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NEAR-REAL-TIME FORECASTING OF LARGE-LAKE WATER SUPPLIES; A USER'S MANUAL

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NEAR-REAL-TIME FORECASTING OF LARGE LAKE WATER SUPPLIES; A USER'S MANUAL*

Thomas E. Croley II and Holly C. Hartmann

ABSTRACT. The Great Lakes Environmental Research Laboratory developed a semiautomatic software package for making deterministic or probabilistic outlooks of basin moisture storage conditions, basin runoff, net lake supplies, and lake levels six full months into the future for large lakes. We designed the package especially for use on small computers with a standard FORTRAN-77 or TURBO-PASCAL compiler, 2-5 Megabytes of disk storage, and a minimum of CPU and memory resources. The package combines our Large Basin Runoff Model applications on each of the subbasins about a lake to represent the entire basin. Our near-real-time data reduction system uses new algorithms to efficiently determine daily area1 averages of meteorologic variables over each of the subbasins. The model and data reduction system are combined into a useful, easy-to-use, semiautomatic package that consists of easily supported modules for making near real-time forecasts of basin runoff and lake levels. Although the package was developed for use on the Laurentian Great Lakes, we currently use it on Lakes Superior and Champlain and can apply it in little more than the time it takes to receive climatologic records for an area. The modules' construction is presented in some detail; the use of these modules and their component computer programs also are detailed herein with the Lake Superior Basin used as an example.

1. INTRODUCTION

Near'real-time outlooks of a lake's net basin supply (basin runoff plus lake precipitation minus lake evaporation) are useful for lake level management. They are necessary in determining flooding impacts, not related to wind setup, over a daily time interval or longer and are required in the Lake Superior regulation plan (International Lake Superior Board of Control, 1981, 1982); current uses of statistical autoregressions of net basin supplies do not consider water stored in the basins. With the intrinsic memory of large basins and lakes, there is much potential for developing useful short-term operational forecasts in the face of uncertain meteorology. The Great Lakes Environmental Research Laboratory (GLERL) has developed a conceptual model-based software package that uses near real-time information to establish forecasts that consider both the existing basin storages and anticipated or forecast meteorology. This package is based on GLERL's Large Basin Runoff Model (LBRM), applied to each of the subbasins about a lake, as described in

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the next section. Our forecast package enables us to consider the historic record in applying the runoff model, provisional data as they become available in making estimates of current basin moisture conditions, and forecast meteorology in predicting basin runoff, net basin supply, and lake levels. GLERL is using the forecast package for Lakes Superior (developed for the U.S. Army Corps of Engineers, Detroit District) and Champlain (developed for the National Weather Service Northeast River Forecast Center, Croley and Hartmann, 1985b); it will soon be available for the remaining Laurentian Great Lakes.

The forecast package is outlined following the discussion of the model and its applications; it is further discussed in detail in subsequent sections. The sections of this manual are designed for different user perspectives; following the description of the runoff model and its applications, a user's overview is given that fully presents the part of the forecast package that is used often, including a detailed checklist of steps to foilow in making a forecast. Subsequent sections detail the component parts of the forecast package for those who wish to understand how the programs work or who wish to install it on their system. Finer details are provided in Appendix B. Finally, an evaluation for use on the Lake Superior basin is given as an indication of the worth of the package and to delineate areas where additional work is required. This attention to different user perspectives has resulted in some redundancies between the various sections but has allowed comprehensive coverage. Programs and example data sets are available from GLERL.

2. RUNOFF MODELING

The GLERL Large Basin Runoff Model (LBRM), pictured schematically in Fig. 1, consists of several moisture storages arranged as a serial and parallel cascade of tanks (Croley, 1983a;b). It makes use of physical concepts for snowmelt and net supply to the watershed surface, infiltration, heat available for evapotranspiration, actual evapotranspiration, and mass conservation. As a conceptual model, the LBRM is useful not only for predicting basin runoff, but for facilitating our understanding of watershed response to natural forces as well. The main mathematical feature of the LBRM is that it may be described by strictly continuous equations; none of the complexities associated with intertank flow rate dependence on partial filling are introduced. For a sufficiently large watershed, these nuances are not observed, owing to the spatial integration of rainfall, snowmelt, and evapotranspiration processes.

2.1 Physical Concepts

Daily precipitation, temperature, and insolation (the latter available from climatic summaries as a function of location) may be used to determine

Snowpack accumulations and net supply. Water enters the snowpack (SNW in Fig. 1)*, if present, and some then is available as net supply to the watershed surface based on degree-day determinations of snowmelt (M); potential snowmelt varies with degree-days as reflected by a melt factor (a_s). Net supply thus occurs only when temperatures are above freezing, and comprises precipitation and snowmelt. The net supply is divided into infiltration to the upper soil zone and surface runoff in relation to the relative upper soil zone moisture content (USZM); under the partial-area infiltration concept, infiltration is proportional to the net supply rate and to the area1 extent of the unsaturated portion of the upper soil zone.

Calculations of outflows from the various storages within the watershed are based on the linear reservoir concept; outflow from a tank is proportional to the moisture in storage as reflected by the linear reservoir coefficient. Percolation to the lower soil zone is dependent on the upper soil zone moisture and the percolation coefficient (α_{per}). Likewise, interflow from the lower soil zone to the surface and deep percolation to the groundwater zone depend on the lower soil zone moisture content (LSZM) and the interflow (α_{int}) and deep percolation (α_{dp}) coefficients, respectively. Groundwater flow depends on the groundwater zone moisture content (GZM) and the groundwater coefficient (α_{gw}), and basin outflow depends on the surface storage (SS) and basin outflow coefficient (α_{sf}).

The evapotranspiration rate from the upper and lower soil zones is proportional to available moisture in the upper and lower soil zone storages, the heat rate available for evapotranspiration (e_p), and the evapotranspiration coefficients for the upper (β_{eu}) and lower zones (β_{el}); it is also based on the concept of complementary evapotranspiration and heat available for evapotranspiration. Over large areas, actual evapotranspiration affects temperatures, wind speeds, and humidities, and hence modifies the evapotranspiration opportunity or capacity; the heat used for evapotranspiration reduces the heat available for additional evapotranspiration. This concept proves superior to classical "potential evapotranspiration" concepts when applied to large areas (Croley, 1985b). The total amount of heat in a day, to be split between that used for evapotranspiration and that still available for evapo- . transpiration, is estimated empirically from the average air temperature, a long-term heat constant, and a base scaling temperature (Tb). The long-term heat constant is determined from a long-term heat balance; all absorbed insolation not used for snowmelt sooner or later appears as other components of the heat balance. Also, evaporation from the surface storage and groundwater evapotranspiration are neglected here.

2.2 Analytic Solution

Mass continuity yields a first-order linear differential equation for each of the tanks in Fig. 1; outputs from one tank are used in lower tanks where their outputs appear as inputs. There are 30 different analytic results (Croley, 1982), depending upon the magnitudes of all inputs, initial

*Due to the nature of this document all Figures appear in Appendix A storages, and the nine parameters identified above. Since the inputs and initial storages change from day to day, the appropriate analytic result, as well as its solution, varies with time; mathematic continuity between solutions is preserved, however. Numeric solutions are unnecessary so that approximation errors are avoided. Furthermore, solutions may proceed for either flow rates or storage volumes directly without the complication of constraints consideration.

The differential equations for the mass balance can be applied over any time interval by assuming that the input (precipitation and snowmelt) and the heat available for evapotranspiration are uniform over the interval. Thus, the resolution of the equations is limited only by the intervals over which precipitation and temperature data are available; the mass balance computation interval may be any length greater than or equal to the interval length for which meteorologic data are available. The model is applied to daily data with either a fixed l-day or a fixed 7-day mass-balance computation interval. Net supply and the heat available for evapotranspiration are determined on a daily basis and summed over the time interval as input to the mass-balance computations. The model is applied to monthly data with a variable mass-balance computation interval; the interval may represent 28 to 31 days, depending on the month and year, and net supply and the heat available for evapotranspiration are computed over the same period.

2.3 Parameter Calibration

The LBRM is calibrated to determine the set of parameters with the smallest sum-of-squared-errors between model and actual daily flow volumes for the calibration period. Unlike approaches used in other rainfall-runoff models, especially in stochastic models, calibration of the LBRM is designed to result in parameter values that represent our physical understanding of the watershed hydrology (Croley and Hartmann, 1985c).

2.3.1 Calibration Procedure

The following data are required to calibrate and apply the model: daily precipitation, daily maximum and minimum air temperatures, a climatic summary of daily extraterrestrial solar radiation, and for comparison purposes, daily basin outflows. The area of the watershed is also required. The basin is first divided into subbasins draining directly to the lake. Meteorologic data from, typically, 150-300 stations about and in the subbasins are combined through Thiessen weighting to produce areally averaged daily time series of precipitation and maximum and minimum air temperatures for each subbasin. Weights are determined for each day of record, if necessary, since the data collection network changes frequently as stations are added, dropped, and moved, or fail to report from time to time. This is now feasible through the use of a new algorithm for determining the Thiessen area-of-influence about a station by its edge (Croley and Hartmann, 1985a). Records for all "most-downstream" flow stations are combined by aggregating and extrapolating for gauged areas to estimate the daily runoff to the lake from each subbasin.

Snowpack, upper soil moisture, lower soil moisture, groundwater, and surface storage zones must be initialized prior to modeling. While the initial snowpack moisture equivalent is easy to determine as zero during major portions of the year, these variables are generally difficult to estimate. If the model is to be used in forecasting or for short simulations, then it is important to determine these variables accurately prior to use of the model. If the model is to be used for calibration or for long simulations, then the initial values are generally unimportant. The effect of the initial values diminishes with the length of the simulation, and after 1 year of simulation, the effects are nil from a practical point of view. Calibrations are repeated with initial conditions equal to observed long-term averages until there is no change in the averages, to avoid arbitrary initial conditions when their effects do not diminish rapidly.

Applications of the LBRM require the determination of the model's nine parameters as described elsewhere (Croley and Hartmann, 1984). Parameters are determined in an automated systematic search of the parameter space to minimize the sum-of-squared-errors between actual and model outflow volumes. We search each parameter, selected in rotation, until all parameter values converge to two digits instead of searching until the sum-of-squared-errors stabilizes. Such an approach is important where synergistic parameter interactions allow the parameters to change significantly even after the sum-of-squared-errors has stabilized; this was seen repeatedly in calibrations for the Ontario, Champlain, and Superior basins (Croley, 1983b; Croley and Hartmann, 1983, 1984, 1985b,c).

By combining the meteorologic and hydrologic data for all subbasins to represent the entire basin, the LBRM may be calibrated in a lumped-parameter application to the entire basin at one time. Although the application of lumped-parameter models to very large areas necessarily fails to represent area1 distributions of watershed and meteorologic characteristics, spatial filtering effects tend to cancel data errors for small areas as the areas are added together. Distributed-parameter applications, in which the LBRM is calibrated for each subbasin and model outflows are combined to represent the entire basin, make use of information that is lost in the lumped-parameter approach; the integration then filters individual subbasin model errors.

2.3.2 Calibration Concerns

The LBRM captures a "realism" in its structure that has several advantages over other models. Basin storages, modeled as "tanks," are automatically removed as respective parameters approach their limits. Thus, the structure of the model changes within a calibration. This is achieved without the use of "threshold" parameters in the model since physical concepts are used which avoid discontinuities in the goodness-of-fit as a function of the parameters; these concepts appear especially relevant for large-basin modeling. Because the "tanks" relate directly to actual basin storages, initialization of the model corresponds to identifying storages from field conditions that may be measured; interpretations of a basin's hydrology then can aid in setting both initial and boundary conditions. The tanks in Fig. 1 may be initialized to correspond to area1 measurements of snowpack and soil moisture water equivalents available from aerial or satellite monitoring (Gauthier et al., 1984).

Studies on the Lake Ontario and Superior Basins (Croley, 1982; Croley and Hartmann, 1983, 1984, 1985c) show that the simple search algorithm described herein does not give unique optimums for calibrated parameter sets because of synergistic relationships between parameters. However, the calibration procedure does show a high degree of repeatability for recalibrations with different starting values, and consistent parameter values are obtained for subbasins with similar hydrologic characteristics. On the other hand, the nonuniqueness of calibrated parameters was demonstrated by recalibrating for a synthetic data set. The model was calibrated for the entire Lake Superior Basin and then used to simulate outflows to create a new data set for calibration. Subsequent calibration started with a very different initial parameter set and yielded an "optimum" parameter set different from the original with a relatively poor goodness-of-fit. If the original parameter set had been unique, the parameter values produced from the recalibration to the synthetic data set should have been the same as the parameters used to create that data set. This illustrates the nonuniqueness of the parameters, the importance of the starting values used in the search, and the problems inherent in searching the parameter space. Additionally, some components of the LBRM (such as linear reservoirs) are more likely to adequately represent their processes in the real world than others (such as degree-day melting or complementary evapotranspiration). Parameter estimation techniques that properly weight the more accurate parts of the model could improve parameter estimates.

3. FORECASTING WATER SUPPLIES

Forecasts are integrations of modeling and near-real-time data handling. Deterministic and probabilistic forecasts of water supply 6 months into the future are possible in near-real time by using the LBRM with forecast meteorology. The calibrated model is used from the end of the climatic data sets to the present by using provisional data from a near-real time data network. We can thus establish basin moisture conditions (the tank storages in the model) to be used as initial conditions in the forecast. Then, forecast meteorology is used with the model to estimate basin runoff and basin storages over the next 6 months. Finally, estimates of the other components of water supply (precipitation over the lake, lake evaporation, and net groundwater flux to the lake) are included to generate the water supply forecast and hydraulic routing enables the lake level to be forecast. Although our forecast package is designed to produce a forecast from the end of the available provisional data through the next 6 full months, basin storages are also computed over a 24-month period that ends with the end of the forecast, for a perspective on recent basin moisture conditions.

The procedure, outlined schematically in Fig. 2, consists of six modules for (1) preparing climatic subbasin files of areally averaged historic meteorologic and hydrologic data, (2) calibrating the runoff model for each subbasin, (3) preparing initial data bases for the forecast module, including climatic hydrometeorologic quantiles to aid in selecting a forecast meteorologic scenario and to provide historic perspective for the forecasts, (4) updating provisional data bases with near-real time meteorologic data and updating basin storage conditions with the model applied to the provisional data or with field measurements, (5) selecting a forecast meteorologic scenario, and (6) transforming forecast meteorology into forecast basin runoff, net basin supply, and lake levels. The first three modules are used infrequently as new climatic data become available every 1 or 2 years, whereas the last three modules are used often as provisional data become available and as forecasts are desired. Modules that are executed often are transferred to the agencies responsible for forecasts on a given lake; they are simple and easy to use, trap errors, identify problems and corrective actions, and are transferable to smaller machines. The first three modules are implemented for a mini- or mainframe computer, since the computations are extensive; the third module prepares the forecast data bases especially for use on small computers. The last three modules use these data bases in a highly efficient manner and are implemented for speed and a minimum of CPU time, memory, and disk storage; they thus can be used efficiently on either large or small computers.

3.1 User's Overview

This section contains the user's perspective on use of the forecast package, consisting of the last three modules in Fig. 2. All the modules identified in Fig. 2 are detailed in subsequent sections. The use of these modules is further illustrated in the conceptual diagrams of Fig. 3 depicting the computations sequentially with heavy time lines. The user provides up to four types of information to the package; two of them are optional. First, daily meteorologic provisional data, detailed in section 4.4, must be obtained from stations in and around the lake basin through a near real-time data acquisition network. The user makes an individual file for each station, including all data available since the last time the forecast package was used, as well as older additions, deletions, or changes. Second, the user may provide field measurements of basin moisture conditions if they are available; otherwise, model storages are used. Third, if the lake levels option is used (lake level forecasts are desired in addition to forecasts of runoff, basin storages, and net basin supplies), then the user must also provide a value for the lake level as an initial condition. Fourth, the user must provide meteorologic time series representing forecast meteorology or tell the package which historic meteorologic sequence to use as a forecast. If a deterministic forecast is desired, the user need only provide a single sequence of forecast meteorology; a probabilistic forecast requires multiple forecast meteorologic sequences. After supplying these four items, the user may generate a water supply forecast by running the programs listed in the Appendix B.

The fourth module in Fig. 2 accepts new provisional data and adds them to the provisional data bases. Provisional data are minimum and maximum air temperatures and precipitation values that are reported in near-real time as available. Effective operational forecasts require reception and processing of meteorologic data from all stations (typically 20-50) in a provisional measurement network within a week after measurement (Croley and Hartmann, 1984; Gauthier et al., 1984). Provisional data are contained in individual station files, depicted in Fig. 3a as near-real-time meteorologic point measurements. Each file contains the station location and the latest daily values of minimum and maximum air temperature and precipitation since the last time that the data bases were updated. The data do not need to be continuous or chronologic. However, they must be later than the end of the climatic data bases constructed in module 1. The station files may also contain new, corrected, or changed data values for any days prior to the last update. All provisional station files are checked for format and range errors and are incorporated into a provisional data base (Fig. 3b); only new or changed data are incorporated and the corresponding dates are "flagged." The provisional data base is then scanned and only flagged dates are considered to compute the daily subbasin and entire-basin area1 averages which either overwrite old values in subbasin and basin files or are appended to them (Figs. 3c and 3d); the flags are then removed. The subbasin files are then used with the LBRM to update subbasin and entire basin storage conditions (Figs. 3e and 3f); the updates are made only from the date of the earliest change or addition of provisional data to the end of the provisional data. Field measurements of basin moisture conditions, available from snow course, aerial, or satellite monitoring, may be incorporated for the LBRM in this module by placing them in the parameter table that the LBRM uses; these measurements can be for any date later than the end of the climatic data bases. At present, model-generated storages are replaced by known field conditions on the date corresponding to their measurement. Thus, field measurements are taken as being more valid than the model. Other approaches that recognize the worth of the model estimates relative to the field measurements are required to adequately consider boundary conditions. Methods must also be developed for updating model storages on the basis of line measurements of soil moisture changes (which are more readily available than soil moisture values) and area1 measurements of snow cover extent, snow temperatures, albedo, and other environmental conditions. Thus, current subbasin storages in the fourth module are estimated with the model as applied to the most recent provisional data and available field measurements, and they serve as initial conditions for a forecast.

Basin runoff is forecast by applying the LBRM for each subbasin to a Forecast meteorologic sequence. The selection of this sequence is important and difficult; the resulting forecast of runoff will be no better than the forecast of air temperatures and precipitation used in the simulation. A standard method involves using median air temperatures and precipitation, selected from the historic record, as the estimate of the most-likely meteorology for the future. This method does not recognize the limited expertise that exists for predicting the weather and ignores the interdependencies that exist between air temperatures and precipitation. Since median air temperatures do not usually occur at the same time as median precipitation, their use together introduces bias into the forecasts. Likewise, medians are computed by assuming that air temperatures and precipitation are both serially independent as well as mutually independent, introducing other biases into a forecast. An alternative method involves the estimation of statistical models of the time series of air temperatures and precipitation. However, this approach involves considerable uncertainty in the selection of an appropriate multivariate model that could adequately relate the meteorologic processes at many points over the basin. The spatial and temporal interdependencies of all meteorologic variables would be difficult to capture with any confidence. A workable method was sought that preserves the spatial and temporal interdependencies of all meteorologic variables and that recognizes the limited expertise available in forecasting meteorology.

The U.S. National Weather Service (NWS) provides monthly and seasonal weather outlooks semi-monthly for the North American continent (NWS, 1984) which consist of maps of air temperature and precipitation probabilities for the coming month and 3-month season. Module 5 in Fig. 2 uses these outlooks to construct a biased sample of forecast meteorologic sequences; the meteorologic quantile non-exceedance probability tables (compiled in module 3) are scanned to identify several years of the historic record for the entire basin which best match the probabilistic weather forecasts over the period of interest. These years are used in an "Extended Streamflow Prediction" (ESP) approach to forecasting. For each subbasin, the historic daily values of areally averaged minimum and maximum air temperatures, precipitation, and lake evaporation corresponding to the forecast period of interest then are taken from the identified years of record and used as the forecast meteorologic sequences (Figs. 3g and 3h). Thus, the spatial and temporal interdependencies of the meteorologic processes are preserved. Admittedly, the extremes are limited to those of record, but this is not considered a problem since subbasin area1 averages are used, corresponding to very large areas that do not have as extreme data values as small areas have.

The sixth module in Fig. 2 accepts a single set of forecast meteorologic sequences (i.e., a sequence for each subbasin, all from the same period of the historic record) from module 5 and uses it with the LBRM for its respective subbasins to automatically simulate the resulting basin runoff (Fig. 3i); the forecast basin runoff is then predicated on the forecast meteorology and the basin storages that exist at the beginning of the forecast period (end of the provisional data period as computed in module 4). The subbasin runoff and the storage outlooks are aggregated over the entire basin (Fig. 3j), comparison historic quantiles are extracted and tabulated (Fig. 3k), and the total basin runoff, lake precipitation, and lake evaporation are combined to forecast net basin supply for the lake (Fig. 31). Net basin supply is used in conjunction with hydraulic routing models and the user-supplied initial lake level to calculate forecasted lake levels (Fig. 3m). For probabilistic forecasts, module 6 in Fig. 2 is then repeated for every year of the historic record selected in module 5. Various forecast statistics are computed (Fig. 4) and the forecast entire-basin storage conditions are averaged and plotted with (optional) historic quantiles for perspective. An example is pictured in Figs. 5-9. The generation of a deterministic forecast consists simply of selecting a single year of record for the meteorologic forecast, best matching the NWS outlook, and module 6 is executed only once. The forecast meteorology also is then plotted (optionally) as in Figs. 10 and 11.

The six modules of Fig. 2 are reused as required for successive product updates, provisional data updates, and forecasts as illustrated thereon. After a forecast is made, modules 5 and 6 are re-executed if there are alternative meteorologic sequences that are desired for consideration. As new provisional data become available in near-real time, modules 4-6 are re-executed to include the data and make revised forecasts. As data-collection agencies revise their provisional data and make them available to add to the historic records, the entire package of Fig. 2 may be re-executed to revise the historic data bases, recalibrate the runoff models for each subbasin, and reinitialize the provisional data bases. Modules l-3 are executed infrequently (every 2-5 years) as historic data are available in machine-readable form; modules 4-6 are executed frequently (every day, week, or month) as provisional data are received in near-real time and as forecasts are desired. Modules 4-6 are encoded to run conveniently on small computers with 2-5 Mbytes of disk storage; the computer programs in these modules are configured to use a minimum of memory, but sufficient additional memory should be available to contain the digital map of the basin.

3.2 Forecast Procedure

This section describes in detail the steps that must be followed to make a water supply forecast. All programs communicate with each other through a coordinating disk file, through which are passed various dates (generated internally) and information on each program. Thus, the user cannot initiate a module unless all required prior modules have been completed successfully; each subsequent module has information on everything that went before it. The forecast package was written for use on any of several lake basins by GLERL; as such, the programs are designed to work on any lake basin named in the coordinating file for which sufficient information is available in supporting data files. Thus, there are data files, filename conventions, and program code that appear unnecessary for use on a specific lake basin, but allow general use on several lake basins. GLERL also has implemented other programs to automatically modify the source code of some of the programs presented herein for use on different lake basins. GLERL uses these programs in a computer procedure that runs the individual programs and performs all file manipulations; this makes possible the automatic preparation of forecast products. This procedure is not included here as it is specific to GLERL's VAX 11/780 minicomputer system.

The following files must be present on the user's disk before a forecast is made; complete documentation on all of these files is contained in Appendix B.

1. AREA.xxx This file contains the subbasin and lake areas and is read only. The extension, xxx, denotes the three-byte lake name in GLERL's applications on the VAX 11/780 computer (e.g., "SUP" for Lake Superior). See documentation in Appendix B, section V.C.

2. BSNNM. This file contains the basin name and other information required by the forecast programs; it is read and written. See documentation in Appendix B, section I.A.

3. NBSQUANTS.xxx This file contains monthly net basin supply quantiles computed from historic records and is read only. See documentation in Appendix B, section XIV.N.

4. LVLQUANTS.xxx This file contains mean monthly beginning-of-month lake levels, computed from historic records, and is read only. See documentation in Appendix B, section XIV.J.

5. RUNQUANTS.xxx This file contains quantiles of monthly runoff to the lake, computed from historic records, and is read only. See documentation in Appendix B, section XIV.M.

6. STOQUANTS.xxx This file contains quantiles of daily basin storages, computed from the LBRM applied to historic records, and is read only. See documentation in Appendix B, section XI.B.

7. PARMTABLE.xxx This file contains the runoff model parameters for the LBRM for each subbasin about the lake, including field measurements of basin moistures that are to be used as boundary conditions in the forecast; the file is read only. See documentation in Appendix B, section VI.D.

8. xxx%%.CLM, where [%%] = [00], [01], ..., [number of subbasins about the lake (e.g., 22 for Lake Superior)]. These files, one for each subbasin and one for the lake itself, contain the historic hydrometeorologic area1 averages for each day of record and are read only. See documentation in Appendix B, section VII.D.

9. xxx%%.PRV, where [%%] = [00], [01], ... [number of subbasins about the lake]. These files contain the provisional meteorologic area1 averages for each day of record for all subbasins and the lake; the files are read and written. See documentation in Appendix B, sections V.E and VII.D.

10. xxx%%.SUM, where [%%] = [01], [02], ..., [number of subbasins about the lake]. These files contain the daily model storages for each subbasin and are read and written. See documentation in Appendix B, section VI.C.

11. xxxALL.MET This file contains the provisional meteorologic area1 averages for the entire basin for each day of record. It has the same structure as xxx%%.PRV and is read and written. See documentation in Appendix B, section X.F.

12. xxxALL.SUM This file contains the daily entire-basin moisture storages compiled by aggregating model results for each of the subbasins over the provisional data period. It has the same structure as xxx%%.SUM and is read and written. See documentation in Appendix B, section VIII.E.

13. xxxBYTCOD.MAP This file contains the digital map of the lake and its subbasins, consisting of an array of codes representing the various subbasins, the lake, and area external to the entire basin. This file is read only. See documentation in Appendix B, section V.D.

14. ZSEVAP.xxx This file contains the daily lake evaporation and net groundwater flux to the lake, computed from the historic records, to be added to basin runoff for computation of net basin supply. This file is read only. See documentation in Appendix B, section XII.G.

15. NBSTABLE.NUL This file contains the template for the one-page forecast summary. It is read only. See documentation in Appendix B, section XV.D.

16. NOAASYM.DAT This file contains plot data for the NOAA symbol for use with the programs that plot basin moisture storages and meteorology. It is read only. See documentation in Appendix B, section XVI.I.

17. Mx#######.PRV where x = "U" for a United States station and "C" for a Canadian station, and ####### = seven-digit station identification number. These files, one for each station, contain new or changed provisional meteorologic data. They must be supplied by the user; they are read only. See documentation in Appendix B, section I.C.

18. PROVISNAL.LIS This file contains the full filename specification for each provisional data file (Mx#######.PRV) to be included in the provisional data update. It is read only. See documentation in Appendix B, section I.B.

19. DATEFILE.INT This file contains the date of the beginning of one of the historic meteorologic time series selected for use as the forecast sequence to be used for generation of the forecast water supplies. It also contains the date that the forecast is made (present date). One version of this file must be supplied by the user for each historic time series selected; files are read only. See documentation in Appendix B, section IX.G.

20. PROVISNAL.xxx and PROVISTWO.xxx These files constitute the provisional data base created and maintained by the forecast package. They contain all data provided by the user in all past forecast sessions. They need not be present the first time the package is used; they are created if nonexistent and then must be present subsequently; they are read and written. See documentation in Appendix B, section II.C.

21. YEARFILE.INT This file contains the year of record of each historic sequence used for generation of the forecast water supplies. It is read only. See documentation in Appendix B, section XIV.D.

Of the above files, AREA.xxx, BSNNM., NBSQUANTS.xxx, RUNQUANTS.xxx, PARMTABLE.xxx, xxx%%.CLM, xxx%%.PRV, xxx%%.SUM, xxxALL.SUM, xxxBYTCOD.MAP, ZSEVAP.xxx, NBSTABLE.NUL, Mx#######.PRV, PROVISNAL.LIS, DATEFILE.INT, YEARFILE.INT, and PROVISNAL.xxx and PROVISTWO.xxx (except for the first time) are required and LVLQUANTS.xxx, STOQUANTS.xxx, xxxALL.MET, and NOAASYM.DAT are optional. The files: Mx#######.PRV, PROVISNAL.LIS, YEARFILE.INT, and DATEFILE.INT (one version for each year selected from the historic record) must be supplied by the user. The forecast is generated by the following procedure:

0. Backup all data bases and unprotect all files.

1. Add new provisional data by creating provisional meteorologic station data files for addition to the data base, one file for each station named. See documentation in Appendix B, section I.C.

2. Create filename list file, PROVISNAL.LIS, containing the filename of each of the files created in step 1. See documentation in Appendix B, section I.B.

3. Check for obvious data errors in the Mx#######.PRV files by running ERRCHECK.NI4; see documentation in Appendix B, section I. (Note: the extension "NI4" is used to denote that the FORTRAN-77 program must be compiled to use only 2-byte integers.) If data errors are reported, then correct the appropriate provisional meteorologic station data files and repeat step 3.

3a. Backup all correct provisional station data files.

4. Add the new provisional data (in Mx#######.PRV) to the data base (PROVISNAL.xxx and PROVISTWO.xxx) by running PROVISNAL.NI4. See documentation in Appendix B, section II.

5. Optionally repack the provisional data base (PROVISNAL.xxx and PROVISTWO.xxx) by running REPACK.NI4; although not necessary, repacking is recommended. See documentation in Appendix B, section III (1).

6. Optionally look at the provisional data base (PROVISNAL.xxx and PROVISTWO.xxx) by running PROVISSEE.NI4. This program has no effect on the data base, but lists the linked-list data structure (PROVISNAL.xxx and PROVISTWO.xxx) logically for inspection; see documentation in Appendix B, section III (2).

7. Archive the user-supplied provisional meteorologic data files (Mx#######.PRV), if desired, and remove from the active disk storage.

8. Optionally repeat steps l-7 for more provisional data additions, changes, or deletions as desired.

9. Add the NEW data in the provisional data base (PROVISNAL.xxx and PROVISTWO.xxx) to the provisional subbasin data files (xxx%%.PRV) by computing subbasin area1 averages by running DISAVGMET.NI4; see Appendix B, section V. GLERL applications prepare this program by running program PRPDSAVMT.FOR; see Appendix B, section IV. The provisional data end date, the forecast end date (6 full months after the provisional data end date), and the plot start date (2 years and 1 day earlier than the forecast end date) are put into file BSNNM. Also, the date of the earliest changed or added data is compared with dates in BSNNM. that represent when updates of files xxx%%.SUM, xxxALL.SUM, and xxxALL.MET must begin; the earlier dates replace later dates in file BSNNM.

9a Optionally repeat steps l-9 for more provisional data additions, changes, or deletions as desired.

10 Add field measurements of subbasin moisture storages, if any, by editing file PARMTABLE.xxx. See comments in Appendix B, section VI.D. for information on format and content of these additions.

11. Create parameter files (SUPARAM%%.INT) for updating the subbasin model storages files (xxx%%.SUM) with provisional data in step 12 by running program CPFFUOPMS.NI4; see Appendix B, section VI.

12. Update the subbasin model storages files (xxx%%.SUM) with provisional data by running the LBRM with the parameter files (SUPARAM%%.INT) and subbasin data files (xxx%%.PRV) by running program WATOUT.NI4; see Appendix B, section VII.

13. Update the entire-basin model storages file (xxxALL.SUM) with provisional data by aggregating the subbasin model storages files (xxx%%.SUM) by running program LUMPSTOR.NI4; see Appendix B, section VIII.

13a. Optionally repeat steps 1-13 for more provisional data additions, changes, or deletions as desired.

14. Backup all data bases (PROVISNAL.xxx, PROVISTWO.xxx, xxx%%.PRV, xxx%%.SUM, and xxxALL.SUM) now that they have all been updated.

15. Set a start date for the historic meteorologic time series to be used as the forecast sequence. The start date must be on or after the beginning date of the xxx%%.CLM files and the ZSEVAP.xxx file and earlier than 6 full months before the ending date of all those files. This date will be used by taking the 6 or more months of data, that start on this date, from the climatic data files (xxx%%.CLM and ZSEVAP.xxx) as the forecast meteorology. The day and month of this date must correspond to the day and month of the start of the forecast period (day after the end of the provisional data) and the year must be within the climatic data bases (xxx%%.CLM and ZSEVAP.xxx). If the user wishes to use an independently generated meteorologic sequence for the forecast, then the user must substitute for the xxx%%.CLM and ZSEVAP.xxx files. In either case, the user must create file DATEFILE.INT (see Appendix B, section IX.G) with the following structure.

    First, the historic meteorologic start date for the forecast:

    1st record: day number (1,..., 31), 18 format
    2nd record: month number (1,..., 12), 18 format
    3rd record: year number (1952,..., 2040), 18 format

    Second, the current date (date this forecast is made):

    4th record: day number (1,..., 31), I8 format
    5th record: month number (1,..., 12), 18 format
    6th record: year number (1952,..., 2040), 18 format

    Third, the end-of-day lake level on the last day of the available provisional data period (equivalent to the beginning-of-day lake level on the first day of the forecast period):

    7th record: lake level elevation (meters above a base datum) F10.3 format

16. Recreate parameter files (SUPARAM%%.INT) for extending the subbasin model storages files (xxx%%.SUM) over the forecast period in step 19 by running program CPFFSROMR.NI4; see Appendix B, section IX.

17. Optionally construct the simulation and forecast meteorologic time series for the entire basin for purposes of plotting or listing by running program CMOFPOSRO.NI4; this option is generally run only if a single meteorologic time series is to be used in generating the water supply forecast (a deterministic forecast). See Appendix B, section X.

18. Optionally construct comparison storage quantiles for the simulation and forecast period for purposes of plotting or listing by running program CSQFPOSRO.NI4; see Appendix B, section XI.

19. Update the subbasin model storage files (xxx%%.SUM) with forecast meteorology by running the LBRM with the parameter files (SUPARAM%%.INT) and the data files (xxx%%.CLM) by running program WATOUT.NI4; see Appendix B, section VII.

20. Update the entire-basin model storage file (xxxALL.SUM) with forecast meteorology by aggregating the forecast portion of the subbasin model storage files (xxx%%.SUM) by running program LUMPSTOR.NI4; see Appendix B, section VIII.

21. Tabulate forecast basin runoff, basin storages, and net basin supply for a single forecast meteorology sequence by running program LUMPOUT1.NI4; see Appendix B, section XII.

22. Optionally compute lake levels over the forecast period by running program LAKELVL.NI4; see Appendix B, section XIII.

23. Repeat steps 15, 16, and 19-22 for all desired forecast sequences (all desired years of record selected from the climatic data period).

23a. Create file YEARFILE.INT containing each historic year used as a forecast, referred to in the third record of each version of DATEFILE.INT; see Appendix B, section XIV.D.

24. Determine the average daily values for all basin storages and the average monthly values for runoff, net basin supply, and (optionally) lake levels for tabulation and listing or plotting by running program LUMPOUT2.NI4; see Appendix B, section XIV.

25. Fill out summary forecast table (NBSTABLE.NUL) by running program NBSTABLE.NI4 to create file NBSTABLE.INT; see Appendix B, section XV.

26. Optionally create print files of basin moisture storages and (optional) storages quantiles for comparison and (optional with deterministic forecast) air temperatures and precipitation over the basin for the simulation and forecast periods (a 2-year period with the last 6 full months as forecast) by running program

PRNTFCAST.NI4. The print file is FORECAST.PRN; see Appendix B, section XVII.

27. Optionally create plot files of basin moisture storages and (optional) storage quantiles for comparison and (optional with deterministic forecast) air temperatures and precipitation over the basin for the simulation and forecast periods (a 2-year period with the last 6 full months as forecast) by running program PLOTFCAST.FOR; it requires the ISSCO DISSPLA plotting package and file NOAASYM.DAT. See Appendix B, section XVI.

28. Print output files of interest and clean up all intermediate files. Delete all files with the ".INT" extension; they are intermediate to the operation of the forecast package and are not part of the permanent data bases.

The above forecast procedure normally executes sequentially (with the exception of the branches at steps 3, 8, 9a, 13a, and 23) as just given, as long as the user makes no errors running the programs, constructing user-supplied files, or adding user-supplied information to existing files. To alleviate possible problems, there are several error traps built into the forecast procedure programs. For example, if any of the programs are run out of sequence, an appropriate error message is generated with the required corrective action to be taken. Other error traps and their corrective actions are summarized below; the numbers refer to the respective steps, given above, in the forecast procedure:

3. If error = PROVISNAL.LIS not available, go to step 2.

4. If error = attempt to add data previous to base year, omit offending provisional data and go to step 1.

   If error = insufficient number of days allowed, redimension array in PROVISNAL.NI4, recompile, and go to step 4.

   If error = PROVISNAL.xxx does not have valid data on base date, add appropriate provisional data for the base date and go to step 1.

   If error = problems with PROVISNAL.xxx or PROVISTWO.xxx, go to last backup and begin with step 1.

9. If error = end-of-file reached before expected on provisional subbasin data file, go to last backup and begin with step 1.

   If error = provisional subbasin data files do not begin on or prior to base date, restore the xxx%%.PRV files from last backup and go to step 9.

   If error = datafile PROVISNAL.xxx or PROVISTWO.xxx not present or in error, go to last backup and begin with step 1.

11. If error = simulation requires beginning earlier than model storages are recorded, go to last backup and begin with step 1.

12. If error = illegal data filename extension (not "PRV"), correct filenames and go to step 12.

If error = missing data in first record of data file not allowed, restore xxx%%.PRV from last backup and go to step 1.

16. If error = requested forecast date is outside of climatic data period, reselect forecast date and go to step 15.

17. If error = requested plot start date is outside of provisional entire-basin meteorologic data period, either forget this option or go to last backup and begin again with step 15.

19. If error = illegal data filename extension (not "CLM"), correct filenames and go to step 19.

If error = missing data in first record of data file not allowed, restore xxx%%.PRV from last backup and go to step 15.

If error = precipitation array not dimensioned large enough, redimension array, recompile, and go to step 19.

21. If error = unknown specification for computation of lake precipitation, file BSNNM. is corrupted; correct and go to step 21. If error = historic period starts or ends outside of lake evaporation file, reselect forecast sequence from historic records and go to step 15.

4. EXTENDED FORECAST PACKAGE ANATOMY

The use of the forecast package, as detailed in section 3, is supported by data preparation in the first three modules in Fig. 2. Those modules and the remaining details of the last three modules in Fig. 2 are presented in this section.

4.1 Historic Data Reduction (Module 1)

Before using the first module in Fig. 2, a "digital map" of all subbasins must be prepared for use in the ensuing computations. A digital map is a two-dimensional array representing the subbasins. The array indices represent location coordinates of points or cells on the map (Croley and Hartmann, 1985a). For each set of coordinates (array indices), the array contains the number of the subbasin (l-22 for Lake Superior) defining what is in the area at that location. There are also numbers corresponding to the lake and to areas outside the basin. A l-km interval is used to digitize 1:500,000- scale drainage maps for each lake where forecasts are desired. The resolution of the subbasins to the nearest square kilometer results in a precision that is well within the accuracies of the original map. Once the digital map has been created, meteorologic station files (Mx######.DAT) are assembled for all stations about and in the subbasins, and hydrologic station files (Fx#######.DAT) are assembled for all "most-downstream" flow stations in the subbasins. The first module then automatically constructs the climatic subbasin data files (xxx%%.DLY).

Each meteorologic station file (Mx#######.DAT) contains daily values of minimum air temperature, maximum air temperature, and precipitation for the length of the historic record as well as the location of the station. Only about 30 years of daily data are used in subsequent processing. An edge-determination algorithm for arbitrary shapes (Croley, 1985a) is first used to identify the total basin boundary from the digital map in a completely automated fashion. The files are then ordered by distance from the total basin and the nearest 150-300 stations are identified for subsequent use. The actual number used depends on the station density, data quality, and length of record available at each station. The remaining data reduction procedure to process station files is then automatically implemented; the choice of procedure is dependent on system limitations as to number of files allowed open at one time and on the amount and form of the disk storage available for processing. For each subbasin; for each day, all stations reporting on that day are considered to compute Thiessen weights for the resulting networks for each of minimum air temperature, maximum air temperature, and precipitation if those networks have not already been considered in previous days. Special data structures are implemented for efficient use of earlier networks when possible. The meteorologic data from all stations then are weighted and combined for each subbasin to construct the climatic subbasin files (xxx%%.DLY). The hydrologic station files (Fx#######.DAT) are then used to estimate the historic subbasin outflows, which are added to the climatic subbasin files (xxx%%.DLY); records for the "most-downstream" flow stations on separate tributaries are combined by aggregating and extrapolating for ungauged areas.

The weighting process for the meteorologic data could be difficult because the meteorologic network is never static. Stations are always being added, deleted, moved, or temporarily dropped from the network when they fail to report for short periods of time (missing data). Various methods of computing Thiessen weights either have large computational overheads or provide unacceptable approximations. A new algorithm was developed (Croley and Hartmann, 1985a) that determines weights by finding first the edges of the Thiessen polygon about each station and then the intersections of the polygons with watershed areas. It makes use of the fact that Thiessen polygons are convex sets of points. The edge-definition procedure is especially advantageous for high-resolution maps of watershed areas, even with extremely high-density data-observation networks. Considerable computational savings result by defining polygons by their edges instead of by their area1 extent; this savings has made feasible the use of all available meteorologic data in the historic record without approximating Thiessen network changes, and the near-real-time reduction of provisional data as they are available from the field.

4.2 Calibration (Module 2)

Each of the climatic subbasin files (xxx%%.DLY), except for the one corresponding to lake meteorology (xxx00.DLY), is used with the LBRM, as outlined in the previous discussion of the runoff model, to determine optimum parameter sets for each subbasin. These parameter sets are combined into a parameter table contained in file PARMTABLE.xxx, described in the Appendix B, section VI.D. The initial conditions and any boundary conditions available from field measurements are also placed therein.

4.3 Provisional Data Bases Initialization (Module 3)

The third module in Fig. 2 concerns the estimation of various quantiles; there are two purposes for this estimation. Quantiles of basin storages, runoff, and net basin supply are useful for providing a historic perspective with which to interpret subsequent forecasts. Also, quantiles of daily average air temperature and precipitation are used in selecting candidate forecast meteorologic sequences corresponding to the National Weather Service monthly and seasonal outlooks. The entire module is completely automated and begins with the creation of subbasin parameter files by using calibrated parameters (in PARMTABLE.xxx) and simulation dates corresponding to the entire period of the climatic subbasin data files (xxx%%.DLY). The LBRM is used with these parameter and data sets to simulate the historic subbasin moisture storages corresponding to each of the "tanks" in the model. Historic runoff from each subbasin is aggregated to compile runoff from the entire basin. A water balance on the lake yields estimates of the historic lake evaporation and net groundwater flux to the lake (placed into file ZSEVAP.xxx) which are combined with historic runoff and precipitation to estimate the historic net basin supply. Non-exceedance quantiles (in 10% increments) of each of the total basin moisture storages (placed into the unformatted file STOQUANTS.xxx), runoff (placed into file RUNQUANTS.xxx), net basin supply (placed into file NBSQUANTS.xxx), and mean lake levels (placed into file LVLQUANTS.xxx) are computed for each day (moisture storages) or month (runoff, net basin supply, and lake levels) of the annual cycle. Next, climatic subbasin data files (xxx%%.DLY) are aggregated to determine the entire-basin spatially lumped daily minimum and maximum air temperatures, precipitation, and runoff for the entire basin. The entire-basin hydrometeorologic data are next analyzed to estimate non-exceedance quantiles (in 5% increments) for monthly, mid-monthly, and seasonal (3-month) air temperature and precipitation by considering the entire record for each selected period; e.g., January precipitation quantiles are computed by considering all Januaries in the total record. After these quantiles are estimated, they are used with each year of record to estimate the non-exceedance probabilities associated with them for their respective period in each year; e.g., the 1964 January non-exceedance probability corresponding to the 50% January precipitation quantile is estimated by the relative number of days in January 1964 that precipitation does not exceed this quantile. There are then 12 non-exceedance tables produced for the monthly historic meteorologic quantiles, 12 for the mid-monthly quantiles (all 24 are placed into file METPROB3.xxx), and 12 for the seasonal quantiles (placed into file METPROB9.xxx). Finally, this module creates unformatted, direct access files of the climatic subbasin hydrometeorologic data sets (xxx%%.DLY => xxx%%.CLM), approximately the last 18 months of the climatic entire-basin hydrometeorologic data (xxxALL.MET), and approximately the last 18 months of the modeled climatic subbasin moisture srorages (xxx%%.SUM). The subbasin storages files (xxx%%.SUM) are aggregated to construct the total basin storages file (xxxALL.SUM). The unformatted, direct access files of provisional subbasin data (xxx%%.PRV) are initialized for use with the forecast data base update and basin response forecast modules.

4.4 Provisional Data Bases Update (Module 4)

The fourth module in Fig. 2 accepts new provisional data and adds them to the forecast data bases. Provisional data are temperatures and precipitation values that are reported in near-real time; they are usually corrected in some way by the collecting agency before they are archived as historic or climatic data. To make timely forecasts, a responsive data collection and reporting system must exist. The first concern must be the data network density necessary for reliable modeling. Special studies of size and location for both meteorologic and hydrologic gauges on the Lake Superior basin, carried out in cooperation with the U.S. Army Corps of Engineers, Detroit District, indicate that from 20 to 30 existing meteorologic stations are suitable for weekly estimates of basin runoff although some additions in Canada are indicated (Croley and Hartmann, 1984). A special study also looked at the effect of data availability on Lake Superior runoff forecasts (Hartmann and Croley, 1984). We found that modeling explained 78% of the variance of basin outflow with no delay in processing data, 70% for a l-week delay, and 66% with a 2-week delay; with a lo-week delay, forecasts are no better than those using data available with a Z-year delay.

The fourth module requires external preparation of individual provisional meteorologic data station files (Mx#######.PRV), one for each station (Fig. 3a). Each file contains the latest daily values of minimum and maximum air temperature and precipitation since the last time that the data bases were updated; they also contain new, corrected, or changed data values for any days prior to the last update. There are no restrictions on continuous or chronologic data; the user can add or delete stations for previous periods and change data values for previous dates as well as add new provisional data. The fourth module then automatically updates all forecast data bases. All provisional station files are checked for format and range errors with program ERRCHECK.NI4. The station files are then read by program PROVISNAL.NI4, one at a time, and added to a provisional data base (PROVISNAL.xxx and PROVISTWO.xxx) as in Fig. 3b, structured as a linked-list of data blocks with each block representing one day of record and consisting of the individual station data for that day; the linked-list is optionally reordered with program REPACK.NI4 from time to time to increase data base operation efficiency and to conserve disk space. The linked-list enables very fast addition of new data or change of old data. As each data item is incorporated into the provisional data base, the data block containing the item is flagged as "new" data for subsequent processing; after the provisional station files (Mx#######.PRV) are incorporated into the provisional data base (PROVISNAL.xxx and PROVISTWO.xxx), they are archived.

The provisional data base (PROVISNAL.xxx and PROVISTWO.xxx) is then scanned by program DISAVGMET.NI4 and each flagged data block is input and used to compute the provisional subbasin area1 averages for incorporation into the provisional subbasin data files (xxx%%.PRV) as in Fig. 3c; the flag is then removed. Thiessen weighting and the polygon edge determination algorithm (Croley and Hartmann, 1985a) are again used for efficient processing while recomputation of Thiessen networks is avoided when unnecessary. Each provisional subbasin data file (xxx%%.PRV) corresponds to the respective climatic subbasin data file (xxx%%.CLM) except that provisional data are used to construct/update them; only those values that changed or were new since the last update (as reflected in the provisional station files, Mx######.PRV) are actually computed and placed directly into these files, overwriting the old or nonexistent values. Program DISAVGMET.NI4 computes and stores (in file BSNNM.) the provisional data end date, the forecast end date, and the simulation plot start date. The forecast end date is taken to be the end of the sixth full month following the end of the provisional data and the plot start date is taken as 2 years and 1 day earlier; it is when the (optional) plots of simulated and forecast basin moisture storages begin. Program DISAVGMET.NI4 also compares the date of the earliest new or changed data with dates already existing in file BSNNM. which represent when updates of files xxx%%.SUM, xxxALL.SUM, and xxxALL.MET must begin; DISAVGMET.NI4 places the earliest of each of the compared dates into file BSNNM.

After the update of the provisional subbasin data files (xxx%%.PRV), subbasin parameter files (SUPARAM%%.INT) are created by program CPFFUOPMS.NI4 from the calibrated parameter sets (PARMTABLE.xxx) and from simulation dates that correspond to the date of the earliest new or changed data and the date of the last data in the provisional subbasin data files (xxx%%.PRV). Initial and boundary conditions, corresponding to field measurements of basin moisture that are present in the parameter table file (PARMTABLE.xxx), are added also to the parameter files (SUPARAM%%.INT). The subbasin parameter files (SUPARAM%%.INT) and provisional data files (xxx%%.PRV) are then used with the LBRM by program WATOUT.NI4 to update each of the subbasin storages files (xxx%%.SUM) as in Fig. 3e; the updates are directly made in the storages files from the point of the earliest change or addition of provisional data to the end of the provisional data. Then the additions to the subbasin storage files (xxx%%.SUM) are aggregated to update the entire-basin storage file (xxxALL.SUM) by program LUMPSTOR.NI4, again from the date of the earliest change or addition to the end of the provisional data base (Fig. 3f). At the completion of this module, the new or changed provisional meteorologic data (in files Mx######.PRV, Fig. 3a) have been incorporated into the provisional data base (PROVISNAL.xxx and PROVISTWO.xxx, Fig. 3b), the provisional subbasin data sets (xxx%%.PRV, Fig. 3c), the subbasin storage files (xxx%%.SUM, Fig. 3e), and the entire-basin storage file (xxxALL.SUM, Fig. 3f).

4.5 Forecast Meteorology Selection (Module 5)

Module 5 in Fig. 2 uses National Weather Service (NWS) monthly and seasonal outlooks of air temperature and precipitation probabilities (NWS, 1984) to select a forecast meteorologic sequence from among the historic records available from module 1. After reading the forecast probabilities for the location of the basin of interest, the meteorologic quantile non-exceedance probability tables (files METPROB3.xxx and METPROB9.xxx, compiled in module 3) are scanned to identify several years of the entire-basin historic record that best match the weather forecasts over the water supply forecast period of interest. The historic daily values of areally averaged minimum and maximum air temperatures and precipitation for each subbasin (taken from files xxx%%.CLM), and lake evaporation (taken from file ZSEVAP.xxx) corresponding to the forecast period of interest then will be taken from the identified years of record and used as the forecast meteorologic sequences in the next module in Fig. 2. Thus, the spatial and temporal interdependencies of the meteorologic processes are preserved; admittedly, the extremes are limited to only those of record, but this is not considered a problem since subbasin area1 averages are used, corresponding to very large areas that do not have as extreme data values as small areas. Each selected sequence, for each subbasin, will be added directly to the provisional subbasin data sets corresponding to the starting date of the forecast in the following module. Each selected sequence is identified by its historic start date; the month and day are those that follow the end of the provisional data, and the year corresponds to the desired historic period. This date is placed into a file (DATEFILE.INT) for transmittal to the next module.

4.6 Basin Response Forecast (Module 6)

The sixth module in Fig. 2 accepts a set of forecast meteorologic sequences (identified by its start date in file DATEFILE.INT) from module 5 and uses it with the LBRM for each of its subbasins to automatically simulate the resulting basin runoff; the forecast basin runoff is then predicated on the forecast meteorology and the subbasin storages that exist at the beginning of the forecast period (end of the provisional data period as computed in module 4). This module starts by creating subbasin parameter files (SUPARAM%%.INT) with program CPFFSROMR.NI4 from the calibrated parameter sets (PARMTABLE.xxx); the simulation start date corresponds to the beginning of the forecast period and initial subbasin storages (from xxx%%.SUM) correspond to the end of the provisional data period. The LBRM is then used in program WATOUT.NI4 on each subbasin with the subbasin parameter files (SUPARAM%%.INT) and "forecast" meteorologic data sets (from xxx%%.CLM) to simulate the forecast runoff and to update the subbasin storages files (xxx%%.SUM) for the forecast period (Fig. 3i). The subbasin storages files (xxx%%.SUM) then are aggregated in program LUMPSTOR.NI4 to update the entire-basin storages and runoff file (xxxALL.SUM) as in Fig. 3j. Optionally, the provisional subbasin meteorologic files (xxx%%.PRV) and the data extracted from the historic subbasin hydrometeorologic files (xxx%%.CLM) are aggregated over the simulation and forecast period by program CMOFPOSRO.NI4 to update the entire-basin areally averaged meteorologic data file (xxxALL.MET), as in Figs. 3d and 3h, and to prepare an intermediate file (SMETOTLKS.INT) of temperatures and precipitation over the simulation and forecast period for plotting or listing. Optionally, the storage quantiles file (STOQUANTS.xxx) is read by program CSQFPOSRO.NI4, which prepares another intermediate file (SSTOQUANT.INT) of storage quantiles (20%, 50%, and 80%) over the simulation and forecast period for plotting or listing (Fig. 3k).

The entire-basin runoff, lake precipitation, and lake evaporation are combined to forecast net basin supply for the lake in program LUMPOUT1.NI4 (Fig. 31); a plot file of basin storages and quantiles over the simulation and forecast period is produced (STOOTLzz.INT, where "zz" is the last two digits of the historic year of record selected for the forecast sequence), as well as a summary table file (FCSTBLzz.INT) and an intermediate file of daily net basin supplies over the forecast period (NBSOTLzz.INT). Optionally, the file NBSOTLzz.INT is read by program LAKELVL.NI4 to compute lake levels in file LVLOTLzz.INT (Fig. 3m). Programs CPFFSROMR.NI4, WATOUT.NI4, LUMPSTOR.NI4, LAKELVL.NI4 (optionally), and LUMPOUT1.NI4 are repeated in this order for each historic year of record selected as a candidate meteorologic sequence for use in the forecast. Program LUMPOUT2.NI4 is then used to combine all STOOTLzz.INT files, all FCSTBLzz.INT files, and (if present) all LVLOTLzz.INT files to produce (1) simulated storages for the approximately 18 months preceding the forecast as file SSTOSIMUL.INT, (2) forecast storages as the average of the simulations resulting from model runs on the selected years of meteorologic record as file SSTOOTLKS.INT, and (3) a table of forecast monthly runoff, net basin supply, and (optionally) beginning-of-month and end-of-month lake levels as the average of the values generated for each of the selected years of meteorologic record as file SFCSTTBLE.INT.

The summary table file (SFCSTTBLE.INT) is used by program NBSTABLE.NI4 along with the template file (NBSTABLE.NUL) to create a summary report of the runoff and net basin supply forecasts (NBSTABLE.INT). The forecast entire-basin storages are printed by program PRNTFCAST.NI4 or plotted by program PLOTFCAST.FOR along with the historic storage quantiles. If only a single historic year of record was selected to make the forecast, then the forecast meteorology is also (optionally) plotted. An example series of forecast products for Lake Superior is pictured in Figs. 4-9; example meteorologic plots for a deterministic forecast are shown in Figs. 10 and 11.

The six modules of Fig. 2 are reused as required for successive product updates, provisional data updates, and forecasts as illustrated thereon. Modules 5 and 6 are reexecuted for each selected year of record to form a forecast sample average. As new provisional data become available in near-real time, modules 4-6 are reexecuted to include the data and make revised forecasts. As data-collection agencies revise their provisional data and make them available to add to the historic records, the entire package of Fig. 2 may be reexecuted to revise the historic data bases, recalibrate the runoff models on each subbasin, and reinitialize the forecast data bases (also replacing the limited provisional data in those data bases with the more comprehensive historic data). Modules l-3 are executed infrequently (every 2-5 years) as historic data are available on machine-readable media; modules 4-6 are executed frequently (every day, week, or month) as provisional data are received in near-real time and as forecasts are desired. Modules 4-6 are encoded to run conveniently on small computers with 5 Mbytes of disk storage, using standard FORTRAN-77 or TURBO-PASCAL; the computer programs in these modules are configured to use a minimum of memory (under 50 kilobytes each on 8-bit machines).

4.7 Data Base Condensation

Two situations require that early provisional data in the forecast package data bases be removed. If the PROVISNAL.xxx and PROVISTWO.xxx data bases reach their maximum file size (32767 records each), no new provisional data may be added until other data in the files are eliminated; early provisional data that require no additions, deletions, or changes may be removed without affecting the forecasts, since the runoff model storages are updated beginning with the earliest date of change in the PROVISNAL.xxx or PROVISTWO.xxx files.

Additionally, as agency-approved data become available the climatic data files xxx%%.DLY and xxx%%.CLM may be extended, eliminating the need for corresponding data in the provisional data files and enabling more efficient processing in generating water supply outlooks. This subsection describes the procedures for removing early provisional data from the forecast package data bases.

As the PROVISNAL.xxx and PROVISTWO.xxx files reach their maximum allowable size, early provisional data must be removed. In fact, removal of early provisional data from all forecast package data bases minimizes storage requirements; however, the user must be confident that no data will be added, deleted, or changed over the period for which data are to be eliminated. To remove the early provisional data from the forecast package data bases, the base date (third record) in the BSNNM. file must be reset to the date the PROVISNAL.xxx and PROVISTWO.xxx files begin. Then, program REPACK.NI4 must be run; it deletes all data prior to the new base date in PROVISNAL.xxx and PROVISTWO.xxx and repacks the files. Finally, program REEPACK.NI4 (see section XVIII in the Appendix B) must be run. That program deletes early provisional data so that the xxxALL.SUM and xxxALL.MET files begin 560 days before the new base date, the xxx%%.SUM files begin one day before the new base date, and the xxx%%.PRV files begin the day of the new base date. The forecast package can then be run as documented in section 3.2.

Updates of the climatic meteorologic data bases (xxx%%.DLY and xxx%%.CLM) eliminate the need for provisional data for the same period in the forecast package data bases. This update is done at GLERL only; it requires a procedure and programs not implemented elsewhere. This update is accomplished by setting the base date (third record) in the BSNNM. file to the day after the end of the new climatic data. Program REPACK.NI4 is then run to shorten the PROVISNAL.xxx and PROVISTWO.xxx files to begin at the new base date. Copies of the current xxxALL.MET and xxx%%.PRV files are protected from modification and saved for future use. The GLERL procedure, QUANTILES.COM (described in section 4.3), is run to add the new climatic data to the xxx%%.CLM files and create new xxx%%.SUM and xxxALL.SUM files. The xxx%%.PRV and xxxALL.MET files produced by the QUANTILES procedure are deleted and their old counterparts are restored for modification; the newly-created xxx%%.SUM and xxxALL.SUM files are protected from modification and saved for future use. Program REEPACK.NI4 (see section XVIII in the Appendix B) is run to shorten the xxx%%.PRV and xxxALL.MET files. Finally, the xxx%%.SUM and xxxALL.SUM files produced by REEPACK.NI4 are deleted and their counterparts from the QUANTILES procedure are restored. The resulting xxx%%.CLM files extend to the day before the new base date, the xxxALL.SUM and xxxALL.MET files begin 560 days before the new base date, the xxx%%.SUM files begin one day before the new base date, and the xxx%%.PRV files begin on the new base date. The forecast package can then be run as documented in section 3.2.

5. LAKE SUPERIOR BASIN EVALUATION

To assess the efficacy of our outlook package, we first compared it with climatologic outlooks for the period August 1982 through December 1984. This period is outside the calibration periods, for the LBRM applied to each of the subbasins, which range from about 1965 through 1978-82. National Weather

Service (NWS) meteorologic probability forecasts are not available prior to August 1982 in their present form. Likewise, sufficient data are not yet available for meaningful comparisons after December 1984. The climatologic approach consists of using 30-year medians for each month from the climatic data base (January 1954 through December 1983) as a forecast of net basin supply over the 6 months beginning each month of the comparison period. There are 29 such forecasts for this period, each 6 months long. Selected statistics are presented in Table 1. Since the comparison period and the climatic data base overlap, there is a slight bias in favor of the climatologic approach. The root mean square error (rmse) between actual and climatologic forecast net basin supplies, in Table 1, is about 41 mm for each of the 1- through 3-month forecasts, with correlations of about 0.82. The bias is rather high at about 15 mm, reflecting the fact that the comparison period had high net basin supplies whereas the climatologic approach predicted median values.

Table 1.--Climatologic supply forecast statistics

Month	Sample Size	Mean (actual) (mm)	Mean (forecast) (mm)	Stand. Dev. (actual) (mm)	Stand. Dev. (forecast) (mm)	RMSE (mm)	Bias (mm)	Correlation
1	29	77.95	63.24	57.98	64.44	40.57	14.71	0.81
2	28	77.61	61.76	58.98	65.09	41.16	15.85	0.82
3	27	76.89	61.45	59.94	66.27	41.60	15.44	0.82
4	26	73.55	62.84	58.57	67.14	32.54	10.71	0.89
5	25	74.08	64.58	59.66	67.89	32.16	9.50	0.89
6	24	75.04	68.12	60.71	66.99	29.41	6.92	0.90

The forecast procedure, as previously described, was used next in a simulated operational mode. For each month of the evaluation period, reception from the near-real time data acquisition network was simulated to correspond to typical data availability for the Lake Superior Basin: 25 stations reporting within 1 week, 17 additional stations reporting within 6 weeks, and reports from all 57 stations updated after 5 months. One-month and 3-month outlook probabilities of daily air temperature and precipitation were taken from the NWS outlooks for the evaluation period, without considering what meteorology actually transpired. These were used to generate 29 6-month forecasts; selected statistics are presented in Table 2. Note that insufficient data exist to estimate seasonal errors, and lack of long-term weather forecasts limits our evaluation to the first three forecast months.

Compared with the climatology in Table 1, the results of the forecast evaluation are not striking at first glance. Correlations for each of the first three forecast months are uniformly poorer for the forecast procedure; likewise, although rmse is slightly better with the forecast procedure for the first month, it is poorer for the second and third forecast months. However, the forecast procedure is much less biased (about 5 mm) than climatology (about 15 mm), which is especially significant for a period of extreme supplies and especially important since the forecasts are used for regulation purposes. Lower bias implies that our forecasts, on the average, will be better than climatology. However, higher rmse and lower bias imply that the forecast procedure has higher estimation variance than climatology (for a single forecast, estimates could be worse than with climatology). The lower bias is due to the consideration of current moisture storages via modeling and field measurements, which is not possible with climatology. Additional analyses (discussed subsequently) show that reductions in estimation variance are possible, giving the forecast package distinct advantages over climatology.

Table 2.--Near-real time supply forecast statistics with NWS probabilities

Month	Mean (mm)	Standard Deviation (mm)	RMSE (mm)	Bias (mm)	Correlation
1	82.77	65.14	40.15	-4.82	0.80
2	72.21	70.49	46.94	5.40	0.75
3	72.84	71.58	43.94	4.05	0.79
4	66.93	60.30	26.50	6.62	0.91
5	68.54	71.05	36.79	5.54	0.86
6	78.30	70.07	32.50	-3.26	0.89

Improvement of the forecast procedure depends upon knowledge of significant error components within the procedure. Several more evaluation runs were made to isolate the error components associated with each of the main parts of the procedure. The first of these looked at the effect of timely reception of all near-real time data. Data from all 57 stations were used as if all were available in near real-time every month. Improvements were only marginal; converting more existing stations to near-real time would not significantly affect the forecast. Improvements may be possible by adding more stations, not currently considered, to the network; this was not investigated here.

Forecast errors are broken into two broad categories: those associated with the NWS meteorologic probability forecast errors, and those associated with modeling and procedural errors. The latter include sampling errors associated with the subjective selection of historic years of record that "match" to some extent the NWS outlooks and with selecting from a limited sample (30 years only are used for the Lake Superior forecasts). The latter also include conceptual modeling errors associated with each component of the water balance (runoff, overlake precipitation, and lake evaporation) and data errors associated with erroneous measurements (outflows from Lake Superior, lake levels, runoff, air temperatures, and precipitation) and associated with basic computations (the water balance to determine historic lake evaporation sums component errors in the evaporation estimate; overlake precipitation is estimated by overland precipitation, ignoring many lake effects). To assess the error component associated with the NWS meteorologic probability forecasts, an evaluation was made using the forecast procedure but not using the NWS probabilities. Instead, actual daily probabilities for each month of the evaluation period were used to select the historic meteorologic sequences for use in the procedure; selected statistics are presented in Table 3 and represent what could be expected from the present net basin supply forecast package if the NWS l-month and 3-month meteorology forecasts were perfect. Major improvements result for the first forecast month in correlation, rmse, and bias. Improvements in correlation and rmse were also seen for the second and third forecast months at the expense of poorer bias. Approximately 22%, 37%, and 10% of the forecast rmse for the first 3 months, respectively, are attributable to the NWS meteorologic probability forecasts over the evaluation period used herein.

Table 3.--Near-real-time supply forecast statistics with actual probabilities

Month	Mean (mm)	Standard Deviation (mm)	RMSE (mm)	Bias (mm)	Correlation
1	78.54	57.72	31.41	-0.59	0.85
2	67.64	61.78	29.34	9.97	0.90
3	67.04	65.28	39.75	9.85	0.81
4	69.40	66.36	33.12	4.15	0.87
5	70.59	66.75	31.78	3.49	0.88
6	75.27	75.96	41.15	-0.23	0.84

The error statistics of Tables 2 and 3 (with and without NWS forecast errors) were analyzed further by comparing observed water balance components of runoff, overlake precipitation, and lake evaporation with their forecasts over the evaluation period; these are summarized in Tables 4 (l-month statistics) and 5 (average 3-month statistics). Note that error compensation between net basin supply components preclude net basin supply error being equal to the sum of component errors in Tables 4 and 5. Improvements in all water balance component forecasts are reflected by all statistics in Tables 4 and 5 as NWS forecasts (and their errors) are replaced with actual probabilities. The majority of the net basin supply forecast error for both the l-month and the 3-month outlook is distributed mainly between overlake precipitation and lake evaporation, each of which is about twice the runoff error. After NWS forecast error is eliminated, the bulk of the conceptual errors is seen to be associated with lake evaporation. By comparing the two rows in each of Tables 4 and 5, we can assign the two categories of errors in Tables 6 and 7. Both tables further illustrate that the NWS forecast error is most keenly felt in the forecast of overlake precipitation; runoff and lake evaporation forecasts are affected little by errors in the NWS forecasts. Conceptual errors again relate mostly to lake evaporation and are about double those associated with runoff. To better depict the runoff modeling errors, an additional evaluation was made by using the forecast package with the actual meteorology that occurred during the evaluation period; results are in Table 8. Since there are only conceptual and data errors associated with runoff modeling, Table 8 shows how well the runoff model works during a period other

Table 4.--Selected l-month outlook error statistics

Forecast Package	Net Basin Supply	Runoff	Lake Precipitation	Lake Evaporation
	Water Supply Components[a]			
With Forecast Probabilities	40.15	11.66	21.30	22.22
	-4.82	0.29	-2.76	2.36
	0.80	0.83	0.67	0.87
With Actual Probabilities	31.41	10.84	13.28	20.51
	-0.59	2.11	2.01	4.71
	0.85	0.86	0.89	0.88

a Each group includes rmse (mm), bias (mm), and correlation, respectively.

Table 5.--Selected 3-month outlook error statistic averages

Forecast Package	Net Basin Supply	Runoff	Lake Precipitation	Lake Evaporation
	Water Supply Components[a]			
With Forecast Probabiiities	43.68	13.43	24.38	21.70
	1.54	2.26	1.52	2.24
	0.78	0.79	0.56	0.87
With Actual Probabilities	33.50	11.99	17.55	19.62
	6.41	3.57	3.22	0.38
	0.85	0.84	0.78	0.88

a Each group includes rmse (mm), bias (mm), and correlation, respectively.

Table 6.--One-month outlook component error estimates

Forecast Package	Net Basin Supply	Runoff	Lake Precipitation	Lake Evaporation
	Water Supply Components			
NWS Forecast Error[a]	8.74	0.82	8.02	1.71
Sampling, Modeling, and Data Errors[b]	31.41	10.84	13.28	20.51

a Difference in rms'e (mm) from Table 4.
b From Table 4, rmse "with actual probabilities."

Table 7.--Three-month outlook component average error estimates

Forecast Package	Water Supply Components: Net Basin Supply	Runoff	Lake Precipitation	Lake Evaporation
NWS Forecast Error[a]	10.18	1.44	6.83	2.08
Sampling, Modeling, and Data Errors[b]	33.50	11.99	17.55	19.62

a Difference in rmse (mm) from Table 5.
b From Table 5, rmse "with actual probabilities."

Table 8.--Water supply forecasts with actual meteorology.

Month	Mean (mm)	Standard Deviation (mm)	RMSE (mm)	Bias (mm)	Correlation
1	77.55	55.14	8.65	0.40	0.99
2	76.80	56.03	8.36	0.81	0.99
3	75.55	56.72	8.31	1.34	0.99
4	72.68	55.76	8.49	0.87	0.99
5	74.20	57.08	8.07	-0.12	0.99
6	75.41	58.26	8.00	-0.37	0.99

than the calibration periods used in applying the model to the Lake Superior subbasins. The model is judged to do an excellent job in simulating basin runoff to the lake.

We cannot assume that the NWS l-month forecast has higher confidence associated with it just because it is over a shorter period of time into the future. Depending upon the time of the year, the 3-month forecast may be more accurate than the l-month. This is especially true during the winter months or when extremes are being forecast (Gilman, 1985; Namias, 1985). Since the subjective selection of historic meteorologic scenarios is based on both l-month and 3-month probabilities, and since these two outlook periods often will indicate different scenario selections, a compromise is generally made in selecting the scenario that best matches both outlooks. Additional evaluations show that we can forecast net basin supplies 1 month into the future with a rmse of 28 mm, a bias of -0.7 mm and a correlation of 0.89 if we have perfect NWS l-month meteorology forecasts. This represents an improvement in forecast rmse for the l-month forecast (compare with Table 2) of about 30% instead of 22% that results from matching both the l-month and 3-month probabilities. Consideration of only the 3-month meteorologic probabilities resulted in generally poorer performance for the first three forecast months compared with results from use of both the l-month and 3-month meteorologic probabilities. This is expected, since without the l-month probabilities much information is lost on the time distributions of the precipitation and air temperatures over the 3-month period.

6. SUMMARY

Potential water supply forecasts in the face of uncertain meteorology are made possible by the intrinsic memory of large basins and lakes. The LBRM has been extended in a package allowing both probabilistic and deterministic near-real-time forecasts of water supplies for large lakes. The model is calibrated with the most recent climatic data for all subbasins about a lake and run from the end of the climatic data sets to the present by using provisional data. Forecast meteorology then is used to estimate basin runoff and basin storages over the next 6 months. Probabilistic forecasts use a biased sample of meteorologic forecasts, matching the monthly and seasonal NWS outlooks. GLERL has automated all calibration, climatic data reduction, provisional data reduction, and forecast procedures to enable the application of the model and forecast package to large lake basins. They have been applied to several of the Laurentian Great Lakes and other large lake basins. While the climatic data reduction and the LBRM calibration require memory resources generally available only on mainframe computers and are thus generally implemented only at GLERL, the provisional data reduction and forecast procedures are designed to run on small machines and to be transferred to agencies responsible for operational water supply forecasts. The provisional data reduction and forecast procedures require only a standard FORTRAN-77 or TURBO-PASCAL compiler, 5 Mbytes of disk storage, and a minimum of CPU and memory resources.

Although the Thiessen-weighting scheme was developed for use with point measurements, procedures must be developed to resolve the combination of simultaneous point, line, and area1 measurements. The use of multi-sensor observations is expected to improve our modeling and forecasting ability. However, other near-real-time data needs remain. The modeling of basin evapotranspiration should improve if we can actually measure the total heat available (rather than relying on a simple function of air temperature). Improved lake evaporation models are expected that can use near-real-time lake surface temperatures. Also, the LBRM was designed to describe only the natural basin response to meteorologic conditions. Thus, we require more information about regulation decision rules or the ability to monitor regulated flows in near-real time.

Our runoff modeling and runoff forecasts are very good over the next 1 to 3 months. Our net basin supply forecasts are less biased than climatology with about the same root mean square error; improvements in net basin supply forecasts await better forecasts and modeling of the components of the water balance other than runoff. For the present, our forecasts offer the additional advantage, over climatology, of incorporating current basin moisture conditions (reducing bias) through modeling and optional field measurements. Error analysis reveals that improvements in the NWS forecast of meteorologic probabilities will directly improve our forecast of net basin supplies, particularly with respect to overlake precipitation. Conceptual modeling improvements will most greatly benefit the forecast of net basin supplies by improving our lake evaporation forecasts. Additional improvements for the next l-month forecast result by using only the l-month meteorology probability forecasts from the National Weather Service.

7. REFERENCES

Croley, T.E., II. Great Lakes basins runoff modeling. NTIS (PB82-254228) Springfield, VA 22161, NOAA Tech. Memo. ERL GLERL-39, 96 pp. (1982).

Croley, T.E., II. Great Lakes basins (U.S.A.-Canada) runoff modeling. J. Hydrol. 64:135-158 (1983a).

Croley, T.E., II. Lake Ontario Basin (U.S.A.-Canada) runoff modeling. J. Hydrol. 66:101-121 (1983b).

Croley, T.E., II. Computer reduction of arbitrary shapes to convex components. In Proceedings of the Tenth Canadian Congress of Applied Mechanics, The University of Western Ontario, London, Ontario, D63-D64 (1985a).

Croley, T.E., II. Evapotranspiration dynamics for large river basins. In Proceedings of the National Conference on Advances in Evapotranspiration, American Society of Agricultural Engineers, St. Joseph, MI, 423-430. (1985B).

Croley, T.E., II, and H.C. Hartmann. Lake Ontario Basin runoff modeling. NTIS (PB83-237420) Springfield, VA 22161, NOAA Tech. Memo. ERL GLERL-43, 108 pp. (1983).

Croley, T.E., II, and H.C. Hartmann. Lake Superior Basin runoff modeling. NTIS (PB84-230028) Springfield, VA 22161, NOAA Tech. Memo. ERL GLERL-50, 284 pp. (1984).

Croley, T.E., II, and H.C. Hartmann. Resolving Thiessen polygons. J. Hydrol. 76:363-379 (1985a).

Croley, T.E., II, and H.C. Hartmann. Lake Champlain water supply forecasting. GLERL Open File Report, Contribution No. 450, Great Lakes Environmental Research Laboratory, Ann Arbor, MI 48104, 56 pp. (198513).

Croley, T.E., II, and H.C. Hartmann. Parameter calibration for the Large Basin Runoff Model. In Proceedings of the Fourth International Hydrology Symposium: Multivariate Analysis of Hydrologic Processes. Colorado State University, Ft. Collins, CO. (1985c).

Gauthier, R.L., R.A. Melloh, T.E. Croley II, and H.C. Hartmann. Application of multisensor observations to Great Lakes hydrologic forecast models. In Proceedings of the Eighteenth International Symposium on Remote Sensing of the Environment, Environmental Research Institute of Michigan, Ann Arbor, MI, 1129-1140 (1984).

Gilman, D.L. Long-range forecasting: the present and the future. Bull. Am. Meteorol. Soc. 66(2):159-164 (1985).

Hartmann, H.C., and T.E. Croley, II. The worth of near real-time meteorological data for Lake Superior runoff estimation. International Association for Great Lakes Research 27th Conference on Great Lakes Research, 30 April-3 May, 1984, St. Catherines, Ontario (1984).

International Lake Superior Board of Control. Regulation of Lake Superior: Plan 1977 Development, Description, and Testing. International Joint Commission, Washington, DC, 56 pp. (1981).

International Lake Superior Board of Control. Regulation of Lake Superior: Operational Guides for Plan 1977. International Joint Commission, Washington, DC, 52 pp. (1982).

Namias, J. Remarks on the potential for long-range forecasting. Bull. Am. Meteorol. Soc. 66(2):165-173 (1985).

NWS (National Weather Service). Monthly and seasonal weather outlook for December 1984. Climate Analysis Center, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, available from the United States Government Printing Office, Division of Public Documents, Washington, DC, Vol. 38, No. 23, 29 November 1984, 8 pp. (1984).

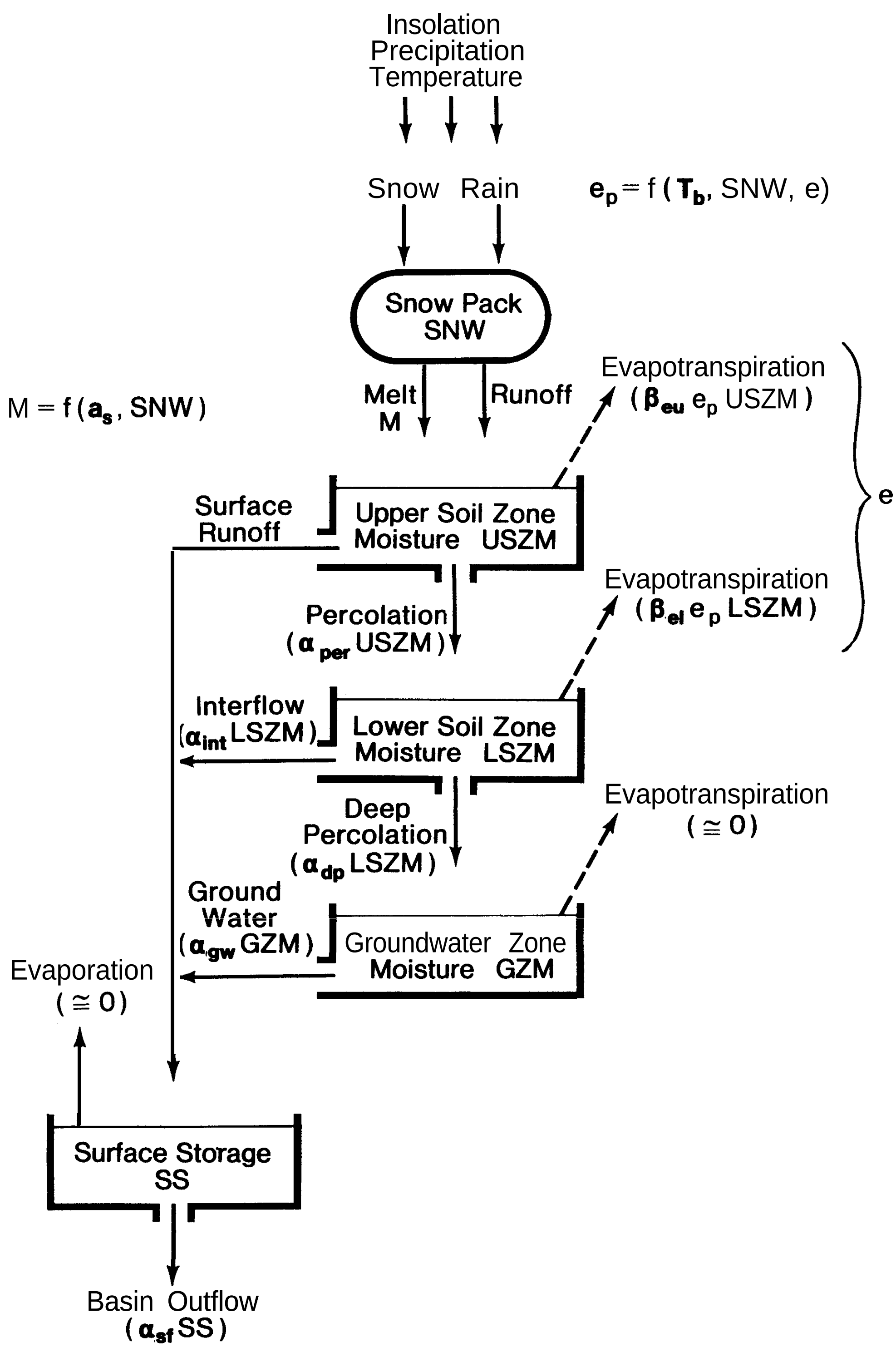
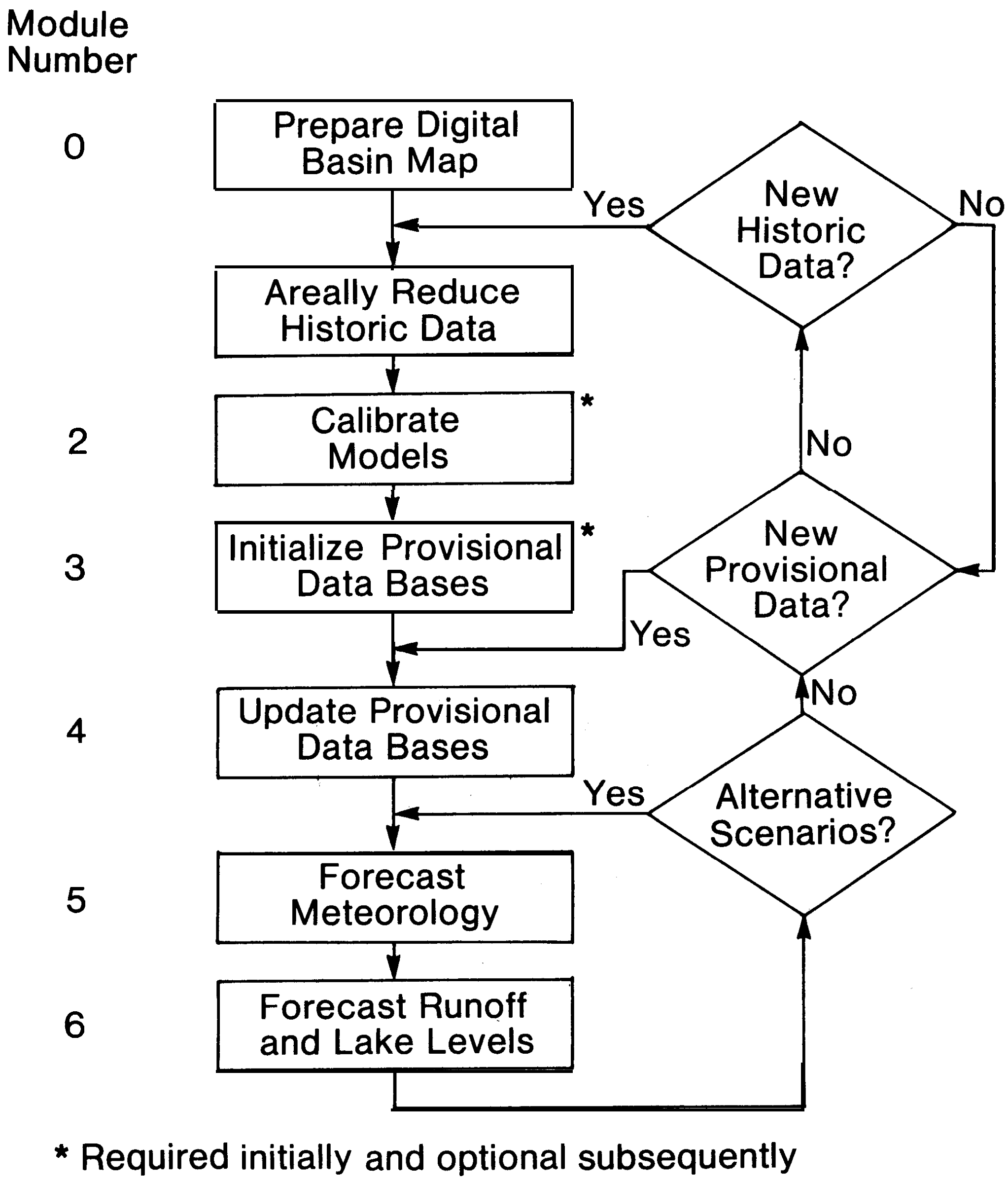


Figure 1.--Conceptual schematic of large basin runoff model.



Fi'gure 2. --Logic diagram of automated forecast package.

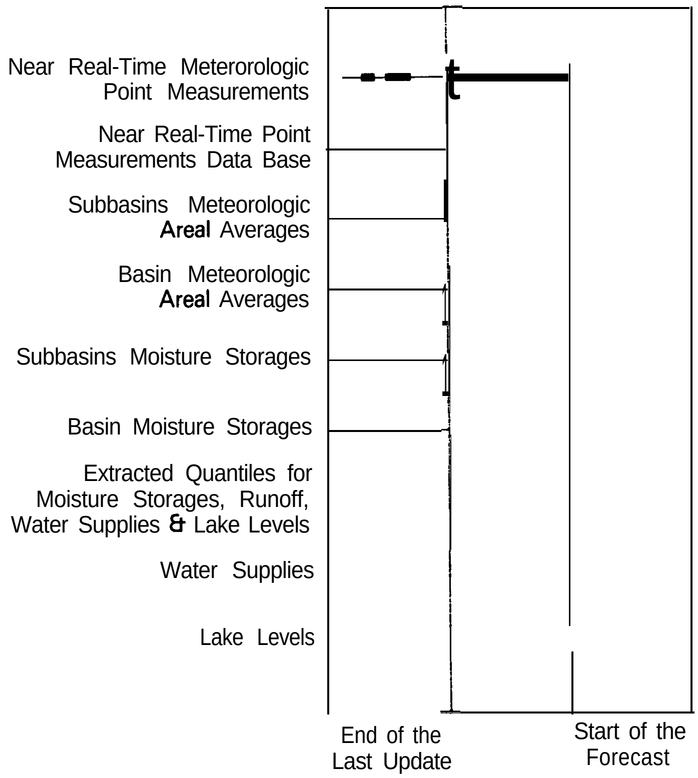


Figure 3a.--Data base state diagrams during the forecast procedure.

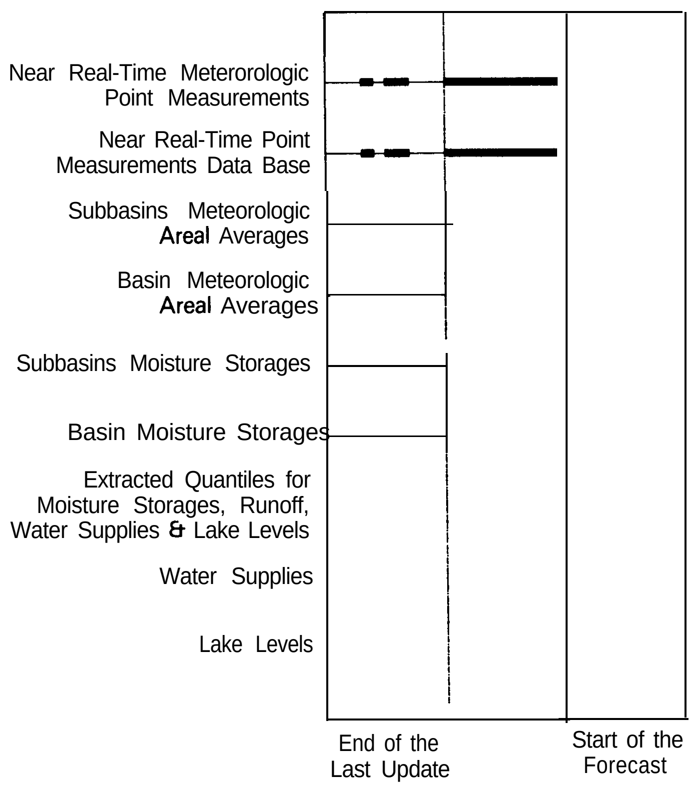


Figure 3b.--Data base state diagrams during the forecast procedure.

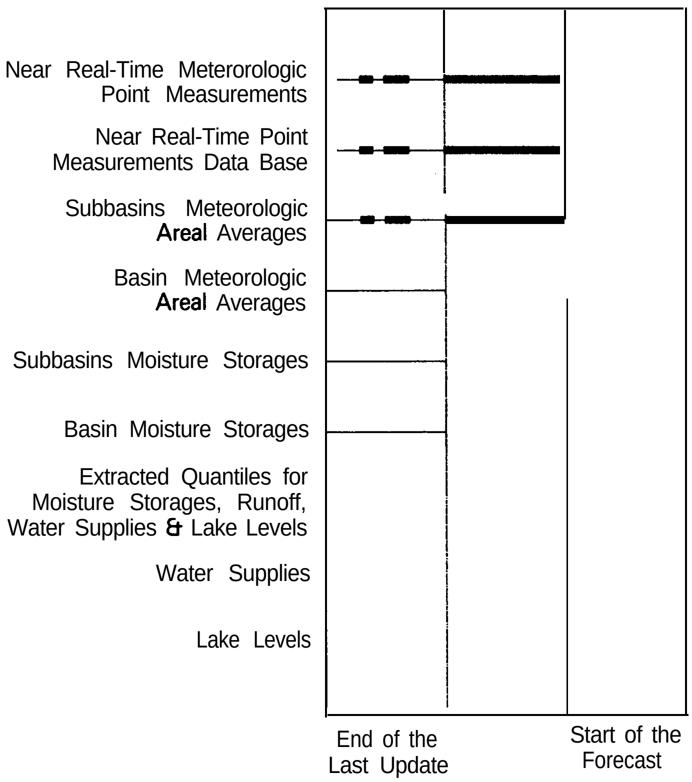


Figure 3c.--Data base state diagrams during the forecast procedure.

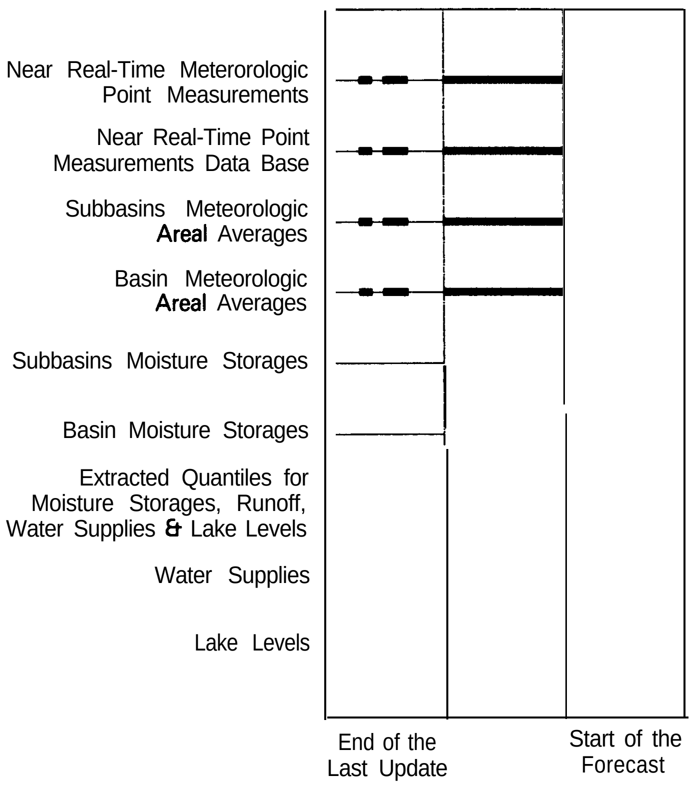


Figure 3d.--Data base state diagrams during the forecast procedure.

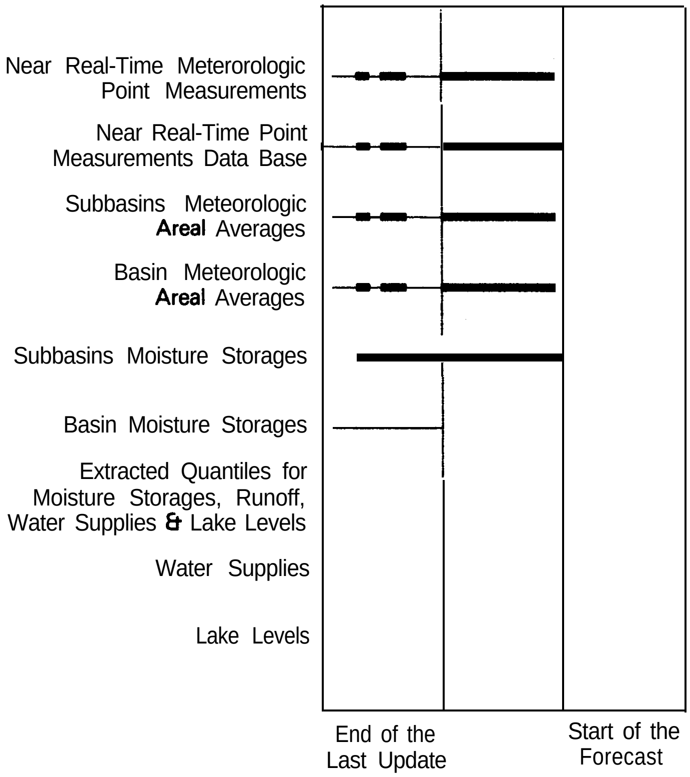


Figure 3e.--Data base state diagrams during the forecast procedure.

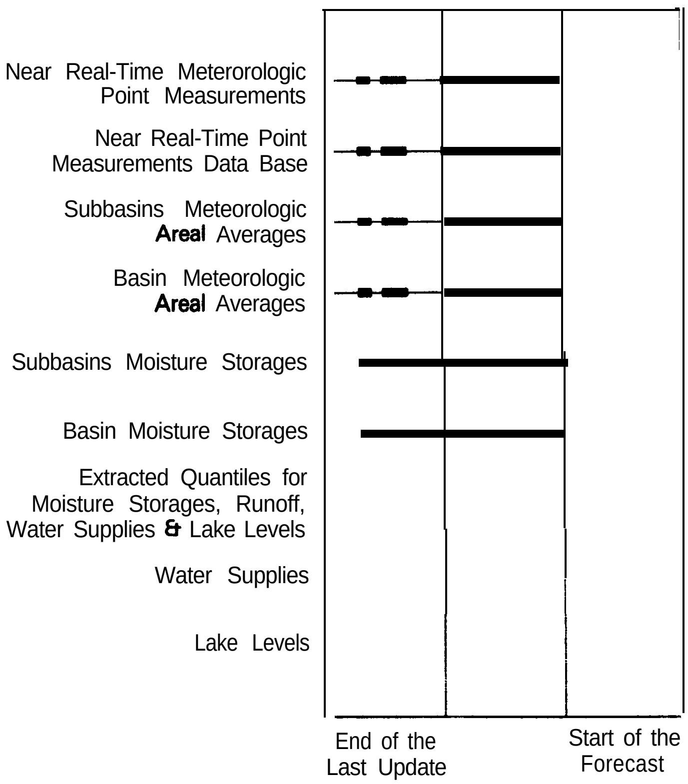


Figure 3f.--Data base state diagrams during the forecast procedure.

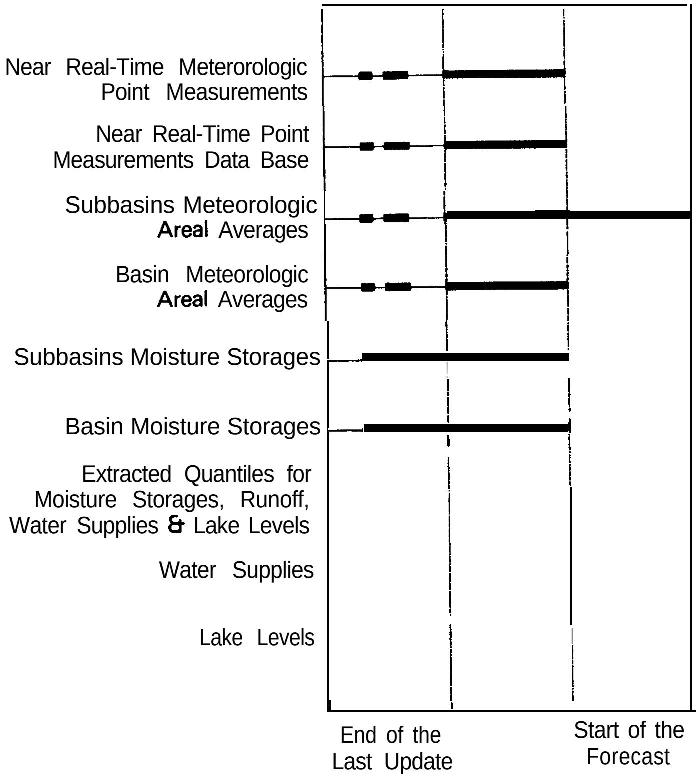


Figure 3g.--Data base state diagrams during the forecast procedure.

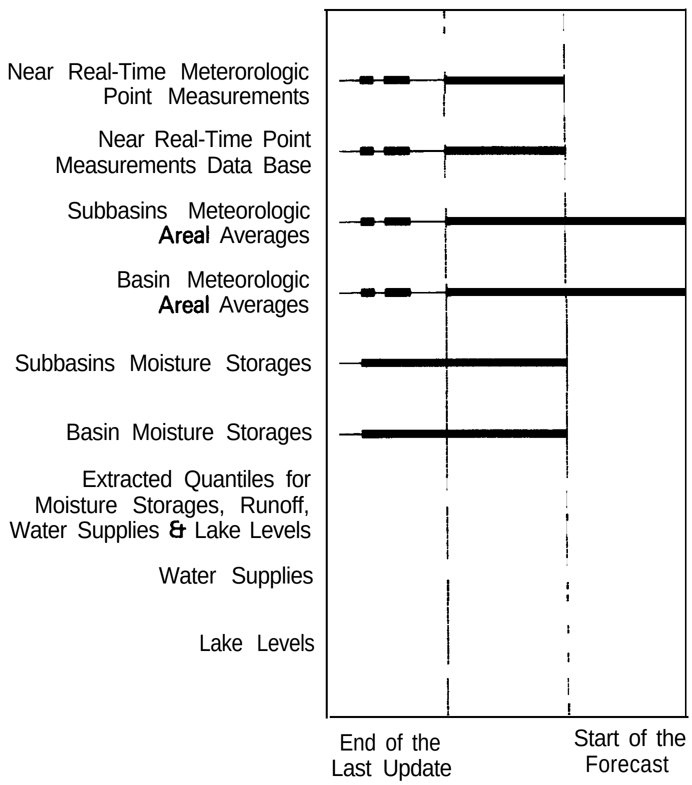


Figure 3h.--Data base state diagrams during the forecast procedure.

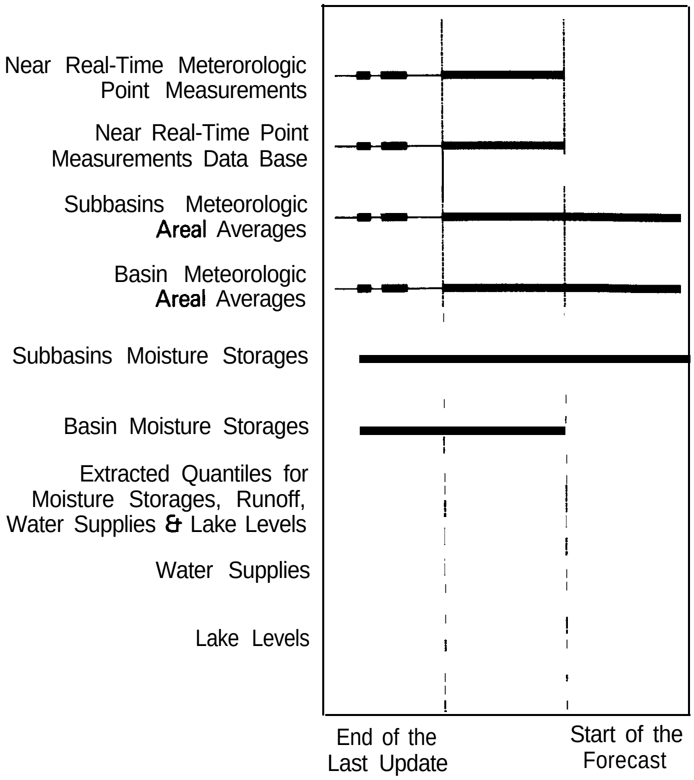


Figure 3i.--Data base state diagrams during the forecast procedure.

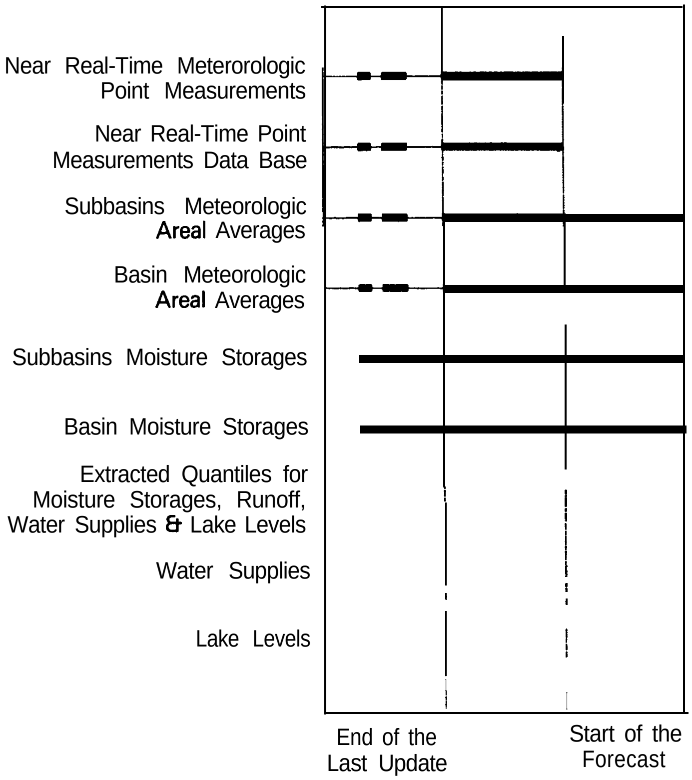


Figure 3j.--Data base state diagrams during the forecast procedure.

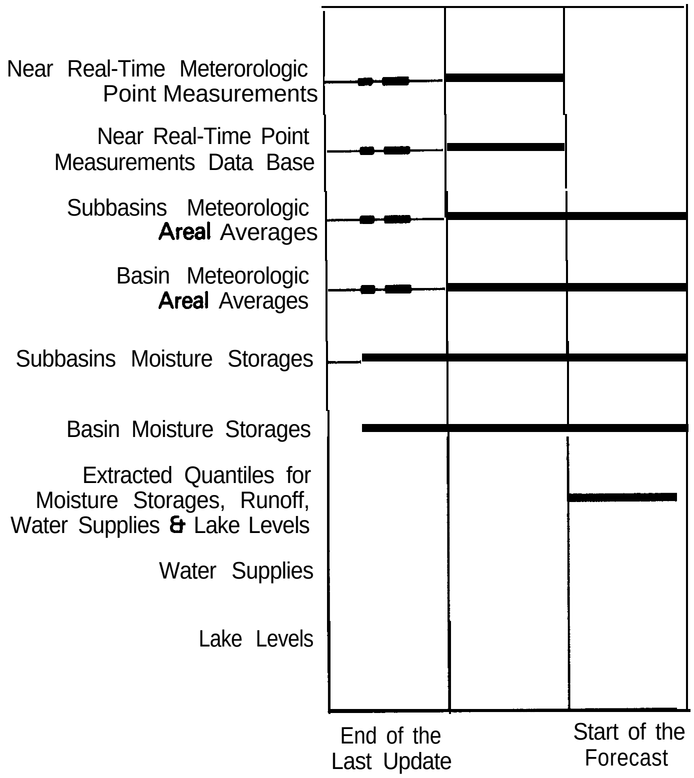


Figure 3k.--Data base state diagrams during the forecast procedure.

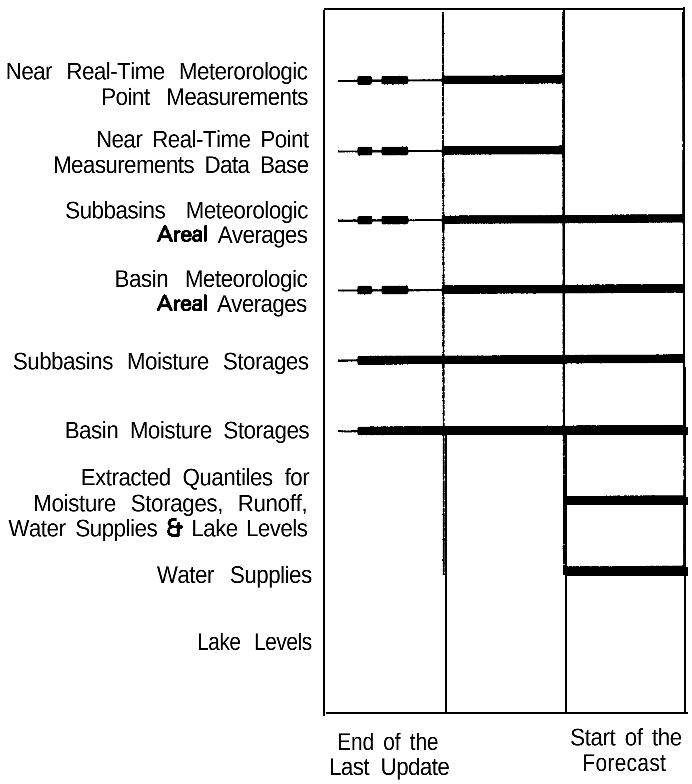


Figure 3l.--Data base state diagrams during the forecast procedure.

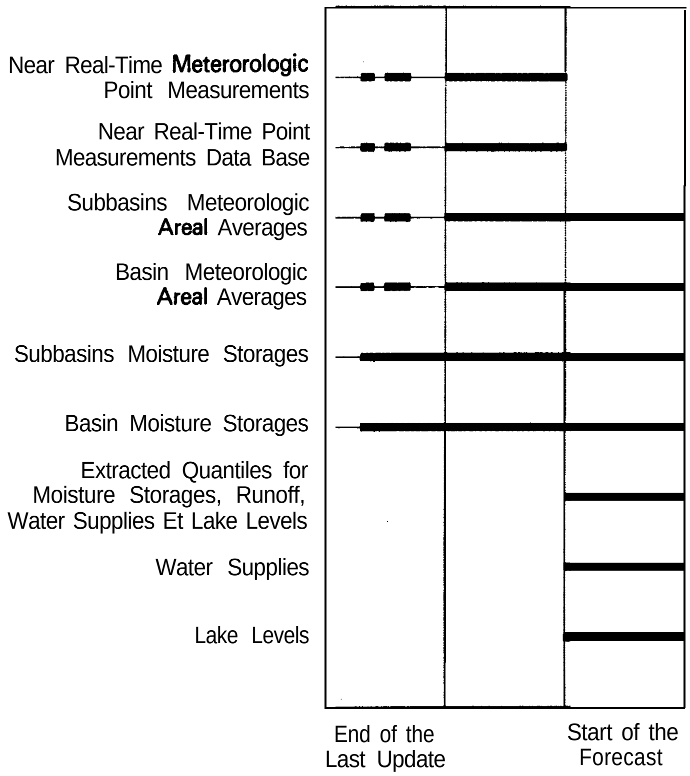


Figure 3m. --Data base state diagrams during the forecast procedure.

EXPERIMENTAL LAKE SUPERIOR WATER SUPPLY OUTLOOK
prepared by
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY, NOAA
Outlook Issue Date: 6 September 1986

The following is a six-month outlook for net basin supply (overlake precipitation + basin runoff - lake evaporation). The outlook is based on a distributed-parameter application of GLERL's Large Basin Runoff Model by using 22 subbasins about the lake. For each subbasin, daily runoff volumes are generated from antecedent provisional daily maximum and minimum air temperatures and precipitation over the subbasin and selected six-month meteorologic outlooks based on past climatology and the NWS Extended Weather Outlooks. When they are available, measured subbasin storages also are used to update the storage states in the model. Subsequent daily runoff volumes are combined over all subbasins, summed over each month, and combined with corresponding outlooks of monthly lake precipitation and lake evaporation to estimate future net basin supplies. The start of the outlook period precedes the above outlook issue date if recent meteorologic data are too sparse, are of poor quality, or are otherwise insufficient. The runoff and net basin supply outlooks are averages based on the 5 most-likely meteorologic sequences in the historical record beginning 1 September: 1955, 1960, 1969, 1970, 1978. The NWS September outlook calls for a 36% probability that temperatures will be warmer than the 70% quantile, and a 31% probability that precipitation will be less than the 30% quantile. The September - November outlook calls for both a 30% probability that temperatures will be cooler than the 30% quantile and a 30% probability that temperatures will be warmer than the 70% quantile, and a 36% probability that precipitation will be greater than the 70% quantile. The outlook is based on incomplete data from about 7 Canadian and 14 U.S. meteorologic stations for June - August 1986, 8 Canadian and 34 U.S. stations for December 1985 - May 1986, and 17 Canadian and 26 U.S. stations for January 1984 - November 1985.

NET BASIN SUPPLY OUTLOOK

Month	Year	Runoff Outlook mm	Historic Median mm	Net Basin Supply Outlook mm	Historic Median mm
September	1986	40	36	61	70
October	1986	50	43	52	25
November	1986	51	43	28	19
December	1986	40	38	-29	-20
January	1987	31	36	-31	-20
February	1987	24	33	17	1

Antecedent and forecast moisture conditions are also included (see attachment). Simple updating of model storage states with boundary conditions (reflecting measured conditions) appears as instantaneous changes in moisture content, and may be notable when actual meteorology is very different from the assumed climatologic outlooks. Also, the provisional meteorologic data comes from a network smaller than that for which historic data are available. Quantiles are based on a distributed model application to historic data from all available stations. For further information, contact Dr. Thomas E. Croley 11 or Holly C. Hartmann at (313) 668-2238.

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Figure 4.--Example of forecast product for Lake Superior (net basin supply table).

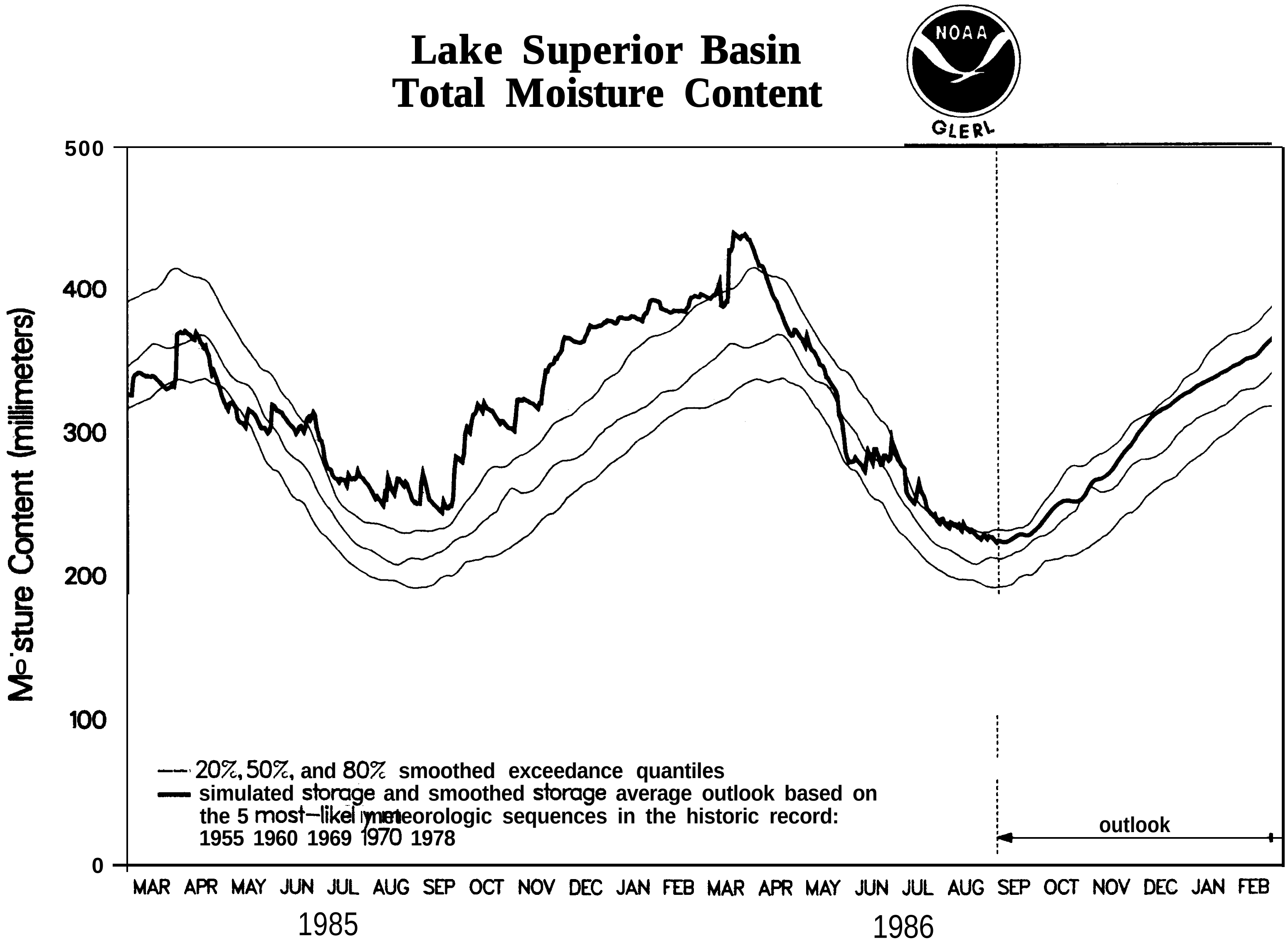

Figure 5.--Example of forecast product for Lake Superior (total moisture).

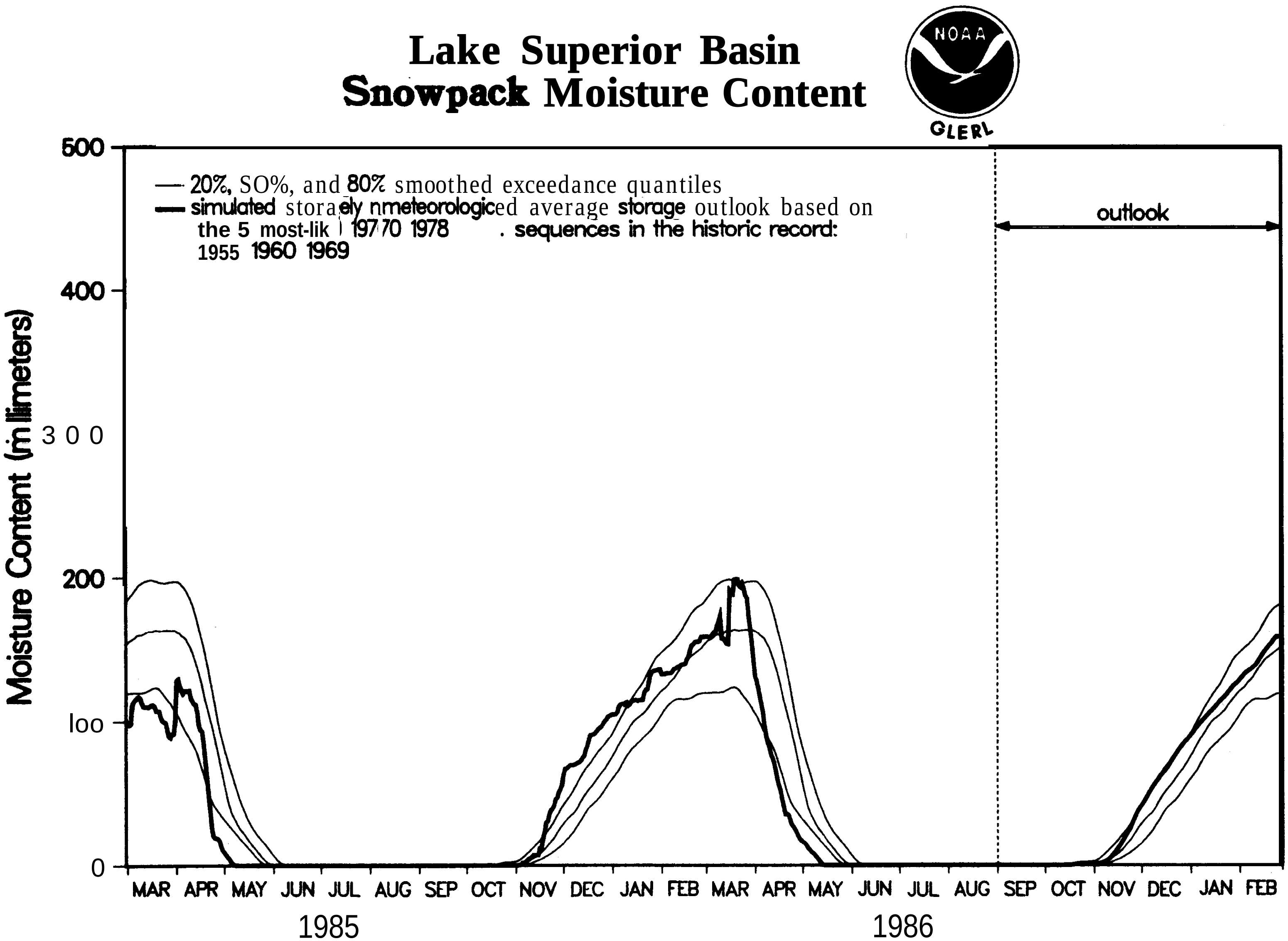

Figure 6.--Example of forecast product for Lake Superior (snowpack moisture).

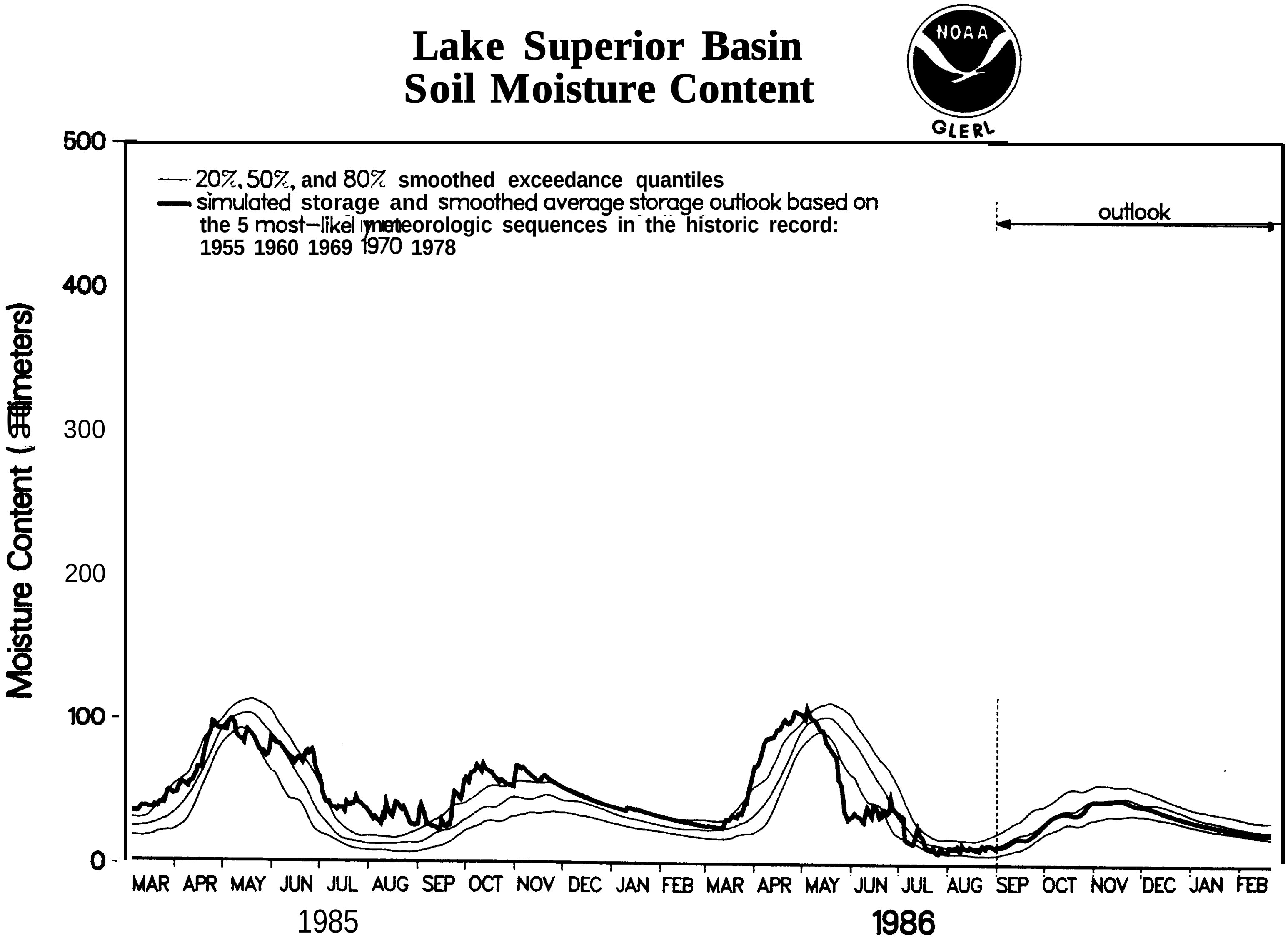

Figure 7.--Example of forecast product for Lake Superior (soil moisture).

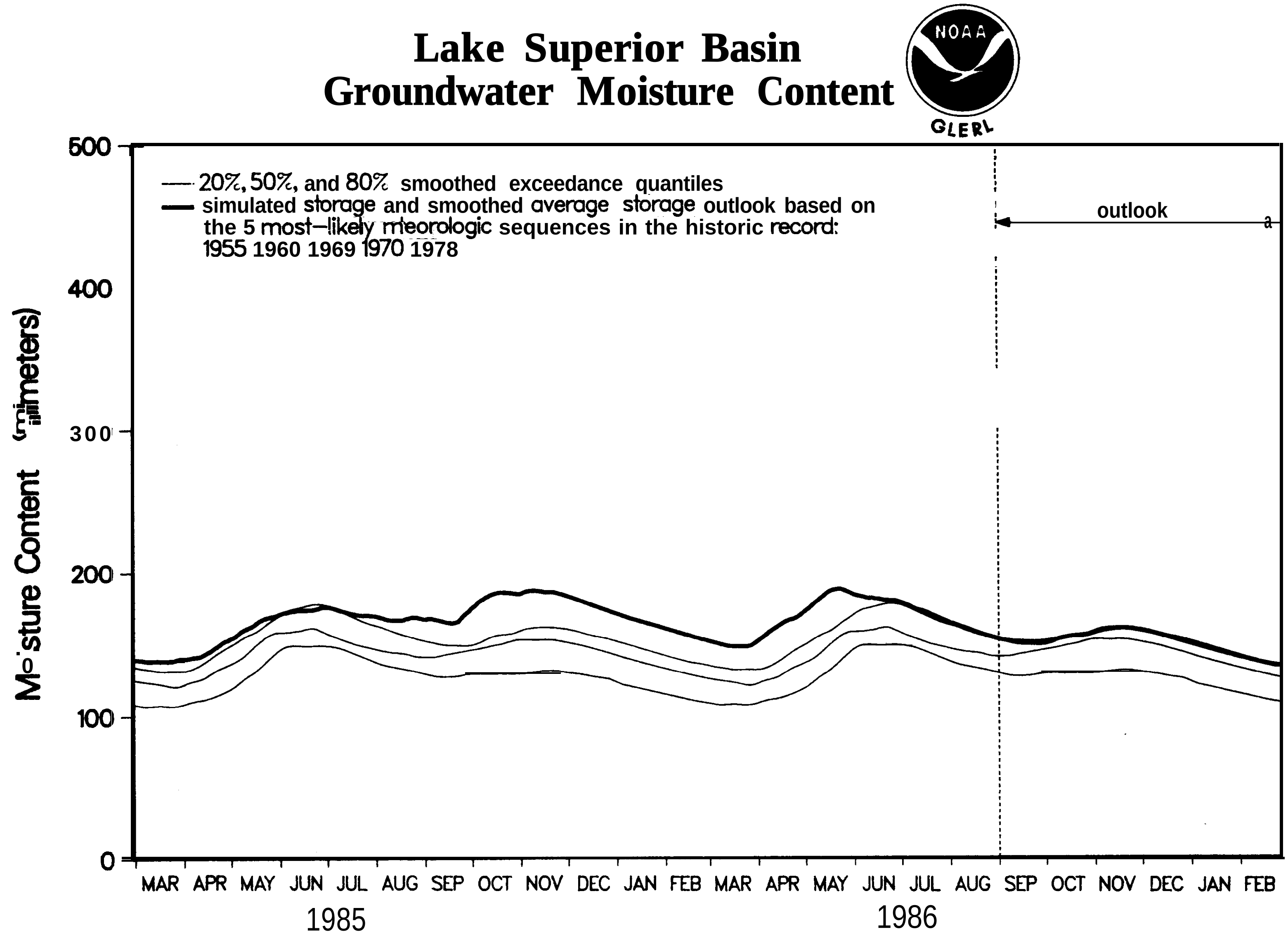

Figure 8.--Example of forecast product for Lake Superior (groundwater moisture).

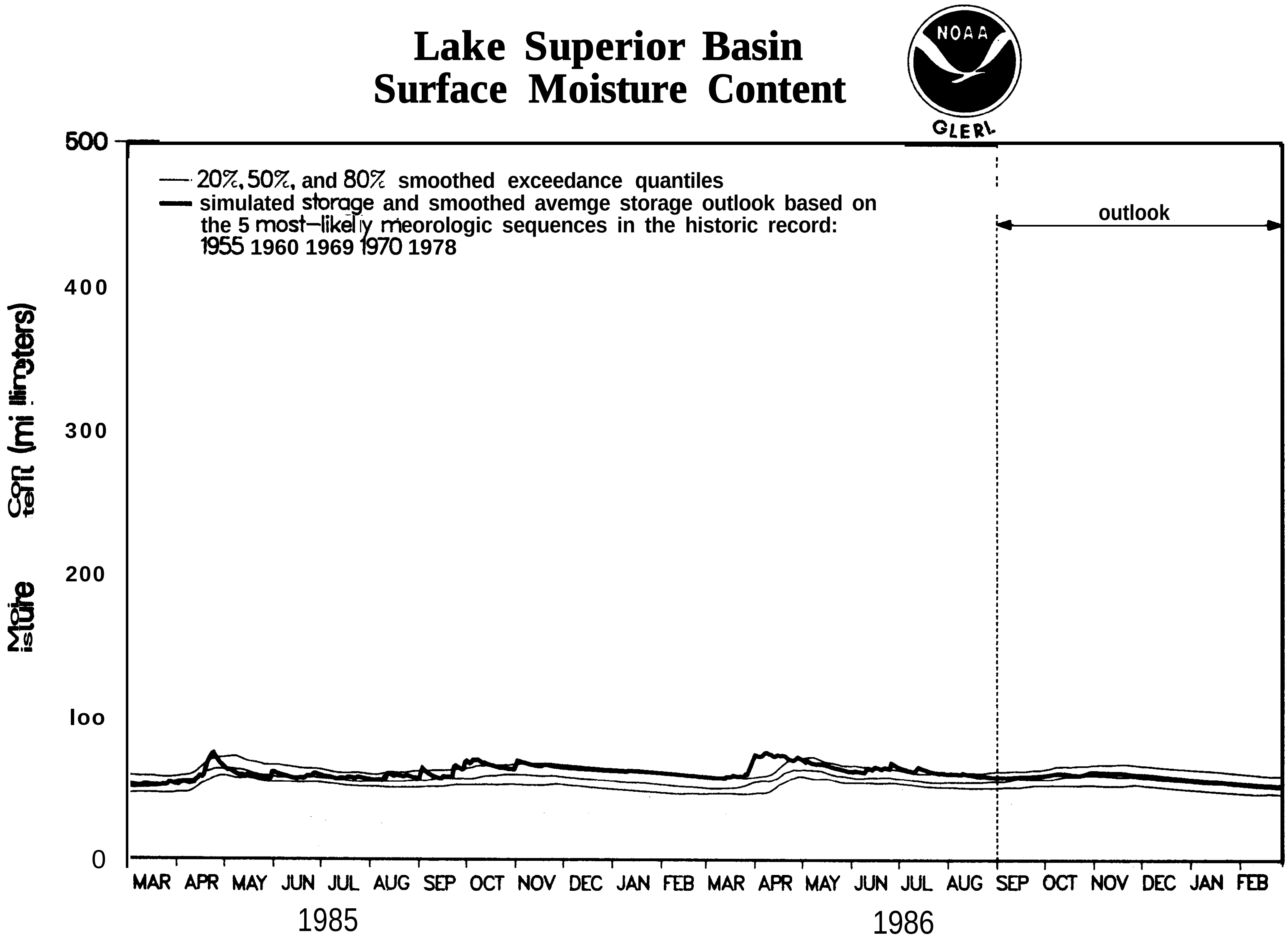

Figure 9.--Example of forecast product for Lake Superior (surface moisture).

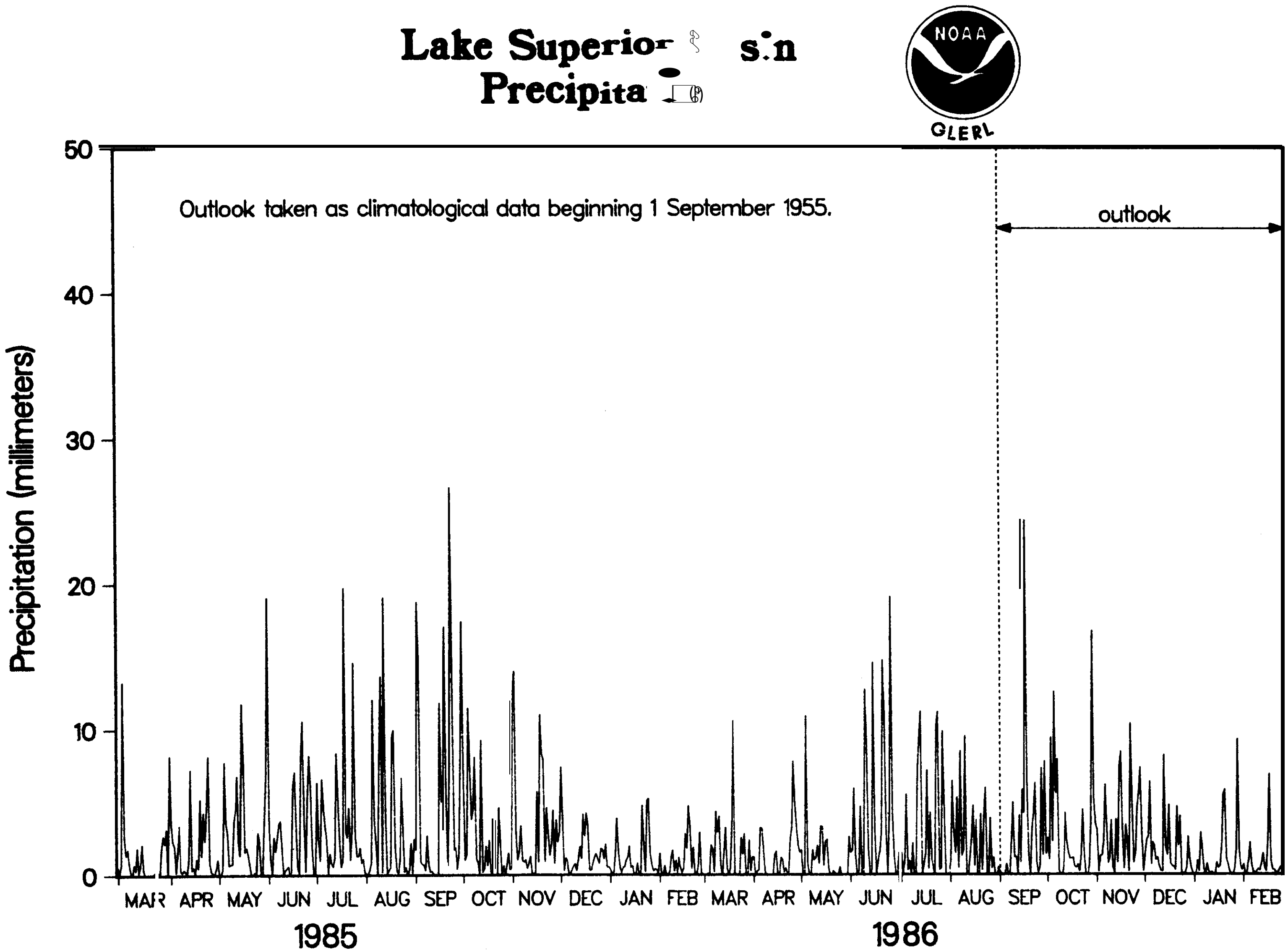

Figure 10.--Example of forecast product for Lake Superior (precipitation).

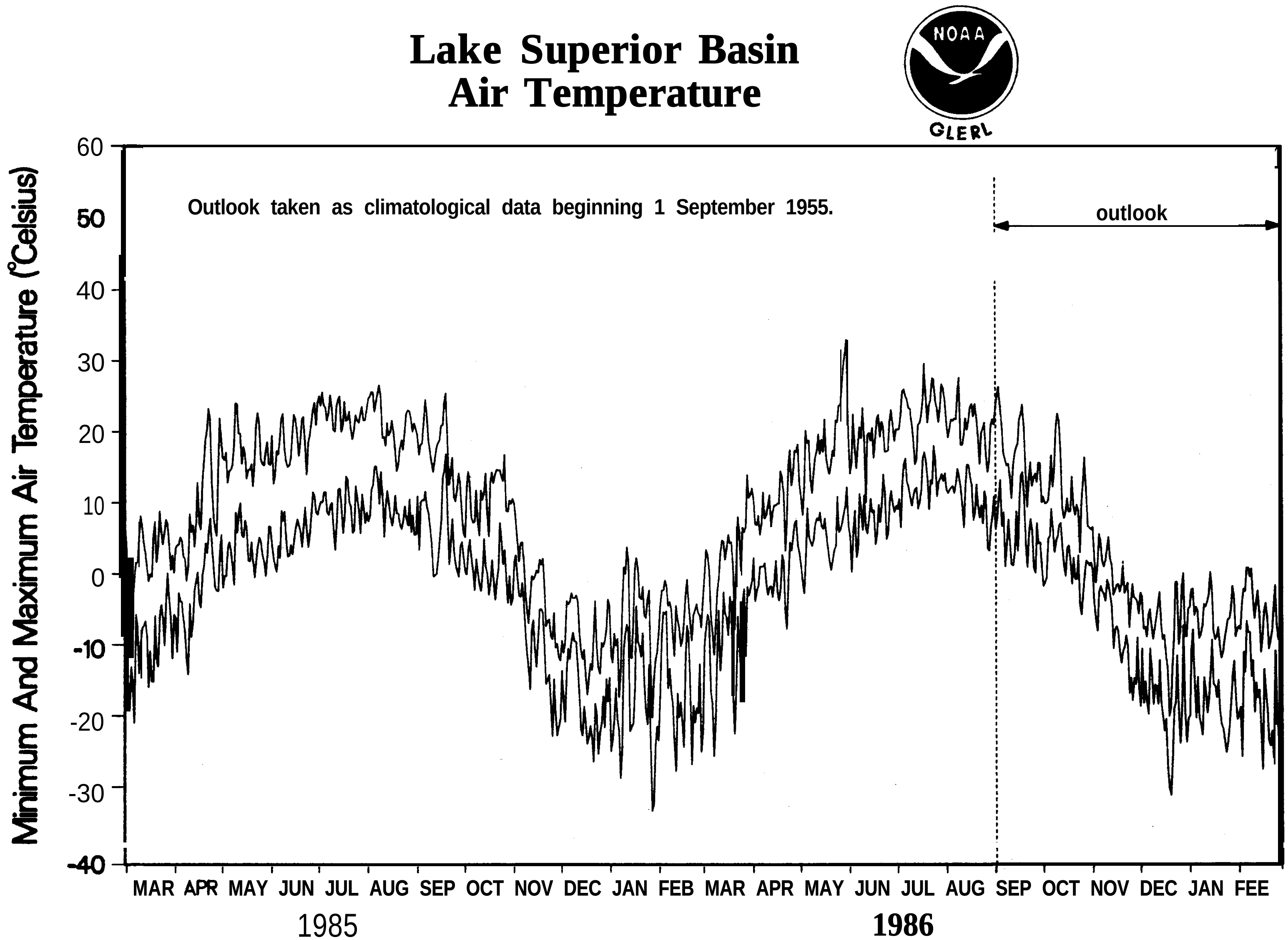

Figure 11.--Example of forecast product for Lake Superior (air temperature).

Appendix B: Outline documentation of forecast programs and data files

The forecast package automatically produces a 6-month outlook of basin moisture storages, basin runoff, net basin supply, and lake levels. The user is required to know on what date all available provisional meteorologic data end, and which historic periods are being used as forecast meteorology. The user must then integrate that knowledge and specify the date on which the forecast will begin (the day and month which immediately follow the last day of provisional data), but with the chosen years of the climatic record. For example, if 1956, 1964, and 1978 have been chosen as the historic periods to use for making a 6-month outlook beginning in January, but the provisional data end on 2 December, the user would initiate the outlook procedure with forecast dates of 3 December 1955, 3 December 1963, and 3 December 1977. Thus, the provisional data will be used up through 2 December, and then the forecast meteorology would be based on data from 3 December (1955, 1963, and 1977) through 30 June (1956, 1964, and 1978). The name of the lake for which the forecast is to be made is also required as well as the lake level at the beginning of the first day of the forecast period.

The following is a listing, in the order of their use, of the various programs and data files used in the forecast package. A description of the file formats is given with explanations of the records found in each of the files. Information on file structures is given under the program heading where each file is first used.

I. ERRCHECK.NI4

This program checks all provisional meteorologic files for obvious errors: check for proper header-format (appropriate length, entries exist for station identification number, latitude, and longitude); check meteorologic station filename for consistency with the station identification contained in the file; check for reasonable values of latitude and longitude; check that no two stations have identical latitudes and longitudes; and check for reasonable data values.

A. BSNNM. Input/Output

All forecast programs read and update this file with the exception of the optional modules. This file is not to be disturbed by the user as it exists only for each program to keep track of what other programs have been run and to reference specific basin information. It is a formatted direct access file and its contents are as follows:

1st record: (FORMAT: All)

```
Name
 !  !
 !_ !    _basin name, left adjusted and blank padded, in all upper
          case
```

2nd record: (FORMAT: 213, A4, 1X)

```
# # switch
 ! ! !____!_________lake precipitation computation switch:
 ! !                "BASN" => estimate by land depths
 ! !                          (uses all subbasin files,
 ! !                           except subbasin 0)
 ! !                "LAKE" => estimate from nearby gauges
 ! !                          (uses subbasin 0 file)
 ! !                 [used in programs WATOUT.NI4, LUMPSTOR.NI4,
 ! !                 and LUMPOUT1.NI4]
 ! !_____________program designator number; each program
 !               has its own and places it in BSNNM. so
 !               programs can check for improper sequence.
 !_____________number of subbasins in basin
```

3rd record: (FORMAT: 213, 15)

```
base date
 !       !
 !_______!___date (day, month, year) of the day after the end of
             climatic data; see PROVISNAL.NI4, section II.
```

This program updates the program designator to 1. The remaining records are filled in during a forecast session and are rewritten by the programs only; each record is a date (day, month, year).

4th through 9th records: (FORMAT: 213, 15)

```
4th record: provisional data end date
5th record: forecast end date (6 FULL months later)
6th record: plot start date (2 years and 1 day prior to
            forecast end date)
7th record: date of earliest changed or added meteorologic data
            in xxx%%.PRV (placed there by DISAVGMET.NI4) since
            the last time that program WATOUT.NI4 was run.  This
            is the date that WATOUT.NI4 must begin updating
            files: xxx%%.SUM.
8th record: date of earliest changed or added meteorologic data
            in xxx%%.PRV (placed there by DISAVGMET.NI4) since
            the last time that program LUMPSTOR.NI4 was run.
            This is the date that LUMPSTOR.NI4 must begin
            updating file: xxxALL.SUM.
```

9th record: date of earliest changed or added meteorologic data in xxx%%.PRV (placed there by DISAVGMET.NI4) since the last time that program CMOFPOSRO.NI4 was run. This is the date that CMOFPOSRO.NI4 must begin updating file: xxxALL.MET.

B. PROVISNAL.LIS Input

This contains the full file specification of each provisional data file to be opened and read by ERRCHECK.NI4. Each record of PROVISNAL.LIS should contain one file specification (filename) left-adjusted in the record, not exceeding 80 bytes.

The input file: PROVISNAL.LIS must have each record contain the name of a file to be incorporated into PROVISNAL.xxx. Each file named must follow the following name convention:

```
Mx####### . PRV
 !!      !
 ! _____!!________seven-character station identification string
 !                which must agree with the seven characters of the
 !                corresponding station identification string
 !                (STATION-ID) in the first record of the file.
 !_____________"U" for U. S. stations and "C" for Canadian.
```

C. Mx#######.PRV Input

```
 !!       !
 !!       !
 !!_______!__seven-character station identification
 !           string; see section I.B.
 !__________"U" for U.S. stations and "C" for Canadian.
```

There is one Mx#######.PRV file for each meteorologic station contributing provisional data to update data bases for use in the forecast package.

Each station file must have the following structure (followed exactly):

First record:

```
STATION-ID ## ## (FORMAT: 1X, A7, 2F10.3)
!          ! !! !!
!          ! !! !!___longitude in decimal degrees, positive from
!          ! !!       the prime meridian east (negative west of the
!          ! !!       prime meridian)
!          ! !!____latitude in decimal degrees, positive from the
!          !        equator north
!__________!______station identification string with left-most
                  character zero for U. S. stations and either 6 or
                  7 for Canadian stations (6 for Ontario and 7 for
                  Quebec)
```

Remaining records:

```
dd mm yyyy Tmax Tmin Precip (FORMAT: 2I3, I5, 3I4)
!! !! !   ! !   !!   !!     !
!! !! !   ! !   !!   !! _   ! _depth of daily precipitation,
!! !! !   ! !   !!  !          in hundredths of inches for U. S.,
!! !! !   ! !   !!  !          in tenths of millimeters for
!! !! !   ! !   !!  !          Canadian.
!! !! !   ! !   !! __! _______minimum daily air temperature,
!! !! !   ! !   !              in degrees F for U. S.,
!! !! !   ! !   !              in tenths of degrees C for Canadian.
!! !! !   ! !   !___________maximum daily air temperature,
!! !! !   !                 in degrees F for U. S.,
!! !! !   !                 in tenths of degrees C for Canadian.
!!  !! !_! ______________four-digit year of data's date
!!  !!__________________two-digit month of data's date
!!___________________two-digit day of data's date
```

Missing data for air temperatures or precipitation must be denoted by a value of -999 for each of the respective missing values. If all meteorologic data are missing for a station for that date, then no record need be present for that date.

II. PROVISNAL.NI4

This program is used to create or update the linked-list files PROVISNAL.xxx and PROVISTWO.xxx. The provisional meteorologic files to be added are listed in PROVISNAL.LIS. WARNING! The date given in the third record of file: BSNNM. (see section I. A.) is the BASE DATE and corresponds to the first day of the provisional data, which MUST BE the day after the last day of the climatic data records available for the application. The user will not be allowed by this program to add or change any provisional data prior to this base date nor is it assumed that there will be any reason to do so. DO NOT CHANGE THIS BASE DATE as it is used in companion programs and must agree. When changed, the previous versions of files: PROVISNAL.xxx and

PROVISTWO.xxx must be amended to correspond to the new base date by deleting all data prior to the new base date and repacking the file. The user should perform this operation only with program: REPACK.NI4 by changing the base date (in file: BSNNM.) and running that program; once that is done, earlier provisional data in PROVISNAL.xxx and PROVISTWO.xxx are lost and unrecoverable. This operation need be performed only infrequently as climatic data become available and the forecast data bases are rebuilt by GLERL (say, once every 2 years or so) or when the files: PROVISNAL.xxx and PROVISTWO.xxx become too large to manage as linked lists with two-byte pointers (maximum file size for each file is 32767 12-byte records or 65534 x 12 = 768 Kbytes; with 20 stations per day [21 records per block], this translates into 3120 days or 8.54 years, for example; with 50 stations, it is 3.52 years). When run in this manner, program: REEPACK.NI4 must also be run (see section XVIII).

A. BSNNM. Input/Output

Updates program designator to 2; see section I. A.

B. PROVISNAL.LIS Input

See section I. B.

C. PROVISNAL.xxx and PROVISTWO.xxx Input/Output

```
          ! !              ! !
          !_!______________!_!  _three-character basin
                                 identifier (SUP, MIC, HUR,
                                 STC, ERI, ONT, or CHA for
                                 applications to Lakes
                                 Superior, Michigan, Huron, St.
                                 Clair, Erie, Ontario, and
                                 Champlain, respectively.
```

Files are composed of "blocks," one for each day of record, arranged in a linked sequential order with every day represented by one block. The files are direct access files with a fixed record length of 12 bytes; all records are unformatted. Missing data for air temperatures or precipitation are denoted by a value of -9999 for each of the respective missing values. If all meteorologic data are missing for a station, then no record is present for that station in the data block. PROVISNAL.xxx contains all negative-linked records and PROVISTWO.xxx contains the others. Each block has the following structure:

First block record:

```
date count max blink * link (UNFORMATTED: 2, 2, 2, 2, 2, 2)
!  ! !   ! ! ! !   ! ! !  !
!  ! !   ! ! ! !   ! ! !  !  pointer to next logical record
!  ! !   ! ! ! !   ! !_-___used only in first physical record
!  ! !   ! ! ! !   !        as pointer to last physical record
!  ! !   ! ! ! !pointer___to  first  record  of  next  logical
!  ! !   ! ! !             data block
!  ! !   ! !_!__________an upper bound on number of stations in
!  ! !   !                any block; used only in first physical
!  ! !   !                record
!  ! !___! ____________number of data records (excluding this
!  !                    header record) in this logical data block
!__!________________date sequence number; if negative, indicates
                    block has been processed by DISAVGMET.NI4
                    ("old"); if positive, indicates block must yet
                    be processed by DISAVGMET.NI4 ("new")
```

Other block records:

```
## ## Tmin Tmax Precip link (UNFORMATTED: 2, 2, 2, 2, 2, 2)
!!  !!!  ! !  !!    !!  !
!! !! ! ! !  ! !    !!  !  pointer to next logical record
!!    !!!    ! !__!_!_-_.depth of daily precipitation in
!!!!!   !!   !            hundredths of millimeters
!!!!!    ! !__! ___________maximum daily air temperature in
!! !! !  !                hundredths of degrees Celsius
!! !! !__!______________minimum daily air temperature in
!! !!                     hundredths of degrees Celsius
!! !!__________________longitude in hundredths of decimal degrees,
!!                     positive from the prime meridian east
!!                     (negative west of the prime meridian)
!!_________________  latitude in hundredths of decimal degrees,
                   -positive from the equator north.
```

D. Mx#######.PRV   Input

See section I.C.

III(l). REPACK.NI4   Optional   Program

This program is used to read the master provisional data base in files: PROVISNAL.xxx and PROVISTWO.xxx, and rewrite it in its logical order, sequentially. Before this routine is called, the logical order of records is not the same as their physical order REPACK.NI4 is then used to rewrite the PROVISNAL.xxx and PROVISTWO.xxx files so that the logical and physical orders of the records are the same. This repacking eliminates any unused space and allows subsequent disk I/O on the file to proceed sequentially thus eliminating "head thrashing" on the disk drive consequent with a linked list spread out unsequentially. This program also eliminates any data prior to the base date specified in BSNNM.; see comments for PROVISNAL.NI4 in section II.

A. BSNNM. Input

See section I. A.

B. PROVISNAL.xxx and PROVISTWO.xxx Input/Output

See section II. C.

III(2). PROVISSEE.NI4 Optional Program

This program is used to view the master provisional data base (PROVISNAL.xxx and PROVISTWO.xxx). It reads the linked-list structure of the data base and writes it to a list device, formatted in logical order.

A. BSNNM. Input

See section I.A.

B. PROVISNAL.xxx and PROVISTWO.xxx Input

See section II.C.

IV. PRPDSAVMT.FOR GLERL-specific Program

This program is used to read the DISAVGMET.SRC FORTRAN program and write a specific version, DISAVGMET.NI4 for use with the specific lake basin under consideration. Extra-GLERL applications may use a version of DISAVGMET.NI4 specially prepared for the specific lake basin under consideration.

A. BSNNM. Input

See section I. A.

B. PROVISNAL.xxx and PROVISTWO.xxx Input

See section II. C.

C. DISAVGMET.SRC Input

FORTRAN program that this routine updates.

D. DISAVGMET.NI4 Output

Updated FORTRAN program.

V. DISAVGMET.NI4

This routine updates the provisional subbasin data files from the provisional data files, PROVISNAL.xxx and PROVISTWO.xxx. It computes Thiessen-weighted area1 averages for minimum and maximum air temperatures and precipitation if they are flagged as new data in the provisional data files and then removes the flags. Otherwise, old data values, computed previously, are left unchanged in the provisional subbasin data files.

A. BSNNM. Input/Output

Updates program designator to 3, places dates into records 4, 5, and 6, and compares the date of earliest changed or added meteorologic data with records 7, 8, and 9 and places the earlier date back into them; see section I.A.

B. PROVISNAL.xxx and PROVISTWO.xxx Input/Output

See section II. C.

C. AREA.xxx Input

```
      ! !
      !_!  _three-character basin identifier; see section II.C.
```

This file contains number-of-subbasins + 1 records. Each record has the format: E13.6E2. The first record gives the area of subbasin 1, the second gives the area of subbasin 2, and so on for all subbasins. The last record gives the area of the lake surface. Each of these areas is in square meters.

D. xxxBYTCOD.MAP Input [TO BE SUPPLIED BY GLERL!]

```
 ! !
 !_!  _three-character basin identifier; see section II. C.
```

This file is a sequential access unformatted file which contains the data for a particular map. It has fixed-length records with a record length of (Map-width + 4)/4 bytes. Each record contains one "row" of the map; the first record contains the top-most row (northern-most) and the last record contains the bottom-most row. There are Map-height rows in the map and Map-height records in the file. Each byte in the record contains a one-byte integer (absolute value) representing a subbasin code; the code is the number of the subbasin that the location, corresponding to the byte's position, is in. Each location represents 1 square kilometer. The left-most byte in the file record corresponds to the western-most location in the map.

NOTE: Map-width and Map-height actually refer to the maximum abscissa and ordinate respectively in the map, e.g., the Superior map contains 760 columns numbered from 0 to 759, thus Map-width is set to 759. Likewise, the Superior map contains 516 rows numbered from 0 to 515, thus Map-height is set to 515.

E. xxx%%.PRV

```
! !!!
! !!!______two-digit subbasin number
!_!______three-character basin identifier; see section II. C.
```

Each of the provisional subbasin files is an unformatted direct access file with a record length of 6 bytes (actually, a record length of 8 bytes must be used in VAX FORTRAN for unformatted files, but only 6 bytes are used for data). The first record contains, in order, the basin/subbasin numeric identifier (see section VII. D.), the number of days in the file, and the starting date sequence number, as three 2-byte integers. All other records contain minimum air temperature (in hundredths of degrees Celsius), maximum air temperature (in hundredths of degrees Celsius), and precipitation (in hundredths of millimeters), in that order, as three 2-byte integer numbers; each record corresponds to a day's data and they are present in chronologic order; see VII. D.

VI. CPFFUOPMS.NI4

This routine creates subbasin parameter files for use with the Large Basin Runoff Model to update model storage files to the end of the provisional data period.

A. BSNNM. Input/Output

Changes program designator to 4; see section I. A.

B. AREA.xxx Input

See section V. C.

C. xxx%%.SUM Input/Output

```
! !!!
! !!!___two-digit subbasin identifier
!_!  _three-character basin identifier; see section II. C.
```

Summary storage files are direct access files with a record length of 12 bytes and are unformatted. They contain modeled moisture storages resulting from application of the Large Basin Runoff Model; all storages except groundwater are expressed as equivalent depths over the subbasin, in hundredths of centimeters. The groundwater storage is divided by a scaling factor to enable large groundwater storages to be expressed as 2-byte integers. They have the following structure:

```
1st  record:

11 12 13 14 BLANK 15 (UNFORMATTED: 2, 2, 2, 2, 2, 2)
!! !! !! !! !    ! !!
!! !! !! !! !    ! !!__scaling  factor  for  groundwater  storage
!! !! !! !! !___!__empty field
!! !! !! !!______total number of records following this one
!! !! !!___sequence  number  corresponding  to  the  date  of
!! !!      the  1st  day's  values  (contained  in  next  record)
!! !!____number of VALID records following this one
!!        (number  of  days  of  record  contained  in  this  file,
!!        starting  with  the  next,  that  result  from  application
!!        of the Large Basin Runoff Model using provisional
!!        meteorologic data rather than forecast meteorologic
!!        data)
!!_____basin/subbasin identifier (e.g., 119 corresponds to Lake
       Superior,  subbasin 19);  see  section  VII.  D.

Remaining  records:

11 12 13 14 15 16 (UNFORMATTED: 2, 2, 2, 2, 2, 2)
!! !! !! !! !! !!
!! !! !! !! !! !!    daily  snowpack  moisture  depth,
!! !! !! !! !!       in  hundredths  of  centimeters
!! !! !! !! !!____daily  surface  storage  depth,
!! !! !! !!         in  hundredths  of  centimeters
!! !! !! !!_____daily  groundwater  storage  depth,
!! !! !!          in  hundredths  of  centimeters
!! !! !!______daily  lower  soil  zone  storage  depth,
!! !!           in  hundredths  of  centimeters
!! !!_______daily  upper  soil  zone  storage  depth,
!!            in  hundredths  of  centimeters
!!________daily  runoff  volume  depth,
          in  hundredths  of  centimeters
```

D. PARMTABLE.xxx Input

```
           ! !
           !_!  _three-character  basin  identifier;
                 see  section  II.  C.
```

Contains the model parameters and initial and boundary moisture storages conditions for each subbasin. Currently, up to five sets of boundary conditions are allowed for each subbasin parameter set; they are expressed as equivalent depths over the subbasin, in centimeters. This file has the following format:

1st record:

```
name (FORMAT: A10)
! !
!_!     _basin/subbasin name, left adjusted, in upper case,
         the left-most three characters of which must equal
         the basin identifier (xxx).
```

2nd through 11th records: model parameters (FORMAT: E13.6E2)

TBASE	base temperature for computation of heat available for evapotranspiration, degrees Celsius
ALBEDS	melt factor (proportionality constant) for degree-day snowmelt computations, cubic meters per Celsius degree-day
ALPPER	linear reservoir coefficient for percolation from upper soil zone moisture storage, inverse days
ALPUEV	partial linear reservoir coefficient for evapo-transpiration from upper soil zone moisture storage, inverse cubic meters
ALPINT	linear reservoir coefficient for interflow from lower soil zone moisture storage, inverse days
ALPDPR	linear reservoir coefficient for deep percolation from lower soil zone moisture storage, inverse days
ALPLEV	partial linear reservoir coefficient for evapo-transpiration from lower soil zone moisture storage, inverse cubic meters
ALPGW	linear reservoir coefficient for groundwater flow from groundwater zone moisture storage, inverse days
ALPSF	linear reservoir coefficient for basin outflow from surface storage zone moisture storage, inverse days
CONS	proportionality constant for computation of heat available for evapotranspiration, calories

12th record:

```
id im iy uszm lszm gzm ss snw (FORMAT: 212, 14, 5E13.6E2)
! ! ! ! ! ! !   ! !   ! ! ! !! ! !
! ! ! ! ! ! !   ! !   ! ! ! !! !_!__ snowpack moisture (cm)
! ! ! ! ! ! !   ! !   ! ! ! !!____surface storage (cm)
! ! ! I ! ! !   ! !   ! !_! ______groundwater storage (cm)
!! !! !! !   !! __! ________lower soil zone storage (cm)
! ! ! ! ! ! __! ___________upper soil zone storage (cm)
!! !! !!______________date's year
!! !!________________date's month
!!_________________date's day
```

This record represents initial model storage conditions on the first day of the calibration period. These initial conditions are never used in any of the forecast programs but are necessary for climatic data preparation programs and are included for completeness. The format of record 12 is repeated between 0 and 4 more times for various boundary conditions that the user might wish to include; these may represent field measurements, for example. Any values present in this manner will be used by the forecast package to replace model-generated storage values on the dates specified.

E. SUPARAM%%.INT Output

```
         !!
         !!___two-digit subbasin identifier
```

The format of the parameter files are as follows:

1st record:

```
name extension (FORMAT: A4, 6X, A3)
!   ! !        !
!   !!_________!___3-byte data-file filename extension:
!  !               "CLM" for climatic data file use and
!  !               "PRV" for provisional data file use.
!  !____________first 4 bytes of basin name, in upper case;
                used for identification purposes, not used by
                programs.
```

2nd record:

```
area (FORMAT: E13.6E2)
!  !
!_ !   _subbasin area in square meters
```

3rd record:

```
istart (FORMAT: 18)
!     !
!_    !  _unused by this program
```

4th record:

```
id im iy (FORMAT: 212, 14)
!! !! !!
!! !! !!___starting year in data file (climatic or provisional)
!! !!       for model simulation
!! !!____starting month in data file (climatic or provisional)
!!        for model simulation
!!_____starting day in data file (climatic or provisional)
       for model simulation
```

5th record:

```
id im iy (FORMAT: 212, 14)
!! !! !!
!! !! !!___ending year in data file (climatic or provisional)
!! !!        for model simulation
!! !!____ending month in data file (climatic or provisional)
!!          for model simulation
!!ending day in data file (climatic or provisional)
       for model simulation
```

6th through 15th records: model parameters (FORMAT: E13.6E2)

TBASE	base temperature for computation of heat available for evapotranspiration, degrees Celsius
ALBEDS	melt factor (proportionality constant) for degree-day snowmelt computations, cubic meters per Celsius degree-day
ALPPER	linear reservoir coefficient for percolation from the upper soil zone moisture storage, inverse days
ALPUEV	partial linear reservoir coefficient for evapotranspiration from the upper soil zone moisture storage, inverse cubic meters
ALPINT	linear reservoir coefficient for interflow from the lower soil zone moisture storage, inverse days
ALPDPR	linear reservoir coefficient for deep percolation from the lower soil zone moisture storage, inverse days
ALPLEV	partial linear reservoir coefficient for evapotranspiration from the lower soil zone moisture storage, inverse cubic meters
ALPGW	linear reservoir coefficient for groundwater flow from the groundwater zone moisture storage, inverse days
ALPSF	linear reservoir coefficient for basin outflow from the surface zone moisture storage, inverse days
CONS	proportionality constant for computation of heat available for evapotranspiration, calories

16th record:

```
id im iy uszm lszm gzm ss snw (FORMAT: 212, 14, 5E13.6E2)
!!!!!!!  !!  ! ! ! !! ! !
!!!!!!!  !!  ! ! ! !! !_!___snowpack moisture (cm)
!!!!!!!  !!  !!!  !!_____surface storage (cm)
!!!!!!!  !!  ! !_!_______groundwater storage (cm)
!! !! !! !  !! __! _________lower soil zone storage (cm)
!!!!!!!__!____________upper soil zone storage (cm)
!! !! !!________________date's year
!! !!________________date's month
!!__________________date's day
```

The 16th record represents the initial model conditions (initial date to begin update of values in the summary storage file and the model storage values to use initially); note that this date agrees with record 4 when this program is used to update the provisional model storages (ext = "PRV") but does not when this program is used to make forecast simulations (ext = "CLM").

When used to update the provisional model storages, from 0 to 4 additional records may follow the 16th and represent boundary conditions to be used in the model. If present, these conditions are used on their associated dates in place of model estimates. The initial and boundary storage conditions are expressed as equivalent depths over the subbasin, in centimeters.

VII. WATOUT.NI4

This program reads parameter files (SUPARAM%%.INT) and data files (xxx%%.ext) and updates summary storage files (xxx%%.SUM).

A. BSNNM. Input/Output

Updates this file with program designator 5 for provisional update and designator 8 for a forecast. When run the first time for a provisional data update (program designator = 5), record 7 is set to correspond to the date of the day after the last valid record in the files: xxx%%.SUM. See sections I. A. and VI. C.

B. SUPARAM%%.INT Input

See section VI. E.

C. xxx%%.SUM Input/Output

See section VI. C.

D. xxx%%.ext Input

```
! !!! ! !
! !!! !_!-I--three-character data-file filename extension
!  !!!       identifying whether provisional or climatic data
! !!!        sets are to be used, i.e., "PRV" or "CLM"
! !!!_____two-digit subbasin identifier
!_!    _three-character basin identifier; see section II. C.
```

Data files are direct access files with a record length of 6 (actually 8, see V. E.) bytes and are unformatted. They have the following structure:

1st record:

```
11 12 13 (UNFORMATTED: 2, 2, 2)
!! !! !!
!! !! !!___sequence number corresponding to the date of
! ! ! !      the 1st day's values (contained in next record)
!! !!____number of records following this one (number of
!!        days of record contained in this file)
!!_____basin/subbasin identifier; basin # * 100 + subbasin #;
      basin 1 = Lake Superior, 2 = Michigan, 3 = Huron,
      4 = St. Clair, 5 = Erie, 6 = Ontario, 7 = Champlain
      (e.g., 119 corresponds to Lake Superior, subbasin 19)
```

Remaining records:

```
11 12 13 (UNFORMATTED: 2, 2, 2)
!! !! !!
!! !! !!___daily precipitation depth over the subbasin, in
!! !!       hundredths of millimeters
!! !!____daily maximum air temperature in hundredths of degrees
!!        Celsius
!!daily minimum air temperature in hundredths of degrees
      Celsius
```

E. SFCSTTBLE.INT Output

The entire-basin daily precipitation for the full forecast period is stored here; it is expressed as a volume, in cubic meters. This is an unformatted file with 4-byte records, and is created only when this program uses the xxx%%.CLM files (climatic data).

VIII. LUMPSTOR.NI4

This routine reads the files BSNNM. and SUPARAM01.INT to determine the date on which to begin updating the entire-basin runoff and moisture storages, and the length of the update. It then reads modeled subbasin runoff and storages from files xxx%%.SUM, lumps them over the entire basin, and writes the entire-basin values to file xxxALL.SUM.

A. BSNNM. Input/Output

Updates this file with program designator 6 for a provisional update and designator 9 for a forecast. When run the first time for a provisional data update (program designator = 6), record 8 is set to correspond to the date of the day after the last valid record in the file: xxxALL.SUM. See sections I. A. and VIII. E.

B. AREA.xxx Input

See section V. C.

C. xxx%%.SUM Input

See section VI. C.

D. SUPARAM01.INT Input

See section VI. E.

E. xxxALL.SUM Input/Output

```
!_!
!_!  _three-character basin identifier; see section II. C.
```

This file contains the lumped entire-basin values of modeled subbasin runoff and storages from the xxx%%.SUM files. It is a direct access unformatted file with record length of 12 bytes.

First record:

```
11 12 13 14 BLANK 15 (UNFORMATTED: 2, 2, 2, 2, 2, 2)
!! !! !! !! !    ! !!
!! !! !! !! !    ! !!____scaling factor for groundwater storage
!! !! !! !! !___!empty field
!! !! !! !!__________total number of records following this one
!! !! !!___________sequence number corresponding to the date of
!! !!               the first day's values (contained in the next
!! !!               record)
!! !!__________number of VALID records following this one (number
!!             of days of record contained in this file, starting
!!             with the next, that result from climatic and
!!             provisional meteorologic data rather than forecast
!!             meteorologic data), initially 560 (to guarantee 18
!!             months and 1 day for plotting purposes)
!!________basin/subbasin identifier (basin # * 100 + # of
          subbasins + 1); see section VII. D.
```

Subsequent records:

```
11 12 13 14 15 16 (UNFORMATTED: 2, 2, 2, 2, 2, 2)
!                 !
!_________________!.-lumped entire-basin runoff and storage
                     values in hundredths of centimeters over
                     the basin (respectively, flow, upper soil
                     zone moisture, lower soil zone moisture,
                     groundwater zone moisture, surface zone
                     moisture, and snowpack moisture)
```

IX. CPFFSROMR.NI4

This routine recreates subbasin parameter files for use with the Large Basin Runoff Model to generate model storages to the end of the forecast period. This routine also checks that the forecast meteorologic data files exist and encompass the desired forecast dates, by looking at the first subbasin data file only.

A. BSNNM. Input/Output

Updates program designator to 7; see section I. A.

B. AREA.xxx Input

See section V. C.

C. PARMTABLE.xxx Input

See section VI. D.

D. xxx%%.SUM Input

See section VI. C.

E. SUPARAM%%.INT Output

Writes these files with CLM extension in first record; see section VI. E.

F. xxx%%.CLM Input

See section VII. D.

G. DATEFILE.INT Input

This file is created anew by the user for each meteorologic scenario to be used in making a forecast. It contains the day and month on which the forecast is to begin (1 day after the end of the provisional meteorologic data), and the year for which the meteorologic data are to be extracted from the historic record, to be used as forecast meteorology. It also contains an initial lake level corresponding to the beginning of the first day of the forecast, and the date on which the forecast is to be issued.

records 1 through 6: (FORMAT: 18)

record 1: day of the date of the beginning of the forecast
record 2: month of the date of the beginning of the forecast
record 3: year of the date corresponding to the beginning of the forecast, but selected from the historic record
record 4: day of the forecast issue date
record 5: month of the forecast issue date
record 6: year of the forecast issue date
record 7: lake level initial value, in meters above datum, at the end of the provisional data (= beginning of forecast period) (FORMAT: F10.3).

X. CMOFPOSRO.NI4 Optional Program

This routine compiles the simulation/forecast meteorologic outlooks used in the simulation/forecast package for purposes of plotting. It is an optional part of the package and is not required unless a plot or printout of the meteorology is desired (only possible when a single meteorologic scenario is being considered for a deterministic forecast).

A. BSNNM. Input/Output

After this program performs the update, record 9 is set to correspond to the date of the day after the last valid record in the file: xxxALL.MET (i.e., the date of the day after the end of provisionai data). See sections I. A. and X. F.

B. DATEFILE.INT Input

See section IX. G.

C. AREA.xxx Input

See section V. C.

D. xxx%%.CLM Input

See section VII. D.

E. xxx%%.PRV Input

See section V. E.

F. xxxALL.MET Input/Output
! !
!_! _three-character basin identifier; see section II. C.

This file is a direct access unformatted file for entire-basin meteorologic data (same information, but different units, contained in xxxLUMPED.DLY except this is unformatted, direct access). The record length is 6 (actually 8, see V. E.) bytes.

First record:

```
11 12 13 (UNFORMATTED: 2, 2, 2)
!! !! !!
!! !! !!_____sequence number corresponding to the date of the
!! !!         first day's values (contained in the next record)
!! !!______number of VALID records following this one (number of
!!          days of record contained in this file, starting with
!!          the next, that result from climatic and provisional
!!          meteorologic data rather than forecast meteorologic
!!          data), initially 560 (to guarantee 18 months and
!!          1 day for plotting purposes).
!!______basin/subbasin identifier (basin # * 100 + # of
        subbasins + 1); see section VII. D.
```

Subsequent records:

```
Tmin Tmax Precip  (UNFORMATTED: 2, 2, 2)
!  !!  ! !    !
!  !!  !!____!_____daily entire-basin precipitation depth,
!  !!  !           in hundredths of millimeters over the basin
!  !!__!_______daily entire-basin maximum air temperature,
!  !           in hundredths of degrees Celsius
!  !_________daily entire-basin minimum air temperature,
             in hundredths of degrees Celsius
```

G. SMETOTLKS.INT Output

Unformatted file containing entire-basin values through the end of the provisional meteorology (from files xxx%%.PRV) and a portion of the historic record chosen to represent forecast meteorology (from files xxx%%.CLM). Number of records = Sequence date number for end of forecast data - Sequence date number for plot start + 1. There are three 4-byte real number entries per "record."

```
Precip Tmin Tmax  (UNFORMATTED: 4, 4, 4)
!     !!   !!   !
!     !!   !! __!_____daily entire-basin maximum air temperature,
!     !!   !          in degrees Celsius
!     !! __!______daily entire-basin minimum air temperature,
!     !           in degrees Celsius
!     !           daily entire-basin precipitation depth, in
                  centimeters over the basin
```

XI. CSQFPOSRO.NI4 Optional Program

This routine reads the file STOQUANTS.xxx and creates the file SSTOQUANT.INT containing storage quantiles (20%, 50%, and 80%) for every day of the plotting period.

A. BSNNM. Input

See section I. A.

B. STOQUANTS.xxx Input

```
          ! !
          !_!  _three-character basin identifier;
                see section II. C.
```

Sequential access unformatted file of the entire-basin storages quantile values based on a distributed-parameter application of the Large Basin Runoff Model to approximately 30 years of climatic data, each record equaling one 4-byte longword. Each value of the quantile 3-dimensional array is a quantile value, expressed as an equivalent depth over the basin, in centimeters. The quantile array is as follows:

quantile (day-of-the-year, storage-number, quantile-number)

where

```
day-of-the-year = 1, . . . . 366
storage-number  = 1 upper + lower soil zone moisture
                  2 groundwater zone moisture
                  3 surface storage zone moisture
                  4 snowpack moisture
                  5 total storage moisture
quantile-number = 1 (10% non-exceedence)
                  2 (20% non-exceedence)
                  .


                  9 (90% non-exceedence)
```

C. SSTOQUANT.INT Output

Unformatted file with 15 4-byte real number entries per "record"; the number of records = 24 months + 1 day (i.e., from the plot start date through the forecast end date). It contains the storages quantiles (20%, 50%, and 80%) for every day of the plotting period, expressed as equivalent depths over the basin, in centimeters.

... WATOUT.NI4 run again; see section VII.

... LUMPSTOR.NI4 run again; see section VIII.

XII. LUMPOUT1.NI4

This routine reads the model output file for runoff and storage outlooks for the entire basin (xxxALL.SUM) and computes both a file of basin storages (in centimeters over the basin) and tables of daily values of net basin supply in centimeters over the lake and monthly values of runoff, precipitation, lake evaporation, and net basin supply, all in millimeters over the lake. The file of storages is STOOTLzz.INT and the table files are NBSOTLzz.INT (daily) and FCSTBLzz.INT (monthly).

A. BSNNM. Input/Output

Updates program designator to 10; see section I. A.

B. DATEFILE.INT Input

See section IX. G.

C. AREA.xxx Input

See section V. C.

D. SFCSTTBLE.INT Input

See section VII. E.

E. xxx00.CLM Input

See section VII. D.

F. xxxALL.SUM Input

See section VIII. E.

G. ZSEVAP.xxx Input

```
         ! !
         !_!___three-character  basin  identifier;
               see section II. C.
```

This is a direct access unformatted file of daily lake evaporation and net groundwater flux in centimeters over the lake. The first record contains two 2-byte integers: the number of days contained in the file (number of records after the first) and the sequence number corresponding to the date of the first day in the file. Remaining records each contain a single value representing the combined lake evaporation and net groundwater flux term, in chronologic order, as 4-byte reals.

H. STOOTLzz.INT Output

```
        !!
        !!___two-digit year (19zz) of the historic meteorologic
             sequence under consideration
```

This is an unformatted sequential access file of forecast daily total basin storages, in centimeters over the basin, obtained by using year 19zz. Each record has the following structure:

```
dd mm yyyy s1 s2 s3 s4 s5   (UNFORMATTED: 2, 2, 2, 4, 4, 4, 4, 4)
!        ! !! !! !! !! !!
!        ! !! !! !! !! !!___total moisture storage (cm)
!        ! !! !! !! !!   snowpack moisture storage (cm)
!        ! !! !! !!   surface zone moisture storage (cm)
!        ! !! !!___groundwater zone moisture storage (cm)
!        ! !!   soil zone moisture storage (upper and lower) (cm)
!________!___date (day, month, year)
```

I. NBSOTLzz.INT Output

```
       !!
       !!___two-digit year (19zz) of the historic meteorologic
            sequence under consideration
```

This is an unformatted sequential access file of forecast daily net basin supplies, in centimeters over the lake, obtained by using year 19zz; each 4-byte record contains one real number corresponding to 1 day, in chronologic order.

J. FCSTBLzz.INT Output

```
       !!
       !!___two-digit year (19zz) of the historic meteorologic
            sequence under consideration
```

This is a formatted sequential access file of forecast monthly runoff, lake precipitation, lake evaporation, and net basin supply, all in millimeters over the lake, obtained by using year 19zz, in chronologic order. Each record consists of runoff, precipitation, evaporation, and net basin supply in the format: 4F8.2.

XIII. LAKELVL.NI4 Optional Program

This program reads the file of daily net basin supplies created by the program LUMPOUT1 for the length of the forecast period (from NBSOTLzz.INT). It uses the daily net basin supplies to compute daily lake levels and saves the daily lake levels in the file: LVLOTLzz.INT.

A. DATEFILE.INT Input

See section IX. G.

B. BSNNM. Input

See section I. A.

C. AREA.xxx Input

See section V. C.

D. NBSOTLzz.INT Input

See section XII. I.

E. LVLOTLzz.INT Output

```
        !!
        !!___two-digit year (19zz) of the historic meteorologic
             sequence under consideration
```

This is a formatted sequential access file of forecast daily lake levels, in millimeters above datum, obtained by using year 19zz, in chronologic order. Each record is structured as:

```
dd mm yyyy level  (FORMAT: 1X, 213, 15, F10.3)
!        ! !    !
!        ! !___!.-end-of-day lake level, in mm above datum
!________!___date (day, month, year)
```

XIV. LUMPOUT2.NI4

This routine reads all STOOTLzz.INT and FCSTBLzz.INT files and determines the average (daily or monthly) values for every storage in STOOTLzz.INT and for every variable in FCSTBLzz.INT. It places this information into SSTOOTLKS.INT and SFCSTTBLE.INT, respectively. It places simulated storage results preceding the forecast period into file SSTOSIMUL.INT.

A. DATEFILE.INT Input

See section IX. G.

B. BSNNM. Input/Output

Resets program designator to 0; see section I. A.

C. AREA.xxx Input

See section V. C.

D. YEARFILE.INT Input

This file is created by the user (or calling procedure) to be read by this and following programs. It names each year, selected by the user, that is to be used in the forecast procedure as a candidate meteorologic scenario selected from the historic record. Each year is named, one per record, in the format: 14 and MUST be in the range of the available historic data (xxx%%.CLM and ZSEVAP.xxx); it is unchecked for range by any of the programs.

E. xxxALL.SUM Input

See section VIII. E.

F. SSTOSIMUL.INT Output

This file is a formatted sequential access file of simulated daily storages, in centimeters over the basin, for the 24 months and 1 day preceding the end of the forecast period and has the following structure:

record 1: forecast period length (FORMAT: 13)
record 2: plot start date (dd mm yyyy); see section I. A.
(FORMAT: 213, 15)

Subsequent records:

```
dd mm yyyy sl s2 s3 s4 s5  (FORMAT: 213, 15, 5F8.4)
!        ! !! !! !! !! !!
!        ! !! !! !! !! !!___total moisture storage (cm)
!        ! !! !! !! !!    snowpack moisture storage (cm)
!        ! !! !! !!___surface zone moisture storage (cm)
!        ! !! !!    groundwater zone moisture storage (cm)
!        ! !!___soil zone moisture storage (upper and lower) (cm)
!________!___date (day, month, year)
```

G. STOOTLzz.INT Input/Deleted

See section XII. H. This file is deleted after input.

H. NBSOTLzz.INT Input/Deleted

See section XII. I. This file is simply opened and closed so that the program deletes it; it has served its purpose in program LAKELVL.NI4. Since the LAKELVL.NI4 program is optional, the delete takes place here.

I. SSTOOTLKS.INT Output

This file is a formatted sequential access file of forecast entire-basin daily storages, in centimeters over the basin, for the forecast period. It contains the average (over the historic sequences considered in the forecast) for soil, groundwater, surface, snowpack, and total moisture for every day in the forecast period. The structure of every record is:

```
dd mm yyyy sl s2 s3 s4 s5  (FORMAT: 213, 15, 5F8.4)
!         ! !! !! !! !! !!
!         ! !! !! !! !! !!___total moisture storage (cm)
!         ! !! !! !! !!___snowpack moisture storage (cm)
!         ! !! !! !!___surface zone moisture storage (cm)
!         ! !! !!___groundwater zone moisture storage (cm)
!         ! !!___soil zone moisture storage (upper and lower) (cm)
!_________!___date (day, month, year)
```

J. LVLQUANTS.xxx Input if present

```
          ! !
          !_!  _three-character basin identifier;
                see section II. C.
```

This file is a sequential access formatted file of mean monthly beginning-of-month (BOM) lake levels compiled from the historic record. It contains one value per record, sequentially for months 1 through 12, in format: E13.6E2, in millimeters above datum. If this file is not present, then files: LVLOTLzz.INT are not read and "missing data" (-9999) are placed into SFCSTTBLE.INT.

K. LVLOTLzz.INT Input if present and if LVLQUANTS.xxx is present

See section XIII. E.

L. FCSTBLzz.INT Input/Deleted

See section XII. J. This file is deleted after input.

M. RUNQUANTS.xxx Input

```
          ! !
          !_!___three-character basin identifier;
                see section II. C.
```

This file contains non-exceedance quantiles for entire-basin monthly runoff, in centimeters over the lake, based on approximately 30 years of historic flow data. Each record (12 total) contains the word 'MONTH', the number of the month (1,2,...,12) and the 10%, 20%,..., 90% non-exceedance runoff quantiles in the format: 1X, A5, 13, 1X, 9E13.6E2.

N. NBSQUANTS.xxx Input

```
          ! !
          !_!___three-character basin identifier;
                see section II. C.
```

This file contains non-exceedance quantiles for monthly net basin supply, in centimeters over the lake, based on approximately 30 years of historic hydrometeorologic data. Each record (12 total) contains the word 'MONTH', the number of the month (1,2,...,12), and the 10%, 20%,..., 90% non-exceedance net basin supply quantiles in the format: 1X, A5, 13, 1X, 9E13.6E2.

0. SFCSTTBLE.INT Output

This file is a table of monthly values of forecast lake levels, net basin supply, and net basin supply components; they are averages based on the forecasts resulting from each of the historic meteorologic sequences used. Selected quantiles are also included; all values are in millimeters over the lake. There are six records, one for each full month of the forecast in the format: A10, 15, 10F8.2, as follows:

```
mo yr rav rqn nav nqn bav bqn eav eqn pre evp
!   ! !     ! !     ! !     ! !     ! ! ! ! !
!   ! !     ! !     ! !     ! !     ! ! ! !_!___average lake
!   ! !     ! !     ! !     ! !     ! ! !        evaporation
!   ! !     ! !     ! !     ! !     ! !_!    average lake
!   ! !     ! !     ! !     ! !     !        precipitation
!   ! !     ! !     ! !     ! !_____!___end-of-month lake level:
!   ! !     ! !     ! !     !           forecast average and
!   ! !     ! !     ! !     !           historic mean, res-
!   ! !     ! !     ! !     !           pectively
!   ! !     ! !     ! !_____!.-beginning-of-month lake level:
!   ! !     ! !     !           forecast average and historic
!   ! !     ! !     !           mean, respectively
!   ! !     ! !_____!___net basin supply: forecast average and
!   ! !     !           historic median, respectively
!   ! !.  entire-basin runoff: forecast average and
!   !           historic median, respectively
!___!   name of month and year of this record's correspondence
        in the forecast
```

XV. NBSTABLE.NI4 Optional Program

This routine is used to fill in a standard table for the water supply outlook (NBSTABLE.NUL).

A. BSNNM. Input

See section I. A.

B. SFCSTTBLE.INT Input

See section XIV. 0.

C. DATEFILE.INT Input.

The second date only in this file is used here (the forecast issue date). See section IX. G.

D. NBSTABLE.NUL Input

Sequential file, formatted with fixed record length of 84 bytes per record. It contains text describing the forecast generation and "empty tables" to be filled in by this program and written to the file: NBSTABLE.INT.

E. NBSTABLE.INT Output

Direct access formatted file with the same information contained in NBSTABLE.NUL. (This file will have the first 59 lines and the left 84 columns of the NBSTABLE.NUL file.) Only those records changed by this program are described below.

Record 1: EXPERIMENTAL LAKE xxxxxxx WATER SUPPLY OUTLOOK, where xxxxxxx is the lake name, in an adjustable format based on the length of the lake name

Record 4: Forecast Issue Date: DD MM YYYY (as named by the second date in file: DATEFILE.INT; see section IX. G.)

Record 8: Number of subbasins

Records 31-36:

(format: A10, 1X, 14, 14X, 13, 12X, 13, 14X, 13, 13X, 13)

```
mo yr rav rqn nav nqn
!   ! !     ! !     !
!   ! !     ! !_____!___net basin supply: forecast average and
!   ! !     !           historic median (mm over lake)
!   ! !_____!-entire-basin runoff: forecast average and
!   !             historic median (mm over lake)
!name of month and year of this record's correspondence
        in the forecast
```

Records 44-49:

These are present only if the lake level option was used.
(format: A10, 1X, 14, 13X, 13, 12X, 13, 17X, 13, 12X, 13)

```
mo yr bav bqn eav eqn
!   ! !     ! !     !
!   ! !     ! !_____!-end-of-month lake levels: forecast
!   ! !     !           average and historic mean (mm above
!   ! !     !           datum)
!   ! !_____!beginning-of-month lake levels: forecast average
!   !             and historic mean (mm above datum)
!name of month and year of this record's correspondence
        in the forecast
```

Records 42-49:

They contain text from the NBSTABLE.NUL file shifted upward 12 lines, only if the lake level option was unused.

Record xx:

Contains the serial and version number assigned to the package; xx = line 47 if the lake level option was unused and xx = line 59 if the lake level option was used.

XVI. PLOTFCAST.FOR Optional Program

This routine is used to create plot files for the existing data. Seven different plots are made:

First: Soil Moisture Content
Second: Groundwater Moisture Content
Third: Surface Moisture Content
Fourth: Snowpack Moisture Content
Fifth: Total Moisture Content
Sixth: Precipitation <== made only if just 1 year of historic data was selected as meteorologic scenario
Seventh: Air Temperature <== made only if just 1 year of historic data was selected as meteorologic scenario

Storage moistures and precipitation are plotted as equivalent depths over the basin, in millimeters; minimum and maximum air temperatures are plotted as degrees Celsius. Each of these plots is on a separate page (minimum and maximum air temperatures are plotted on the same page). The plot file that is created can be plotted on either the Calcomp or the Tektronix. The GLERL-specific command procedure (FORECAST.COM) renames the file PLOTFCAST.INT for plotting on the Tektronix. The PLOTFCAST.INT file is copied into the CALPLFCAST.INT file for use on the Calcomp. The file CALPROCESSOR.PST is a post-processor directives file for the Calcomp plots which will make the plots of a desirable size (so they fit on an 8 1/2" by 11" sheet of paper). Note that this routine assumes the existence of 4-byte integers because DISSPLA subroutines use 4-byte integers.

A. BSNNM. Input

See section I. A.

B. DATEFILE.INT Input

Need beginning date of historic meteorologic sequence used in forecast. See section IX. G.

C. SSTOQUANT.INT Input if present

See section XI. C.

D. SSTOSIMUL.INT Input

See section XIV. F.

E. SSTOOTLKS.INT Input

See section XIV. I.

F. SMETOTLKS.INT Input if present

See section X. G.

G. YEARFILE.INT Input

See section XIV. D.

H. PLT2.DAT Output

Meta file created by DISSPLA plot routines. Can be plotted on the Calcomp or Tektronix.

I. NOAASYM.DAT Input

Plot data for the NOAA symbol. There are 1058 records in the format: 2(1X,F7.4); each record contains an X and Y coordinate describing part of the digitized NOAA symbol.

XVII. PRNTFCAST.NI4 Optional Program

This routine is used to print out forecast results.

A. BSNNM. Input

See section I. A.

B. DATEFILE.INT Input

Need beginning historic meteorologic sequence date and current date; see section IX. G.

C. YEARFILE.INT Input

See section XIV. D.

D. SSTOQUANT.INT Input if present

See section XI. C.

E. SSTOSIMUL.INT Input

See section XIV. F.

F. SSTOOTLKS.INT Input

See section XIV. I.

G. SMETOTLKS.INT Input if present

See section X. G.

H. FORECAST.PRN Output

This file contains selected information contained in the plot file created by PLOTCAST.FOR; it is for use at installations without DISSPLA plotting capabilities. The number of lines in the file varies depending on the number of days in the forecast period and on the number of historic meteorologic sequences used to determine the forecast; hence the "?" regarding records 9 onward.

Record 1: 'Runoff model simulation and forecast with the GLERL Large Basin Runoff Model For' BASN, where BASN = the full basin name in format: Al5

Record 3: 'The meteorology for the forecast was taken from' XX 'selected historical sequences', where XX = the number of historic meteorologic sequences used in determining the forecast in format: 12

Record 4: 'and represents a forecast for six months beginning' DATE1 'and ending' DATE2, where DATE1 and DATE2 = the dates (dd mm yyyy) of the beginning and end of the forecast period, respectively, each in the format: 212, I4

Record 6: 'The date of this forecast (when made) is' DATE3, where DATE3 = forecast issue date in format: 212, 14

Record 8: 'The years used from the climatologic record are:'

Record 9:? YEAR1 YEAR2 YEAR3 . . . . .

Record ?+3: 'All moisture storage values and precipitation values are given in tenths of millimeters;'

Record ?+4: 'all temperatures are given in degrees Celsius.'

Record ?+9, ?+10, and ?+11 contain header information for the columns of data that follow.

Values for simulated soil moisture, groundwater, surface storage, snow water, total moisture, precipitation, and minimum and maximum air temperatures are tabulated in following records depending on the existence of the files: SSTOQUANT.INT and SMETOTLKS.INT; each record contains values for one day of the simulation, ordered chronologically.

If SSTOQUANT.INT and SMETOTLKS.INT are both present: format = 1X, 313, 5(I10, 19, 1X), 16, 2F6.1; contents =

```
d m y so som gd gdm su sum sn snm to tom pr tn tx
!   ! !    ! !    ! !    ! !    ! !    ! !! !   !
!   ! !    ! !    ! !    ! !    ! !    ! !! !_  !_ historic or
!   ! !    ! !    ! !    ! !    ! !    ! !!        provisional
!   ! !    ! !    ! !    ! !    ! !    ! !!        minimum and
!   ! !    ! !    ! !    ! !    ! !    ! !!        maximum air
!   ! !    ! !    ! !    ! !    ! !    ! !!        temperatures,
!   ! !    ! !    ! !    ! !    ! !    ! !!        respectively
!   ! !    ! !    ! !    ! !    ! !    ! !!        (degrees C)
!   ! !    ! !    ! !    ! !    ! !    ! !!_ historic or provi-
!   ! !    ! !    ! !    ! !    ! !    !    sional daily pre-
!   ! !    ! !    ! !    ! !    ! !    !    cipitation (tenths
!   ! !    ! !    ! !    ! !    ! !    !    of mm over basin)
!   ! !    ! !    ! !    ! !    ! !____!_ simulated total basin
!   ! !    ! !    ! !    ! !    !        moisture and historic
!   ! !    ! !    ! !    ! !    !        median, respectively
!   ! !    ! !    ! !    ! !    !        (tenths of mm over
!   ! !    ! !    ! !    ! !    !        basin)
!   ! !    ! !    ! !    ! !____!_ simulated snowpack moisture and
!   ! !    ! !    ! !    !        historic median, respectively
!   ! !    ! !    ! !    !        (tenths of mm over basin)
!   ! !    ! !    ! !_   !_ simulated surface storage moisture and
!   ! !    ! !    !        historic median, respectively (tenths
!   ! !    ! !    !        of mm over basin)
!   ! !    ! !___ !_simulated groundwater moisture and historic
!   ! !    !        median, respectively (tenths of mm over
!   ! !    !        basin)
!   ! !____!_ simulated soil (upper and lower zones) moisture and
!   !        historic median, respectively (tenths of mm over
!   !        basin)
!_  !_ date (day, month, year)
```

If SSTOQUANT.INT is present but SMETOTLKS.INT is not: format = 1X, 313, 5(I10, 19, 1X); contents =

```
dy mo yr so som gd gdm su sum sn snm to tom
```

If SSTOQUANT.INT is not present but SMETOTLKS.INT is: format = 1X, 313, 5(I10,10X), 16, 2F6.1; contents =

```
dy mo yr so gd su sn to pr tn tx
```

If neither SSTOQUANT.INT nor SMETOTLKS.INT are present: format = 1X, 313, 5(I10, 10X); contents =

dy mo yr so gd su sn to

AFTER the simulations for the approximately 18 months preceding the forecast period are given, the forecast period is listed following a three-line header.

Values for forecast soil moisture, groundwater, surface storage, snow water, total moisture, precipitation, and minimum and maximum air temperatures are tabulated in following records depending on the existence of the files: SSTOQUANT.INT and SMETOTLKS.INT; each record contains values for 1 day of the simulation, ordered chronologically.

If SSTOQUANT.INT and SMETOTLKS.INT are both present: format = 1X, 313, 5(I10, 19, 1X), 16, 2F6.1); contents =

```
d m y so som gd gdm su sum sn snm to tom pr tn tx
!   ! !    ! !    ! !    ! !    ! !    ! !! !   !
!   ! !    ! !    ! !    ! !    ! !    ! !! !_  !_ forecast min
!   ! !    ! !    ! !    ! !    ! !    ! !!        and max air
!   ! !    ! !    ! !    ! !    ! !    ! !!        temperatures,
!   ! !    ! !    ! !    ! !    ! !    ! !!        respectively
!   ! !    ! !    ! !    ! !    ! !    ! !!        (degrees C)
!   ! !    ! !    ! !    ! !    ! !    ! !_ forecast daily pre-
!   ! !    ! !    ! !    ! !    ! !    !    cipitation (tenths
!   ! !    ! !    ! !    ! !    ! !    !    of mm over basin)
!   ! !    ! !    ! !    ! !    ! !_   !_ total moisture: forecast
!   ! !    ! !    ! !    ! !    !        average and historic
!   ! !    ! !    ! !    ! !    !        median (tenths of mm
!   ! !    ! !    ! !    ! !    !        over basin)
!   ! !    ! !    ! !    ! !____!_snowpack moisture: forecast
!   ! !    ! !    ! !    !         average and historic median
!   ! !    ! !    ! !    !         (tenths of mm over basin)
!   ! !    ! !    ! !____!_ surface storage moisture: forecast
!   ! !    ! !    !          average and historic median (tenths
!   ! !    ! !    !          of mm over basin)
!   ! !    ! !!_groundwater moisture: forecast average and
!   ! !    !         historic median (tenths of mm over basin)
!   ! !_   !_ soil (upper and lower zones) moisture: forecast
!   !         average and historic median (tenths of mm over
!   !         basin)
!___!-date (day, month, year)
```

If SSTOQUANT.INT is present but SMETOTLKS.INT is not: format = 1X, 313, 5(I10, 19, 1X); contents =

d m y so som gd gdm su sum sn snm to tom

If SSTOQUANT.INT is not present but SMETOTLKS.INT is: format = 1X, 313, 5(I10, 10X), 16, 2F6.1); contents =

d m y so gd su sn to pr tn tx

If neither SSTOQUANT.INT nor SMETOTLKS.INT are present: format = 1X, 313 5(I10, 10X); contents =

d m y so gd su sn to

XVIII. REEPACK.NI4 Conditional Program

This program reads the unformatted subbasin provisional meteorologic and storage data files and the unformatted entire basin provisional meteorologic and storage files, and then rewrites them, truncating earlier portions according to the base date found in BSNNM. CAUTION: Like REPACK.NI4, this program will delete data prior to the base date found in BSNNM. It should be used, like REPACK.NI4, only when there will be no new data added, deleted, or changed prior to the new base date. This program then eliminates all the storage and meteorologic data that are never used by the forecast package programs. The user should be sure that data prior to the new base date will never be of interest, since this program eliminates the early provisional data. It allows conservation of disk space and is necessary if REPACK.NI4 is run to reduce the file size of PROVISNAL.xxx and PROVISTWO.xxx, or if the subbasin climatic data files are extended to overlap the provisional data period.

A. BSNNM. Input

See section I. A.

B. xxx%%.PRV Input/Output

See section V. E.

C. xxx%%.SUM Input/Output

See section VI. C.

D. xxxALL.MET Input/Output

See section X. F.

E. xxxALL.SUM Input/Output

See section VIII. E.

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