
(139.865**2)*LAG2(RAINNAT)**2 +
(130.235**2)*LAG8(RAINNAT)**2 +
(131.449**2)*LAG9(RAINNAT)**2;

NEWNAT=NATIONAL-MEANS-MEANR;

DATA NATS; SET NAT;
IF _N_ LE NUMAA;

**** RUN ARIMA WITH ADJUSTED DATA ****;

PROC ARIMA DATA=NATS;

IDENTIFY VAR=NEWNAT NLAG=48;
ESTIMATE P=(1,11) Q=(13)(12) NOINT ML PLOT;

```

FORECAST LEAD=36 OUT=OUTNAT;

DATA OUTNAT; SET OUTNAT;

C=_N_;
YR=(70+INT((C-.5)/12));
MONTH=C-(YR-70)*12;

DATA ONE2;

MERGE OUTNAT (IN=A) NAT (IN=B);
BY YR MONTH;

IF (A OR B) THEN OUTPUT;

**** ADJUST FORECAST FOR # OF DAYS PER MONTH AND OUTPUT ****;

DATA OUTALL (KEEP= YR MONTH F STDF U95 L95);
SET ONE2;

%NUMDAYS
%FOREDAYS

DATA PP;
SET OUTALL NOBS=NUM;
EXTRA=NUM-35;
IF _N_ GE EXTRA;
DROP NUM EXTRA;

PROC PRINT DATA=PP;
TITLE 'FORECAST';

*%FOREPLOT(NATIONAL,N)

```


Variable Definitions

YR	year
MONTH	month
NATIONAL	national hydroelectric generation data
NUMAA	number of observations of national hydroelectric generation data
RAINNAT	national precipitation data
NUMRR	number of observations of national precipitation data
DAYS _k	number of days in month <i>k</i>
DUM _{<i>t,k</i>}	monthly dummy variables where DUM _{<i>t,k</i>} = 1 if <i>t</i> observed in month <i>k</i> and DUM _{<i>t,k</i>} = 0 otherwise
MEANS	average seasonal effect of the hydroelectric generation data; calculated using coefficients of the dummy variables from the procedure ARIMA runs
MEANR	average impact of past and present changes in precipitation; calculated using coefficients of the lags of the correlated precipitation data from the procedure ARIMA runs
VARs	variance of the estimated seasonal mean of the hydroelectric generation data
VARR	variance of the estimated mean of the changes in precipitation; calculated using the approximate standard error of the estimated coefficients from the procedure ARIMA runs
NEWNAT	hydroelectric generation data which has been adjusted for the effects of seasonality and assumed normal forecasted precipitation
F	readjusted forecast for hydroelectric generation
FORECAST	forecast of hydroelectric generation from the procedure ARIMA run on the adjusted hydroelectric generation data
STDF	estimation of the standard deviation of the readjusted hydroelectric generation forecast
STD	standard deviation for the hydroelectric generation from the procedure ARIMA run on the adjusted hydroelectric generation data
U95	estimated upper 95 percent confidence interval for the readjusted hydroelectric generation forecast
L95	estimated lower 95 percent confidence interval for the readjusted hydroelectric generation forecast

Appendix C. Data

Table C1. Out of Sample and STEO Forecasts Using Actual Data through 1989 with Actual Hydroelectric Generation, 1989-1991

Year	Month	Net Hydroelectric Generation	Forecasts	
			STHGM	STEO
1989	January	20.9	NA	NA
	February	18.6	NA	NA
	March	22.6	NA	NA
	April	24.1	NA	NA
	May	28.0	NA	NA
	June	25.9	NA	NA
	July	22.7	NA	NA
	August	20.2	NA	NA
	September	18.9	NA	NA
	October	20.1	NA	NA
	November	21.2	NA	NA
	December	21.8	NA	NA
1990	January	23.4	23.4	22.2
	February	24.2	22.1	20.7
	March	28.0	25.1	22.7
	April	25.4	24.4	24.5
	May	27.0	26.9	27.3
	June	27.7	26.0	25.8
	July	23.7	23.3	23.9
	August	21.0	20.4	21.9
	September	17.0	18.2	19.6
	October	18.6	18.9	19.9
	November	20.0	20.7	22.0
	December	24.0	23.8	25.6
1991	January	25.7	24.4	26.5
	February	21.9	22.3	24.5
	March	25.8	24.9	26.7
	April	25.7	24.2	26.2
	May	28.5	25.7	28.2
	June	25.8	24.7	26.6
	July	24.3	23.1	24.7
	August	21.7	21.0	22.2
	September	18.4	18.6	19.9
	October	17.5	18.7	19.9
	November	18.3	20.2	22.0
	December	21.9	23.4	25.6

Notes: •All forecasts are based on actual generation and precipitation data through the indicated year. •All forecasts assume normal precipitation during the forecast period.

Source: STEO Forecasts: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memo to Office of Energy Markets and End Use dated March 13, 1990. STHGM Forecasts: Energy Information Administration, STHGM run using HYDRO.TIME.SERIES.FINAL.D060193. Actual: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

Table C2. Out of Sample and STEO Forecasts Using Actual Data through 1990 with Actual Hydroelectric Generation, 1990-1992

Year	Month	Net Hydroelectric Generation	Forecasts	
			STHGM	STEO
1990	January	23.4	NA	NA
	February	24.2	NA	NA
	March	28.0	NA	NA
	April	25.4	NA	NA
	May	27.0	NA	NA
	June	27.7	NA	NA
	July	23.7	NA	NA
	August	21.0	NA	NA
	September	17.0	NA	NA
	October	18.6	NA	NA
	November	20.0	NA	NA
	December	24.0	NA	NA
1991	January	25.7	24.4	24.2
	February	21.9	22.0	23.0
	March	25.8	25.1	26.3
	April	25.7	24.5	25.6
	May	28.5	25.2	27.8
	June	25.8	24.3	25.9
	July	24.3	23.3	24.7
	August	21.7	21.1	22.6
	September	18.4	18.7	20.3
	October	17.5	18.3	20.3
	November	18.3	19.8	22.4
	December	21.9	23.1	26.0
1992	January	21.5	24.5	25.0
	February	18.0	23.1	23.8
	March	21.6	25.1	27.2
	April	19.5	24.4	26.5
	May	22.3	26.0	28.7
	June	22.7	24.8	26.8
	July	19.7	23.5	25.5
	August	18.1	21.4	23.4
	September	16.8	19.0	21.0
	October	16.4	19.0	21.0
	November	19.3	20.4	23.2
	December	23.8	23.5	26.9

Notes: •All forecasts are based on actual generation and precipitation data through the indicated year. •All forecasts assume normal precipitation during the forecast period.

Source: STEO Forecasts: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memo to Office of Energy Markets and End Use dated March 19, 1991. STHGM Forecasts: Energy Information Administration, STHGM run using HYDRO.TIME.SERIES.FINAL.D060193. Actual: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

Table C3. Out of Sample and STEO Forecasts Using Actual Data through 1991 with Actual Hydroelectric Generation, 1991-1993

Year	Month	Net Hydroelectric Generation	Forecasts	
			STHGM	STEO
1991	January	25.7	NA	NA
	February	21.9	NA	NA
	March	25.8	NA	NA
	April	25.7	NA	NA
	May	28.5	NA	NA
	June	25.8	NA	NA
	July	24.3	NA	NA
	August	21.7	NA	NA
	September	18.4	NA	NA
	October	17.5	NA	NA
	November	18.3	NA	NA
	December	21.9	NA	NA
1992	January	21.5	23.6	24.8
	February	18.0	22.3	21.7
	March	21.6	23.8	25.4
	April	19.5	23.3	24.8
	May	22.3	25.1	27.3
	June	22.7	24.3	25.1
	July	19.7	22.7	23.8
	August	18.1	20.9	21.8
	September	16.8	18.6	19.3
	October	16.4	18.4	20.4
	November	19.3	19.8	22.6
	December	23.8	22.9	26.2
1993	January	24.5	24.1	26.8
	February	19.7	22.2	24.6
	March	23.6	25.0	27.1
	April	25.2	24.3	26.2
	May	NA	25.9	28.3
	June	NA	24.9	26.3
	July	NA	23.3	24.2
	August	NA	21.3	22.4
	September	NA	18.9	20.6
	October	NA	19.0	20.8
	November	NA	20.4	22.6
	December	NA	23.6	26.2

Notes: -All forecasts are based on actual generation and precipitation data through the indicated year. -All forecasts assume normal precipitation during the forecast period.

Source: STEO Forecasts: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels memo to Office of Energy Markets and End Use dated March 6, 1992. STHGM Forecasts: Energy Information Administration, STHGM run using HYDRO.TIME.SERIES.FINAL.D060193. Actual: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

Appendix D. Census Divisions

Source: United States Bureau of the Census.

**DATE
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END