NATIONAL WEATHER SERVICE
OFFICE of HYDROLOGIC DEVELOPMENT

CONCEPT OF OPERATIONS
And
REQUIREMENTS DOCUMENT

National Weather Service River Forecast System (NWSRFS)
Reservoir Tools Enhancement

Version 3.4

Revision History

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1. INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) has a need to enhance the Joint Reservoir Regulation Operation (RES-J) and LOOKUP3 operation to improve stream-flow regulation accounting within the River Forecast Centers (RFCs). RFCs utilize the hydrologic model software package developed by the Office of Hydrologic Development (OHD) known as the NWS River Forecast System (NWSRFS). The software contains the RES-J and LOOKUP3 operations and handles a variety of scenarios encountered in daily forecasting operations. However, operational use and testing of the current version of RES-J and LOOKUP3 operations, in relation to stream-flow regulation accounting within the Missouri Basin River Forecast Center (MBRFC) area of responsibility, has revealed the need for several enhancements. The completion of this work, and the delivery of these enhancements, is necessary for the MBRFC to move forward with the larger project of implementing Advanced Hydrologic Prediction Service (AHPS) in the South Platte River basin. This new capability will enable the MBRFC to characterize regulation and more accurately prepare long-range probabilistic forecasts of streamflow.

The relevant enhancements to the RES-J Operation implemented in the last phase (HOSIP Project H-05-051) included:

- Modification of the routines that manage carryover to allow RES-J to work properly in the ESP verification process ("Hindcasting capability").
- A new method added to RES-J to compute release as a function of additional system variables, states, or time series value, similar to the capability found in the LOOKUP3 Operation. ("Lookup3")
- Development of one or more methods to allow diversion from a node as a function of current flow at the node, consumptive use demand, or other model states. ("Diversion from a node")
- Modification the RES-J LAG-K method to include the same capability as the LAG-K operation. (i.e. variable Lag) ("Lag/K")

Taken from the Statement of Need (SON).

2. CURRENT STATE OF OPERATIONS

2.1 Description of the Current Environment

The RES-J operation is used to simulate reservoir operations for single reservoirs and systems of reservoirs. RES-J represents this system with various *components*, including *reservoirs, reaches* and *nodes.* The behavior of components is governed by *methods* whose operation is controlled by *rules*. Enhancements to RES-J and LOOKUP3 are needed to better simulate reservoir operations.

The scope of this task is to further enhance the reservoir modeling tools, which include

the RES-J and LOOKUP3 operations, in order to handle a larger set of scenarios encountered in operational river and stream forecasting, specifically scenarios involving streamflow regulation and accounting. The following two enhancements were identified for inclusion in this task and are taken from the Statement of Objectives SOO:

1. Multi-valued Time Series Lookup Operation – The existing LOOKUP3 Operation linearly interpolates for a dependent result given two independent arguments and a family of curves relating the two independent arguments to the dependent argument. This method utilizes a 3-variable relationship between upstream flow (Q1), downstream elevation (E2) or flow (Q2) and elevation from the upstream location (E1): E1 = f (Q1, E2). Only single valued time series are allowed. Soil moisture zone contents and runoff time series can be useful in making operational decisions related to streamflow regulation. For example, soil moisture and runoff can be considered when estimating diversions that are occurring for agriculture. The Sacramento model includes two multi-value time series containing zone contents and runoff components. The values from these time series may be plotted using PLOT-TS (e.g., to facilitate calibration); however, the time series cannot otherwise be accessed for manipulation by other NWSRFS operations. Enhancing the LOOKUP3 operation to have access to the multi-value time series will allow the information to be used in regulation modeling. Additionally, allowing a lookup based on the day of year will allow operating rules to be specified in lookup tables.

2. Integrate NWSRFS Rating Curves – The existing MAXSTAGE method in RES-J allows control of a reservoir release based on only on allowable stage at a downstream streamflow station control point. The MAXSTAGE method requires the user to input a rating curve for the downstream node. It is requested that rating curves defined in the system be accessible to this method in place of the rating curve defined in RES-J. Additionally, the rating curve will always be entered through the NODE Component corresponding to the downstream station. Adding the rating curve at nodes will allow the specific nodes to be used as a forecast point. An option will be allowed to enter a rating table at any nodes to overwrite the rating curve. The existing rating table in the MAXSTAGE Method will be retained only for backward compatibility. This enhancement will ensure the model always uses the most up-to-date rating curve data from NWSRFS database. The current MAXSTAGE method also requires that a stage value be specified, which limits application in cases where operations are based on discharge; consequently, the ability to specify a maximum discharge is needed.

2.2 User/Customer Identification & Organization

Classes of users or customers of the current system include:

- RFC Hydrologic Forecasters
- Research Scientists
- RFC Hydrologic Calibrators

The hydrologic calibrator develops RES-J models as part of forecast segments to simulate river and reservoir systems. Hydrologic forecasters apply the simulation models to create short-term and ESP forecasts. Calibrators, forecasters and research scientists use hindcasting to verify the skill and value of the forecast segments, although the segments containing RES-J currently do not function in hindcasting mode.

2.3 Current Support Environment/Architecture

Parameter input algorithms in NWSRFS define segments to forecast streamflow at some point in a river system. These segments comprise several modeling operations that may include the RES-J and LOOKUP3 operations. Initial RES-J model states and parameters are stored in NWSRFS. When the segment is run in forecast mode, a RES-J operation contained therein relies on the structure of NWSRFS to provide stored model states, model parameters and driving time series to initialize and simulate. Following simulation, the RES-J operation returns model states and output time series to the NWSRFS for storage and use in other operations. Parameters and initial conditions for the RES-J operation, and parameters for LOOKUP3, can be redefined in a segment in a manner similar to how they were defined originally.

3. PROPOSED SOLUTION CONCEPTS

3.1 New Capabilities and Functions

As indicated, the following two enhancements will be implemented. The specific design for these enhancements will be determined in later HOSIP stages.

1. Multi-valued Time Series Lookup Operation – The LOOKUP3 NWSRFS operation will be enhanced to allow a component of a multi-value time series to be used as the input time series, so that the associated component could be used as a factor in regulation modeling (e.g., the soil moisture and runoff information can be used to estimate diversion amounts). Lookup based on the day of year will also be implemented, in order to implement seasonal operating criteria. The resulting output could be utilized by other operations, including RES-J. ***The independent Arguments may be read from either single-valued or multi-valued time series. A new input field Time series value name will be added to allow for multi-valued time series; i.e., data types SMZC includes names UZTDEF, UZFWC, … and ROCL includes names IMP-RO, DIR-RO, … etc.***

2. Integrate NWSRFS Rating Curves – The RES-J operation will be updated to allow a rating curve identifier to be specified at the node. The MAXSTAGE method will be updated to recognize the identifier and table specified at the node, rather than using the rating table specified in the MAXSTAGE method. This is appropriate because the information applies at the downstream controlling node. For calibration purposes, the rating table will also be allowed to be specified at the node because the rating curve data in the operational system is not available during calibration. To facilitate discharge-based operations, a maximum discharge parameter will be added to the

MAXSTAGE method. Appropriate error handling will be implemented to enforce allowed data specification.

These enhancements will be available in the Forecast Component Initialization program (FCINIT), the Forecast Program (FCST) Forecast Execute (FCEXEC) and Ensemble Streamflow Prediction (ESP) functions, the Interactive Forecast Program (IFP), the Manual Calibration Program (MCP3), and the Automated Optimization Program (OPT3) software within NWSRFS.

3.2 Operational Policies & Constraints

3.2.1 Scientific Constraints

There are no scientific constraints.

3.2.2 Technical Constraints

The enhancements will not reduce the functionality in the existing RES-J and LOOKUP3 operations. RES-J and LOOKUP3 will remain backward compatible with no adverse effects to existing implementations.

The ability to hindcast requires a complete picture of historical conditions. However, rating curves (specific to this task), other parametric information such as reservoir and diversion capacity, and operational decisions are not available as historical time series. These data limitations and the approach to hindcasting in light of these limitations is beyond the scope of this task.

3.2.3 Policy Constraints

There are no known policy constraints related to improved reservoir tools functionality.

3.2.4 Financial and/or Schedule Constraints

This project has been identified as a priority by the MBRFC and is funded as a part of the current Advanced Hydrologic Prediction Service (AHPS) NWSRFS Reservoir Tools Enhancement effort. These enhancements will be completed within the budget specified as part of the firm fixed price task order (Task 6-0017). The proposed changes must be completed to meet the AWIPS schedule and for Operational Build 8.3 (OB8.3) delivery deadlines.

3.3 Operational Scenarios

Classes of users or customers of the current system include:

- RFC Hydrologic Calibrator – The RFC Hydrologic Calibrator parameterizes RES-J to represent river and reservoir processes as a part of NWSRFS. Where regulation has a significant impact on streamflow (i.e., ignoring the effects of regulation introduce water balance errors leading to inability to calibrate models or negatively impact the accuracy of operational systems), the calibrator will

develop the model to represent regulation activities that take place in the basin. The enhancements to the RES-J and LOOKUP3 operations will permit the calibrator more flexibility in modeling complex regulations.

- RFC Hydrologic Forecaster – The RFC Hydrologic Forecaster uses RES-J and LOOKUP3 as a part of NWSRFS for operational forecasting for both short-term and long-term forecasts. Enhanced regulation modeling developed through the calibration process will improve forecast accuracy, especially for long range forecasts where the short term plans of regulators cannot be obtained and entered directly into the system.
- Research Scientist – The Research Scientist uses RES-J and LOOKUP3 enhancements as a part of NWSRFS to investigate and validate ESP hindcasts as a part of the Advanced Weather Interactive Processing System (AWIPS). The enhancements will allow the scientist to perform verification analyses on river systems that use the RES-J and LOOKUP3 operations.

3.4 Support Environment/Architecture

RES-J and LOOKUP3 are subsystems of the NWSRFS system. There will be no changes to the current support environment for NWSRFS as a part of this project. However, based on previous experience, some enhancements to the testing environment may occur to facilitate acceptance testing during software delivery.

3.5 Summary of Impacts

3.5.1 Operational Impacts

Additional flexibility in reservoir modeling will become available to users.

3.5.2 Organizational Impacts

Because the enhancements will be developed to preserve compatibility with previous RES-J and LOOKUP3 implementations, there will be no impact to current users of RES-J and LOOKUP3, unless they choose to take advantage of the new features. New capability will be documented in the user's manuals. Software documentation will be updated by the contractor. OHD will work with the Hydrologic Services Division (HSD) to update training materials to reflect new functionality, and the information can be presented in training sessions.

3.5.3 Impacts during Development

The development will be concurrent with an official release of NWSRFS, and should therefore be transparent to users, other than the option they will have of taking advantage of the new capability.

3.5.4 Impacts during Transition

The user should not feel any impacts, except through the added functionality mentioned above in the Operational Impacts section. The program will be backward compatible with the source code provided by OHD for modification under this project.

3.6 Alternatives and Trade-offs Considered

The "do nothing" alternative considered would result in continuation of the current state as described in section 2.1 above. The rating curve enhancement, if not implemented, requires changing the RES-J MAXSTAGE definition whenever a rating curve/table changes in the core NWSRFS data, introducing a data maintenance issue in the operational system.

Other alternatives were not considered given that the specific enhancements are well defined.

4. Requirements Development Methodology

The overall requirements for these enhancements were developed as part of previous phases of the streamflow regulation accounting study. Based on feedback from RFCs and a review of modeling requirements for the South Platte river basin, a list of potential forecast system enhancements were prepared. During a subsequent pilot-modeling phase the list of enhancements was updated and prioritized based on limitations encountered in the pilot implementation, feedback from MBRFC during training, and on anticipated needs for modeling the Upper South Platte.

Having determined which enhancements to implement, requirements for each enhancement were initially discussed with OHD staff. Because the enhancements are fairly specific, the requirements listed in Appendix B are also somewhat detailed. It is expected that a review by users during the HOSIP process will validate the requirements and point out issues that were overlooked.

5. USE CASES

No use cases were created for the update to the RES-J and LOOKUP3 operations. User interaction related to the enhancements to the RES-J and LOOKUP3 operations will involve applying suitable tests to demonstrate and verify the possible combinations of input.

6. REQUIREMENTS

See Appendix B for requirements in tabular format.

APPENDICES

Appendix A – Table of Acronyms

AHPS	Advanced Hydrologic Prediction Service
AWIPS	Advanced Weather Interactive Processing System
ESP	Ensemble Streamflow Prediction
FCEXEC	Forecast Execute
FCINIT	Forecast Component Initialization Program
FCST	Forecast Program
IFP	Interactive Forecast Program
MBRFC	Missouri Basin River Forecast Center
MCP3	Manual Calibration Program
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
OHD	Office of Hydrologic Development
OPT3	Automated Optimization Program
RES-J	Joint Reservoir Regulation operation
RFCs	River Forecast Centers
RTi	Riverside Technology, inc.
SON	Statement of Need
SOO	Statement of Objective
SRA	Streamflow Regulation Accounting

Appendix B – Requirements Table

ID NUMBER	REQUIREMENT	PRIORITY LEVEL	QUALIFICATION TYPE
1.0	**FUNCTIONAL REQUIREMENTS**		
1.1	The LOOKUP3 operation shall allow a component of the multi-value time series to be used as the input time series.	High	Test
1.2	The LOOKUP3 operation shall allow the lookup of the dependent value to be based on the date in a year (i.e., use month and day to determine a value), with interpolation.	High	Test
1.3	The RES-J operation shall allow a rating curve identifier to be specified for a node, to allow access to the rating table information in the NWSRFS operational files.	High	Test
1.4	The RES-J operation shall allow a rating table to be specified for a node, to define rating table information during calibration.	High	Test
1.5	The RES-J MAXSTAGE method shall utilize the node data for rating curve/table if such data exists.	High	Test
1.6	The RES-J MAXSTAGE method shall implement a new parameter to allow specifying the controlling value as a discharge.	High	Test
2.0	**TECHNICAL REQUIREMENTS**		
2.1	The enhanced LOOKUP3 operation shall operate within the NWSRFS architecture.	High	Test
2.1.1	The enhanced LOOKUP3 operation shall utilize existing LOOKUP3 code and components to the extent possible.	High	Inspect
2.1.2	The LOOKUP3 operation parameter initialization, printing, punching, and carryover transfer routines shall be updated / enhanced as necessary.	High	Test
2.1.3	The LOOKUP3 operation enhancements shall not adversely affect nor reduce the functionality of existing LOOKUP3 implementations.	High	Test
2.2	The enhanced RES-J operation shall operate within the NWSRFS architecture.	High	Test
2.2.1	The RES-J operation shall utilize existing RES-J code	High	Inspect

ID NUMBER	REQUIREMENT	PRIORITY LEVEL	QUALIFICATION TYPE
	and components to the extent possible.		
2.2.2	The RES-J operation parameter initialization, printing, punching, and carryover transfer routines shall be updated / enhanced as necessary.	High	Test
2.2.3	The RES-J operation enhancements shall not adversely affect nor reduce the functionality of existing RES-J implementations.	High	Test
3.0	**SECURITY AND PRIVACY REQUIREMENTS**		
	None		
4.0	**INPUT REQUIREMENTS**		
4.1	The LOOKUP3 operation input shall define the data type for the multi-value time series, to be used in the operation (it is recommended that the names used by PLOT-TS be used and that the date format be consistent with the LOOKUP3 method in RES-J).	High	Test
4.2	Optional RES-J operation node and MAXSTAGE method parameters shall be added.	High	Test
4.2.1	New RES-J operation parameters shall reflect existing parameters in style and content to the extent reasonable.	High	Inspect
4.2.2	The RES-J node shall optionally allow a NWSRFS rating curve identifier to be specified.	High	Test
4.2.3	The RES-J node shall optionally allow a rating table to be specified (e.g., for use in the calibration system). If a rating curve identifier is also specified at the node, then an error will be generated	High	Test
4.2.4	If the RES-J MAXSTAGE method input defines a rating table in addition to the rating curve/table at the node, an error shall be generated.	High	Test
4.2.5	The RES-J MAXSTAGE method shall include a “MAXDISCHARGE” parameter for the controlling check. This will meet the need of discharge-based operating decisions. An error will be generated if both MAXSTAGE and “MAXDISCHARGE” are specified.	High	Test
5.0	**LOGISTICS REQUIREMENTS**		
5.1	LOOKUP3 operation source code shall be	High	Inspect

ID NUMBER	REQUIREMENT	PRIORITY LEVEL	QUALIFICATION TYPE
	incorporated into the NWSRFS source code current at the time of delivery.		
5.2	LOOKUP3 operation updated source and header files shall be delivered in a directory structure approved by OHD staff.	High	Inspect
5.3	LOOKUP3 operation updates shall be easily compiled into the existing development cycle without changes to the OHD 'make' process or to the delivered source code.	High	Inspect
5.4	RES-J operation source code shall be incorporated into the NWSRFS source code current at the time of delivery.	High	Inspect
5.5	RES-J operation updated source and header files shall be delivered in a directory structure approved by OHD staff.	High	Inspect
5.6	RES-J operation updates shall be easily compiled into the existing development cycle without changes to the OHD 'make' process or to the delivered source code.	High	Inspect
6.0	**PROCESSING & PERFORMANCE REQUIREMENTS**		
6.1	The enhanced LOOKUP3 operation shall execute at a speed similar to the existing version.	High	Inspect
6.2	The enhanced RES-J operation shall execute at a speed similar to the existing version.	High	Inspect
7.0	**INTERFACE REQUIREMENTS**		
7.1	**System/Component Interface Requirements**		
	LOOKUP3 and RES-J have no interface separate from non-affected NWSRFS programs.	N/A	N/A
7.2	**Data Migration Requirements**		
	None – backward compatibility will be maintained	N/A	N/A
8.0	**TRAINING REQUIREMENTS**		
8.1	The enhancements to the LOOKUP3 and RES-J application shall be reflected in the NWSRFS User's manual. OHD will include the enhancements into pertinent training manuals.	High	Inspect

ID NUMBER	REQUIREMENT	PRIORITY LEVEL	QUALIFICATION TYPE
9.0	**DOCUMENTATION REQUIREMENTS**		
9.1	LOOKUP3 operation documentation shall be updated to reflect the new functionality.	High	Inspect
9.2	RES-J operation documentation shall be updated to reflect the new functionality.	High	Inspect
10.0	**CONSTRAINTS**		
10.1	Development shall conform to NWS HOSIP review and approval process.	High	Inspect
10.2	The enhancements shall be completed within the budget specified as part of the firm fixed price task order (Task 6-0017).	High	None