Options for Forecast-based Operation of Folsom Reservoir

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BIOGRAPHICAL SKETCH

David is a Professor of Civil and Environmental Engineering and Director of the Institute for Dam Safety Risk Management at Utah State University. He is also a Principal with RAC Engineers & Economists. His professional experience includes Director of the Utah Center for Water Resources Research, Branch Manager of Denver Operations for Law Engineering, and civil construction and design in the U.K.

Since 1997 David has led the Utah State University team that has worked with the U.S. Bureau of Reclamation (USBR), Sacramento Area Flood Control Agency (SAFCA), and other agencies to develop and implement software for improving operations and emergency management associated with Folsom Reservoir using real time inflow forecasts.

Over the past twenty years, David has pioneered the development and application of risk assessment and risk management to dam safety, with applications for the USBR, the U.S. Army Corps of Engineers, Ontario Power Generation, and in Australia and England.

2002 California Weather Symposium

Sierra College

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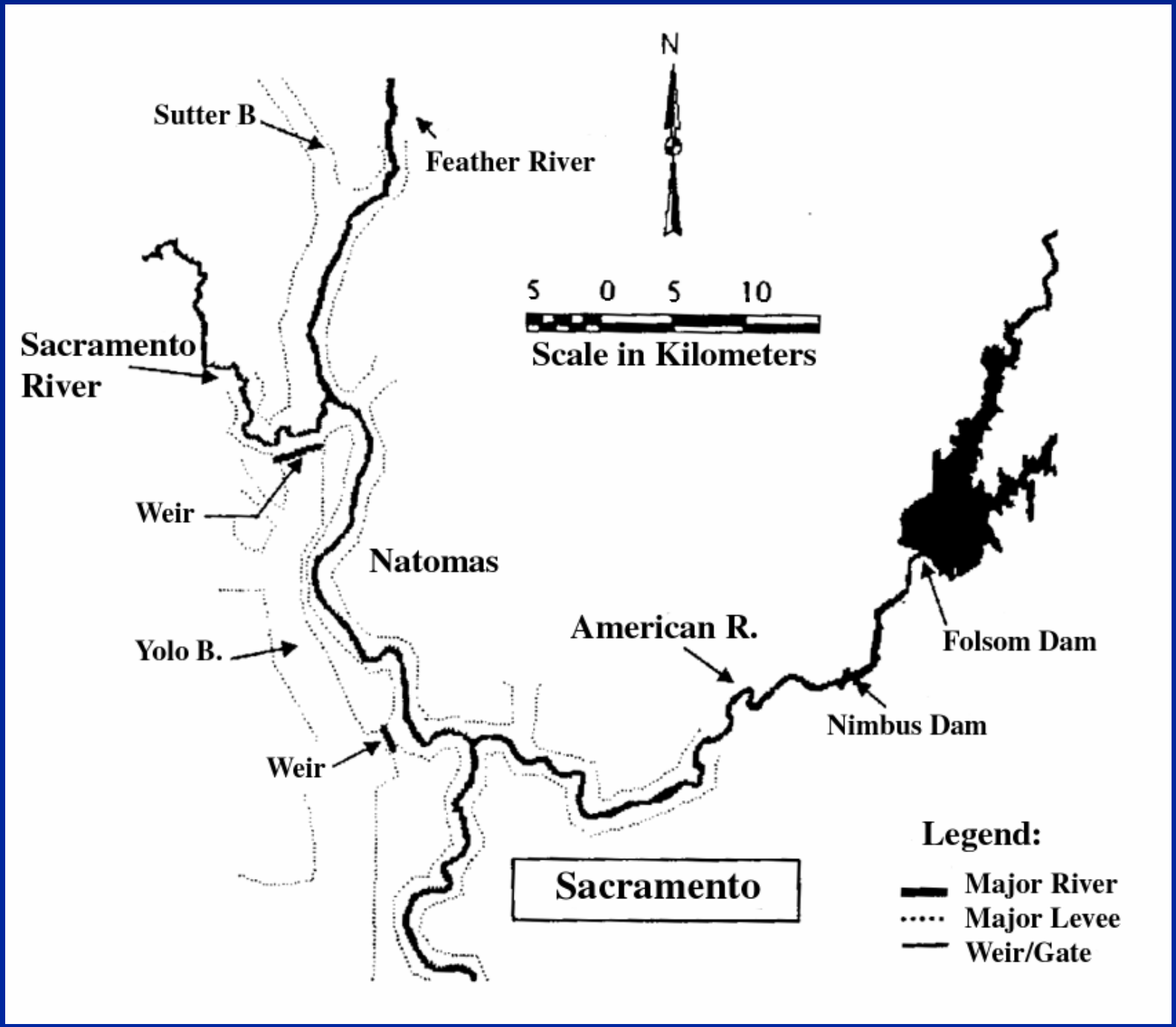
Institute for Dam Safety Risk Management

Utah State University

Utah State University

IDSRM

June 21, 2002


N
Sutter B
Feather River
5 0 5 10
Scale in Kilometers
Sacramento River
Weir
Natomas
Yolo B.
American R.
Folsom Dam
Nimbus Dam
Weir
Sacramento
Legend:
Major River
Major Levee
Weir/Gate

Objectives for Folsom Reservoir Release Forecast Model (RRFM)

1) To forecast the probability for **lead times for Folsom release flow levels and H Street stages**,

   which are critical for initiating downstream warning and evacuation

2) To forecast the probability for **Folsom Reservoir refill probabilities after Advanced Releases (AR)**

3) To provide a **simulation capability** for

   a) Developing **emergency management plans**

   b) Developing **reservoir operation rules**

      including AR with new low level outlets

   c) **Reservoir routing for design floods**

What has been accomplished since last year?

- Completed Inflow Generation Algorithms
- Verified Inflow Generation codes
- Tested Inflow Generation algorithms
- Added interactive (pseudo real time) planning mode for simulation exercises with emergency managers
- Added framework AR rule testing
- Formulated of generalized AR rule
- Operational Version software maintenance
- Delivery and training for COM – USBR/Denver

Outline

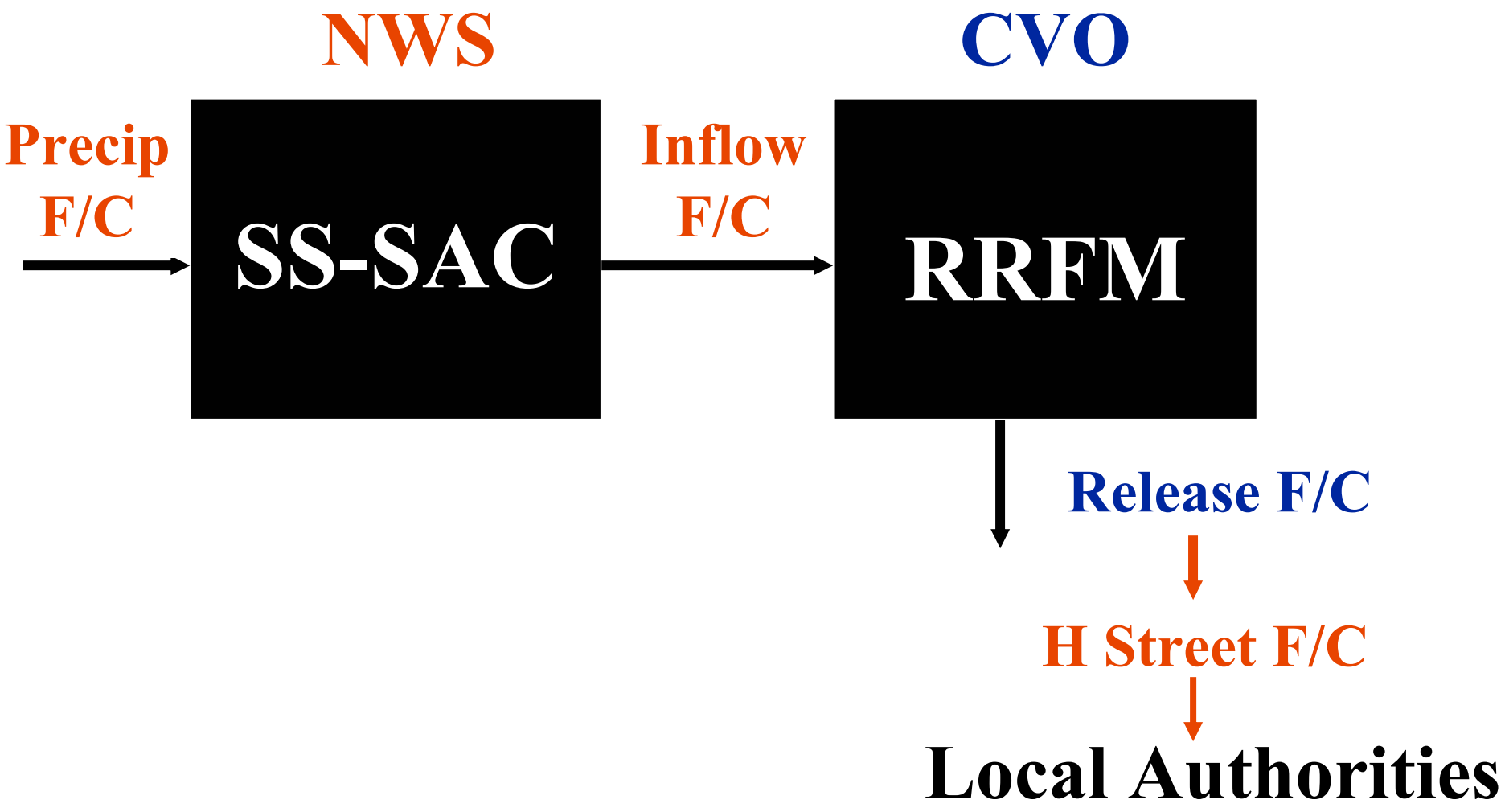
1) Reservoir Release Forecast Model
2) Probability Distribution of Forecast Reservoir Release Lead Times
3) Inflow Forecast Error Generator
4) Forecast Based Operations
   - *Preliminary Generalized Advanced Release Rule*
5) Status

1) Reservoir Release Forecast Model (RRFM-U)

Two major components:

- Inflow Forecast Model
  - Dr. Konstantine Georgakakos, Hydrology Research Center (HRC)
  - NWS CA/NV River Forecast Center, USU
- Reservoir Release Forecast Model (RRFM-U)
  - Utah State University (USU)
  - CVO, NWS, HRC, SAFCA, USACE, City, County, American River FCD

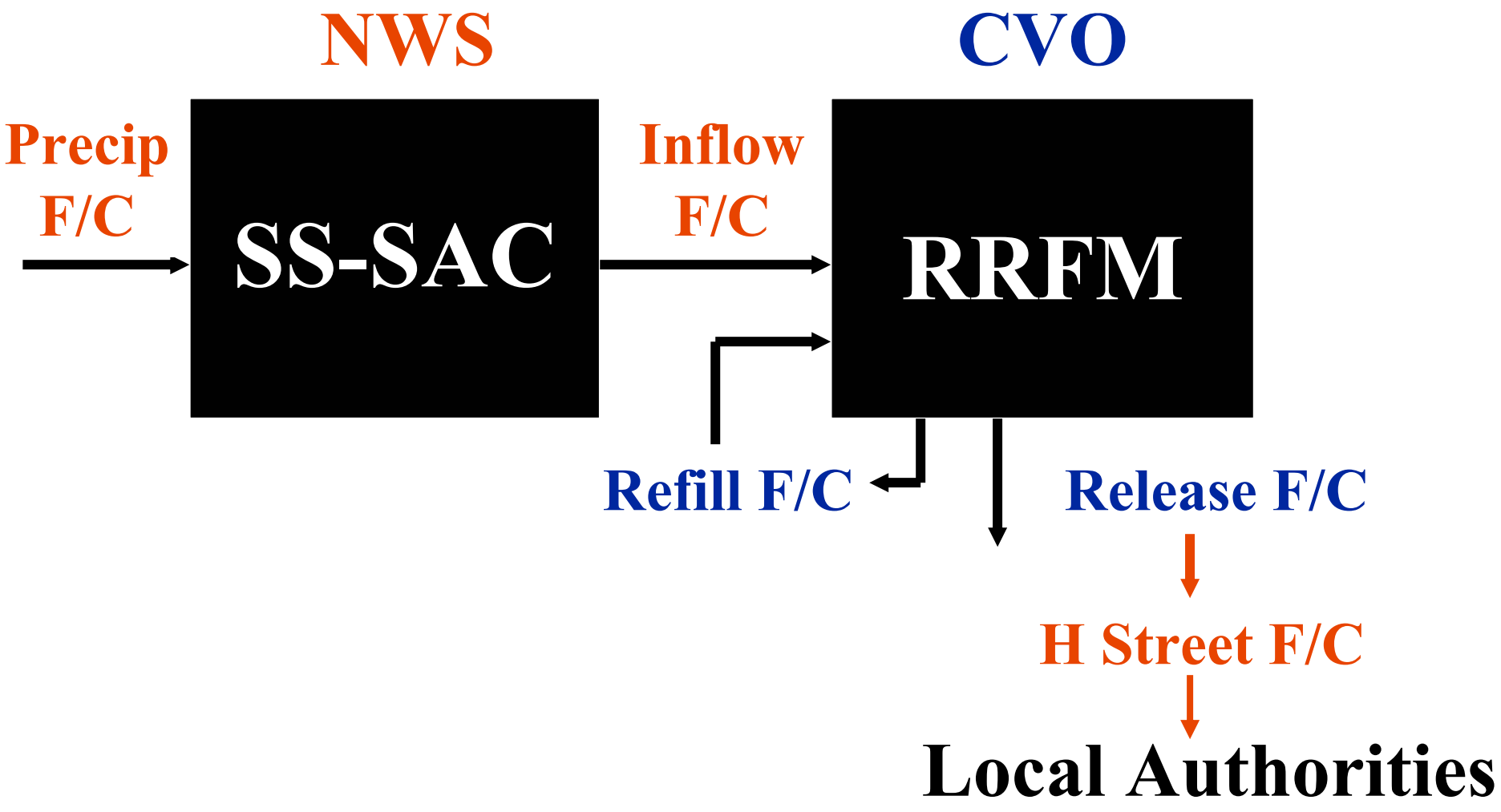
Forecasting System Components

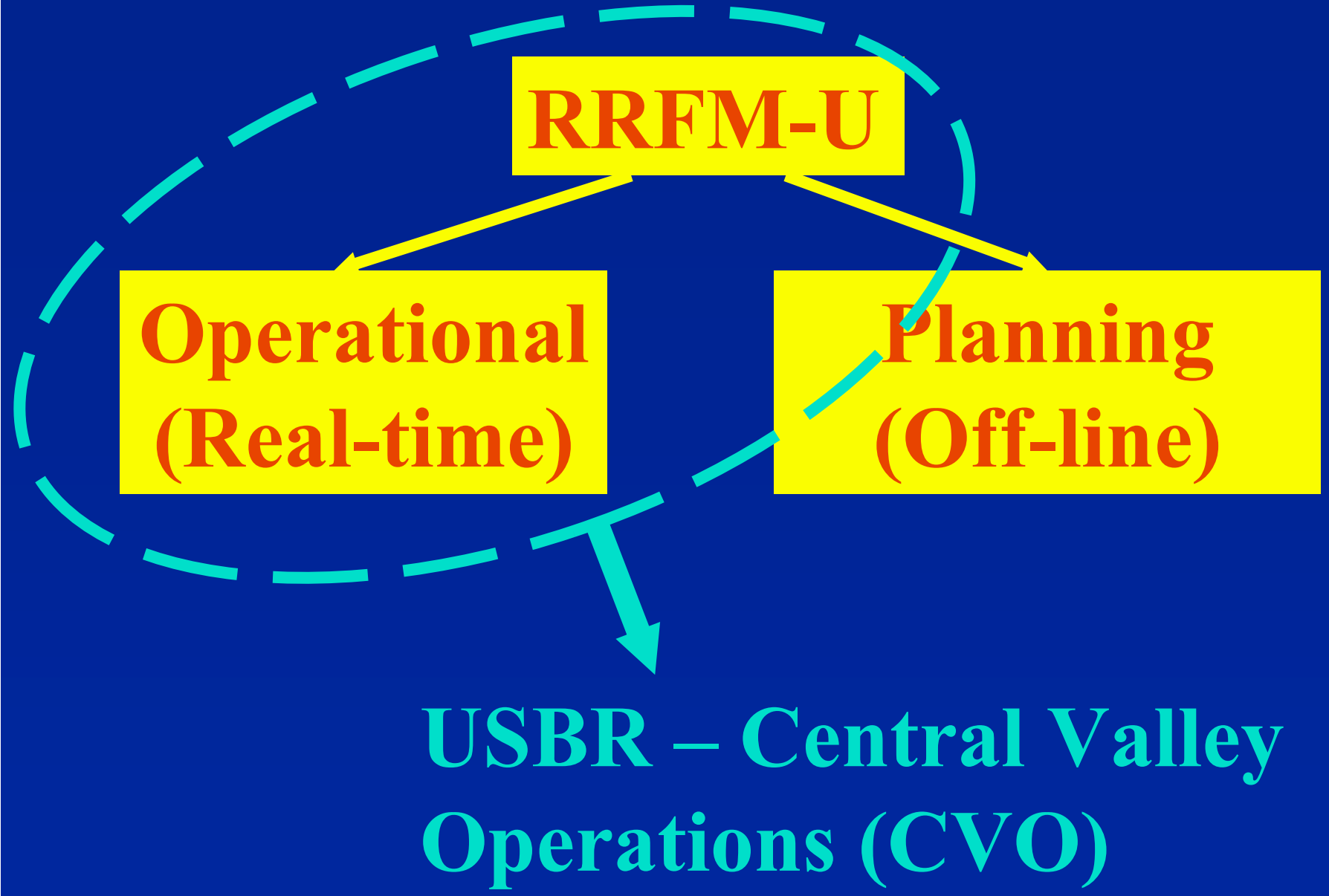


Mass Balance

Change in Storage =
Inflow Volume - Release Volume

Forecasting System Components



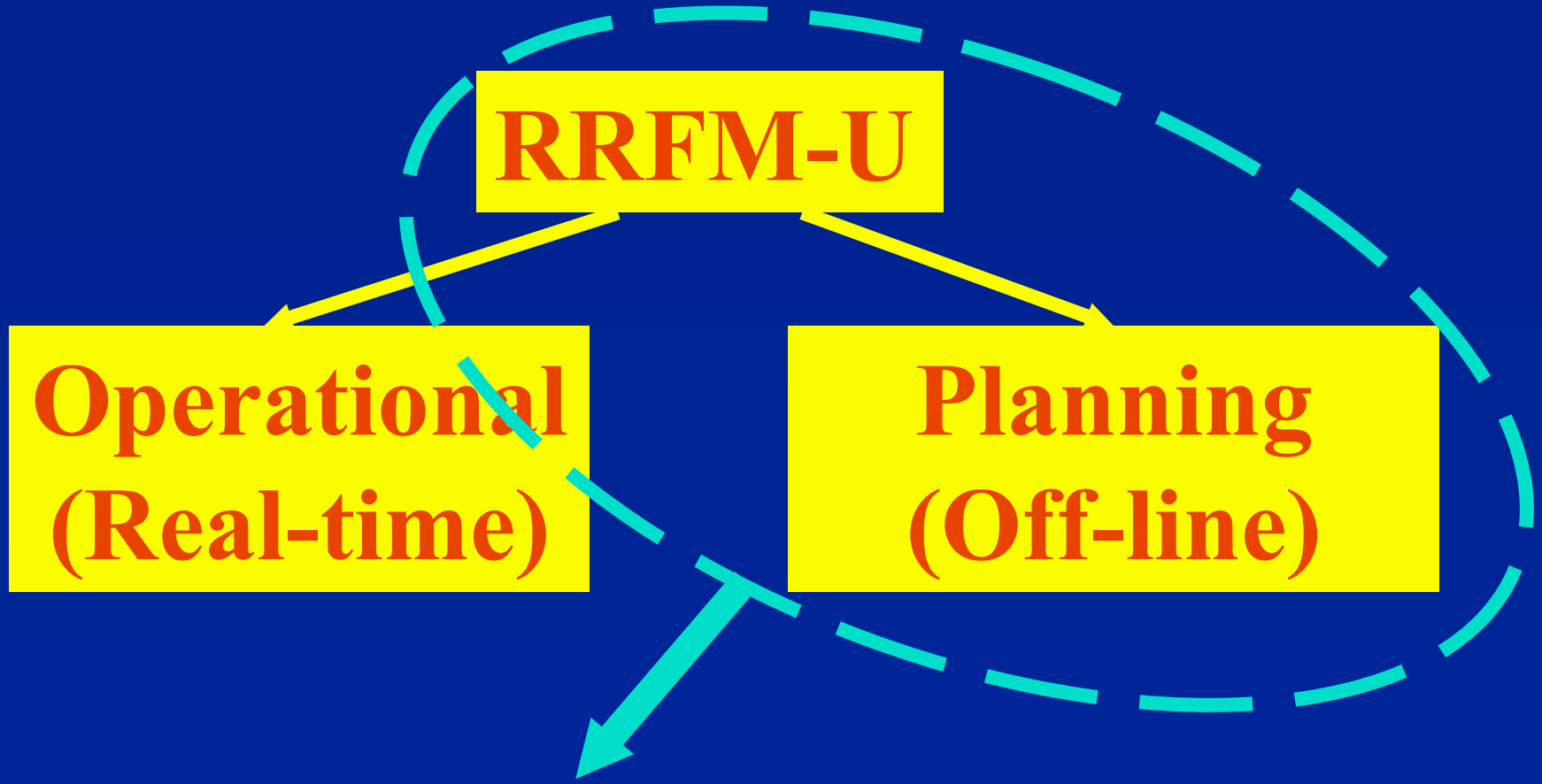

RRFM-U
Operational
(Real-time)
Planning
(Off-line)
USBR – Central Valley
Operations (CVO)

Reservoir Release Forecast Model (RRFM)

- Captures inflow forecasts and other input variables
- Calculates
  - Release capacity from outlet works
  - Forecast releases and reservoir levels using
    - *two flood control diagrams and three emergency spillway release rules, OR*
    - *operator-specified releases, OR*
    - *observed releases*
- Forecasts
  - Lead time for exceeding
    - critical reservoir release rates
    - stages at H Street
  - Reservoir refill for forecast horizon

RRFM-U capabilities (Cont'd)

- Graphical-user interface
- Documents when forecast information is available and records operator's notes
- Provides on-line and off-line planning/simulation capability
- Provides information for release orders for reservoir releases
- Provides visualization of key variables
- *Probability distribution levels on all forecast variables*



COM Version (Off-line)

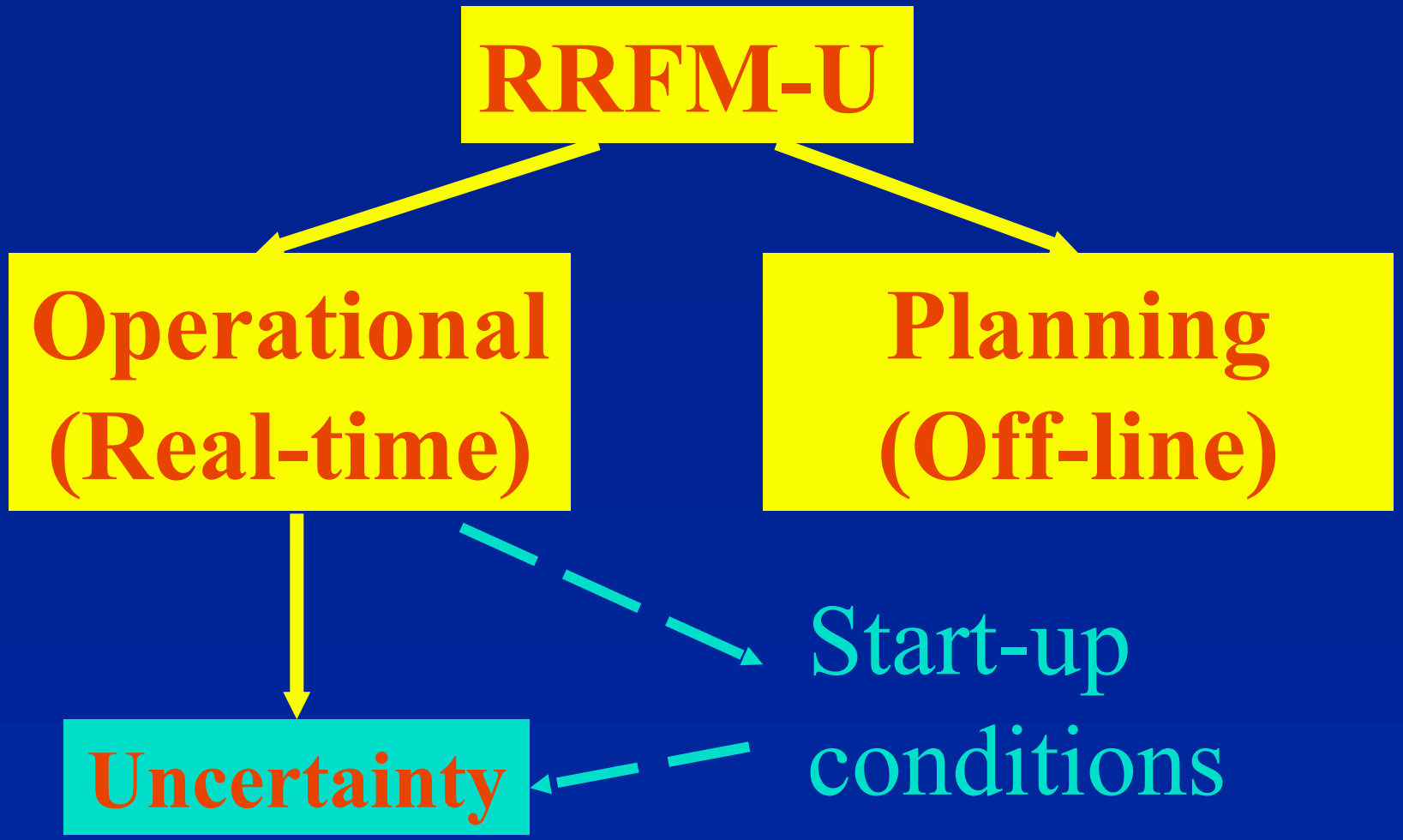
- provides access to RRFM via Excel spreadsheet
- flexible planning tool
- Corps/Sacramento & USBR/Denver

RRFM-COM – Technical Explanation

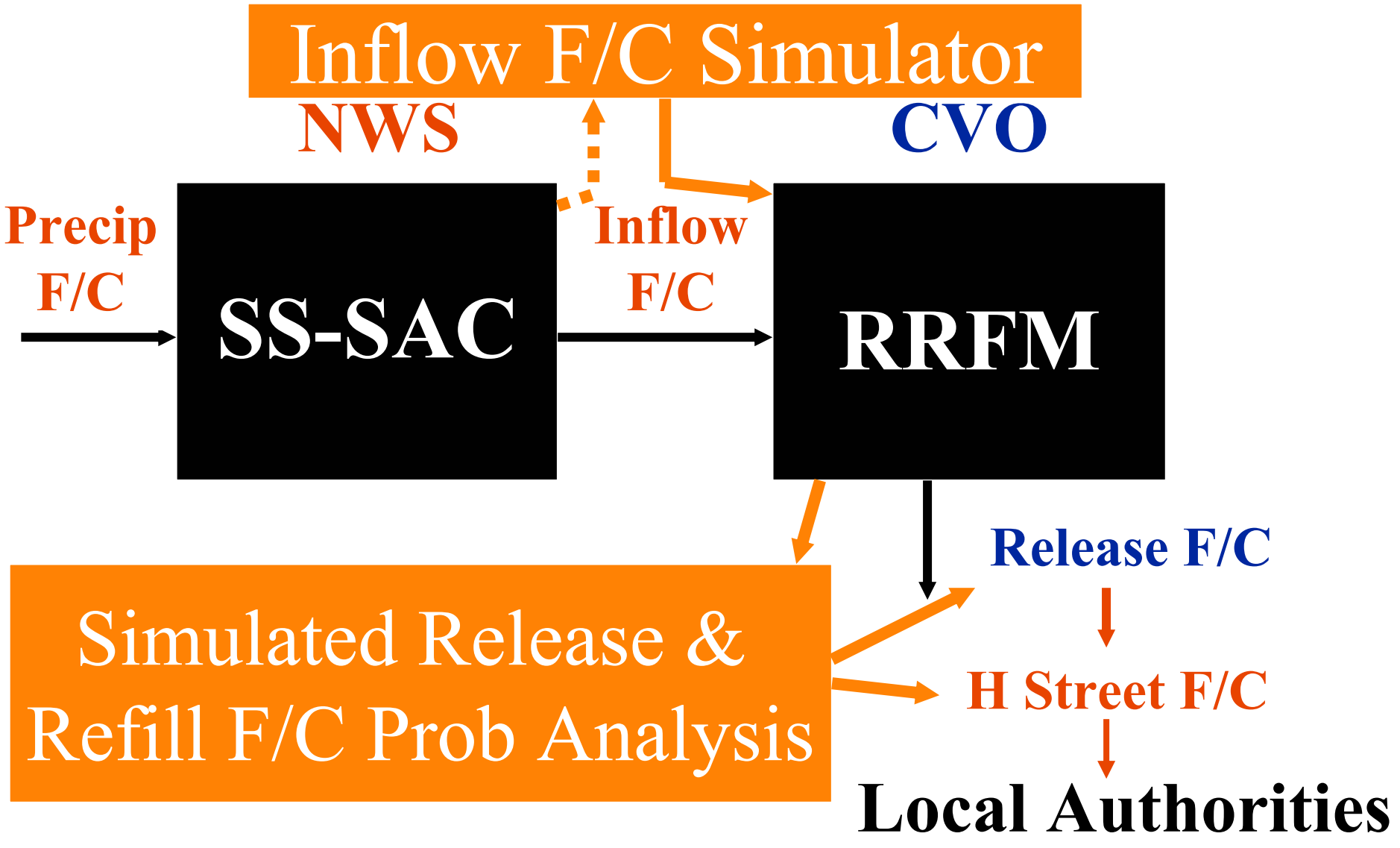
- Component Object Model (COM)
  - Microsoft component technology
  - Develop and re-use core components of larger software systems within many different development environments and applications
- RRFM Database and Analytical code in Visual C++
  - Utilize this code from a RAD (Rapid Application Development) programming tool called Borland C++ Builder

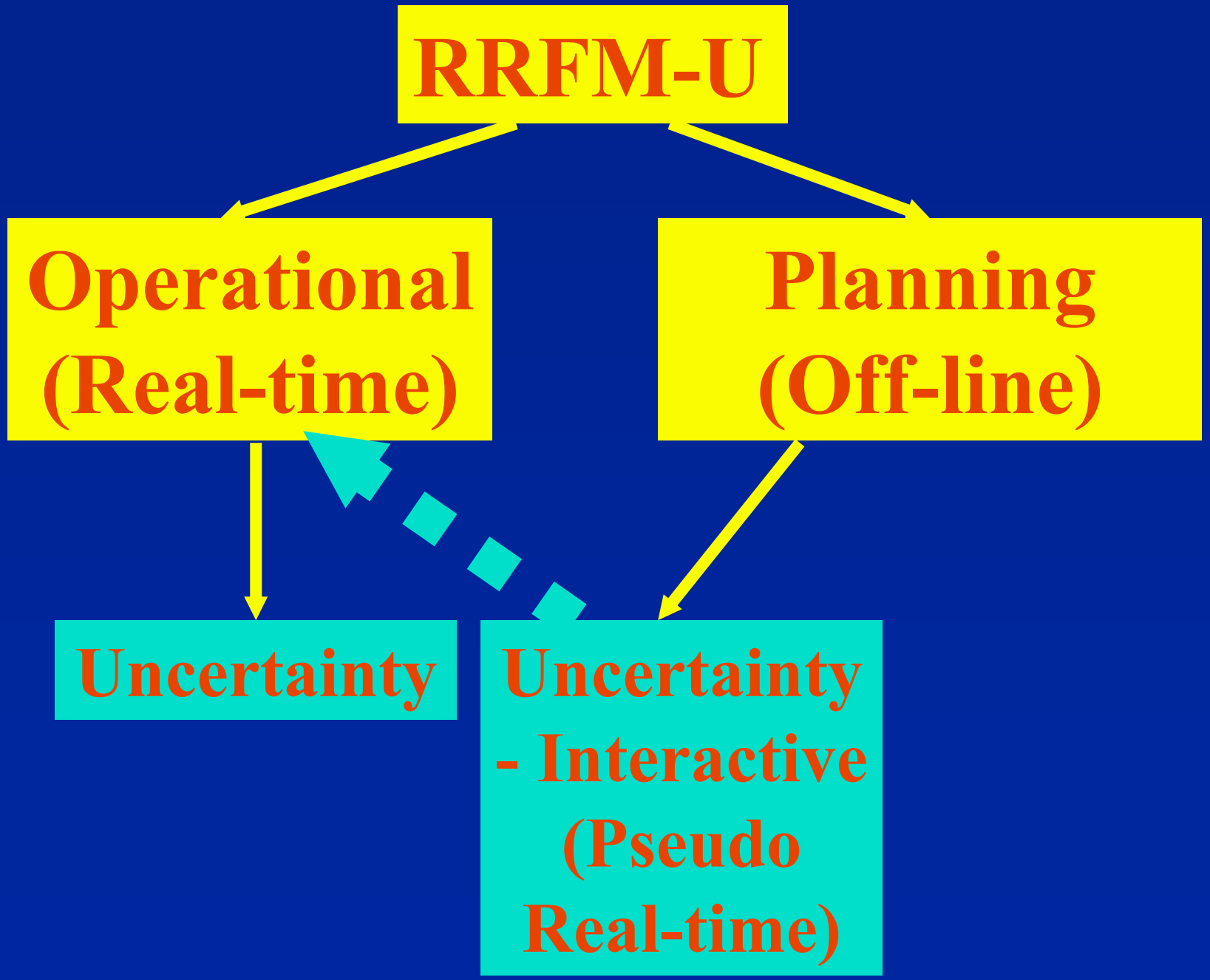
RRFM-COM –User Explanation

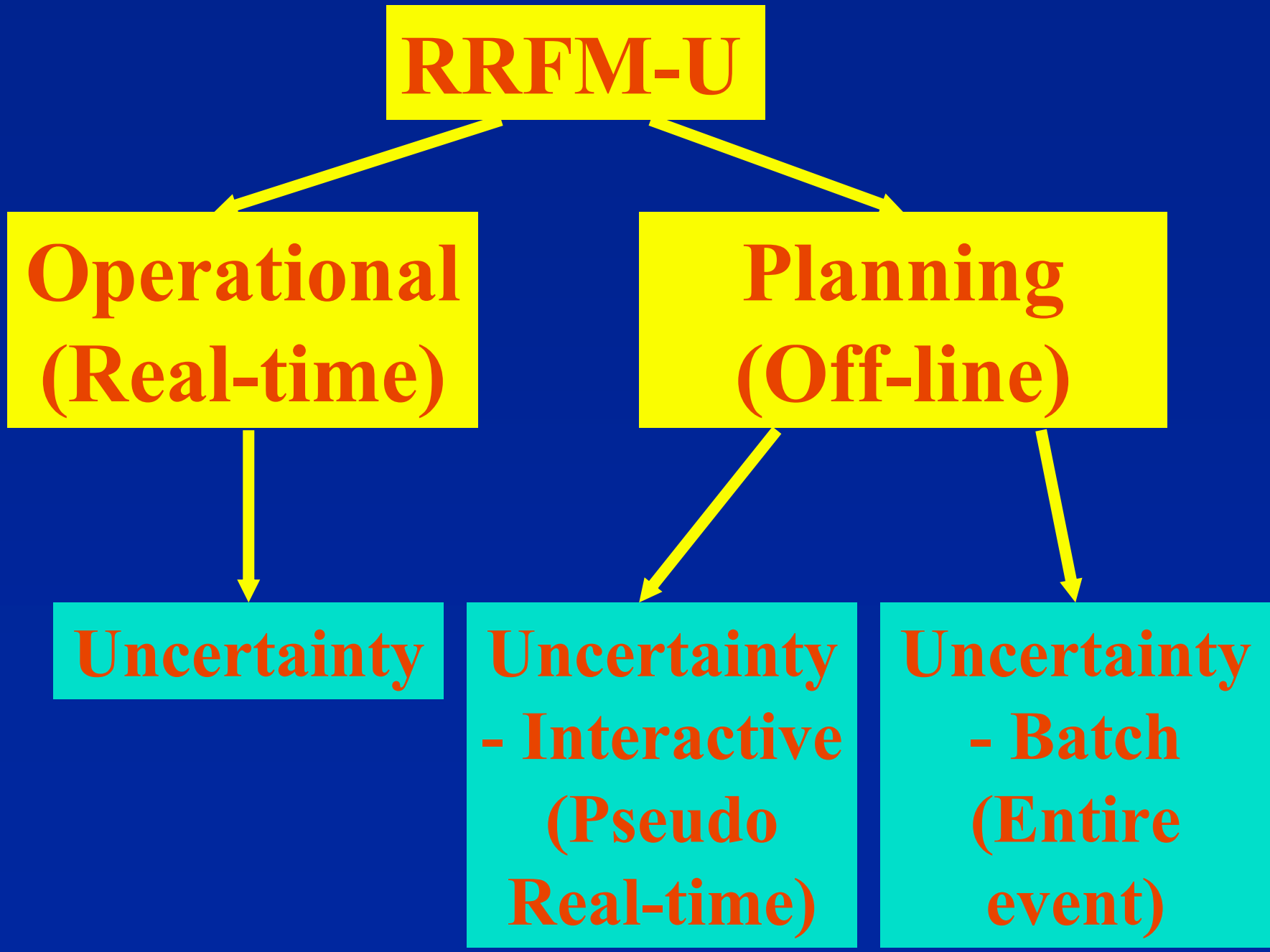
- Run RRFM from Microsoft Excel
- Uses Visual Basic to access RRFM database and analytical code directly, even though written in Visual C++
- Take advantage of the RRFM database and analytical code to build other client applications in MS Excel, Visual Basic, and MC Access
- In use by Corps/Sacramento District since July 2000 and USBR/Denver since June 2001
  - Routing hypothetical floods
  - Assessing changes in outlet works


RRFM-U
Operational (Real-time)
Planning (Off-line)
Uncertainty
Start-up conditions
- storage
- release

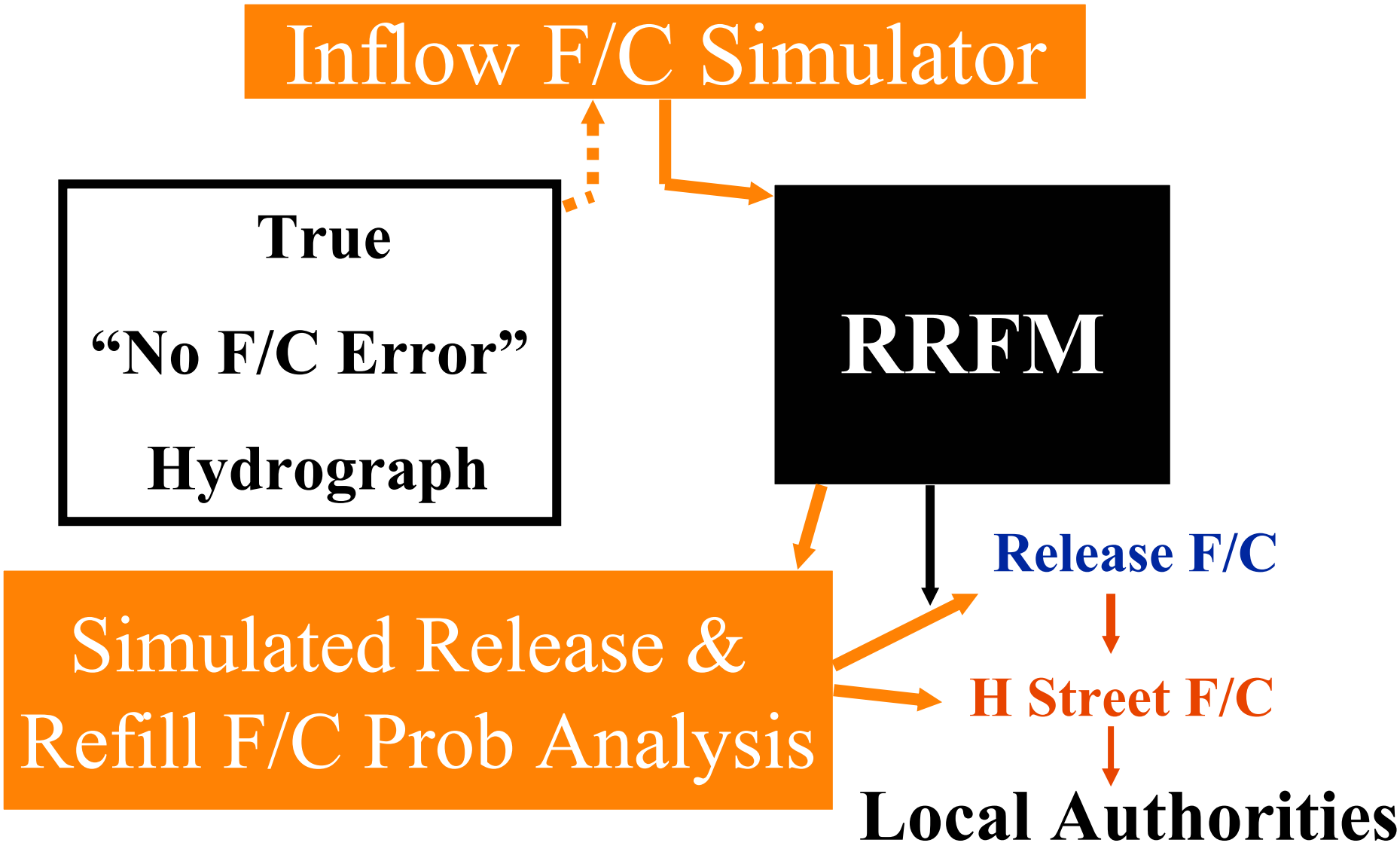
REAL TIME Simulation Forecasting System Components




RRFM-U
Operational (Real-time)
Planning (Off-line)
Uncertainty
Uncertainty - Interactive (Pseudo Real-time)

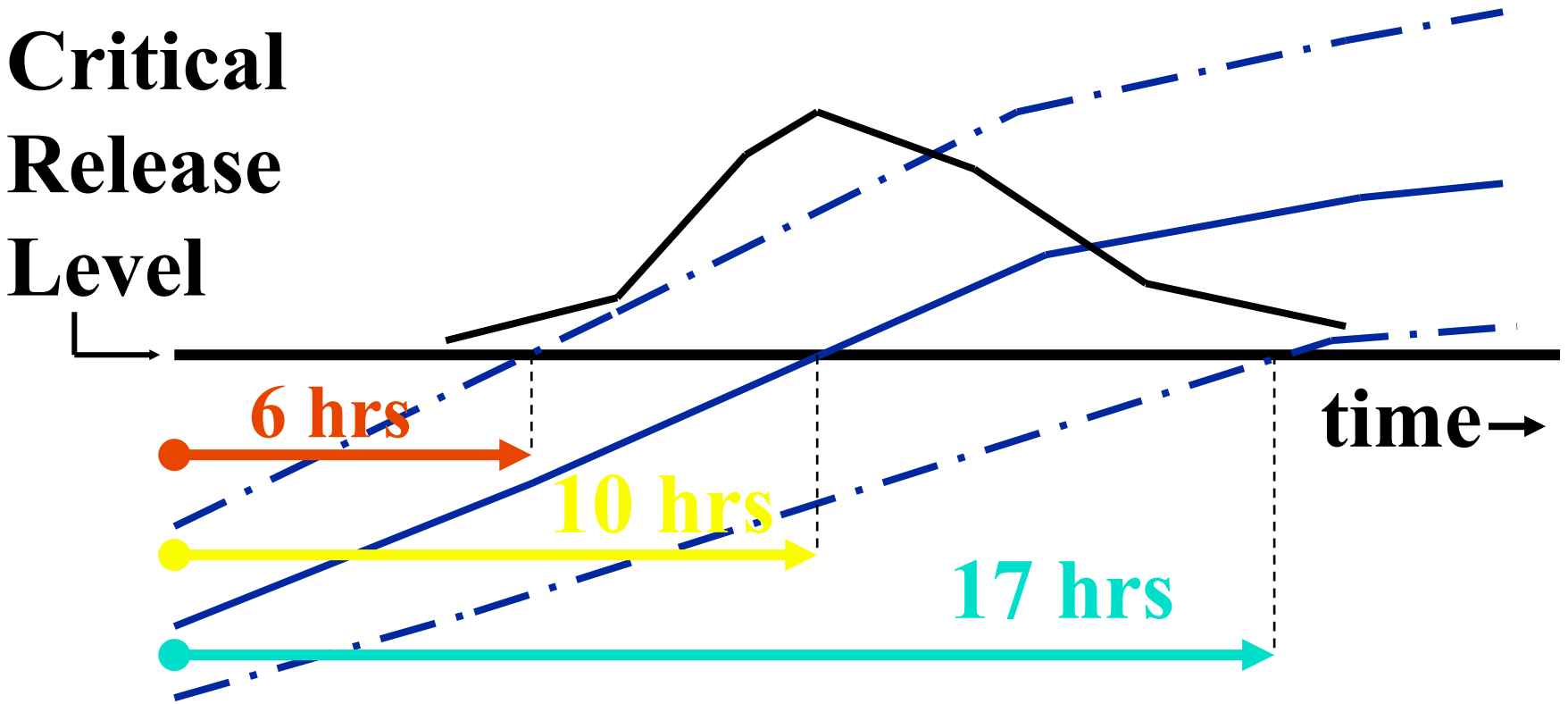

RRFM-U
Operational (Real-time)
Planning (Off-line)
Uncertainty
Uncertainty - Interactive (Pseudo Real-time)
Uncertainty - Batch (Entire event)

PLANNING Simulation Forecasting System Components

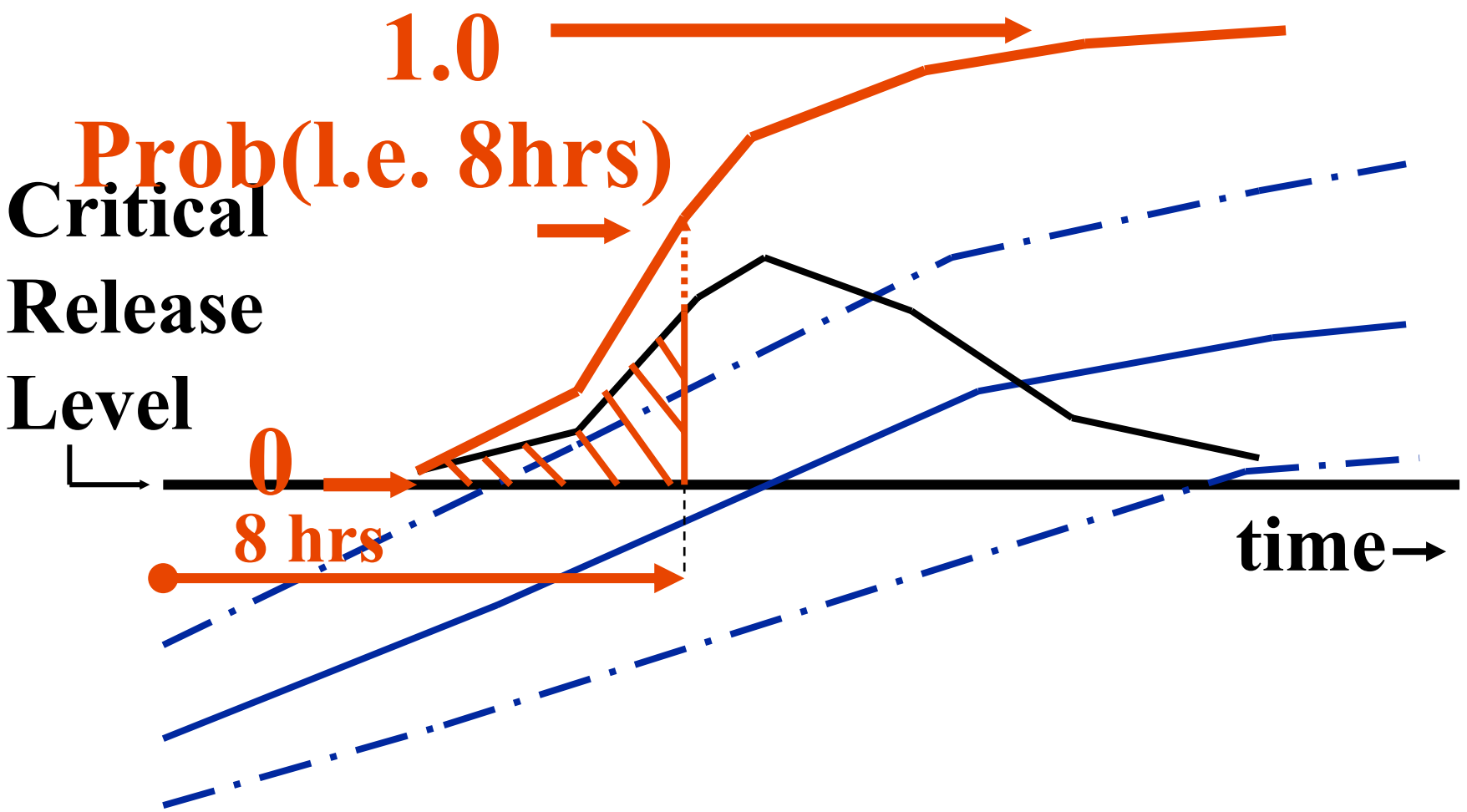


2) Probability Distribution of Forecast Reservoir Release Lead Times

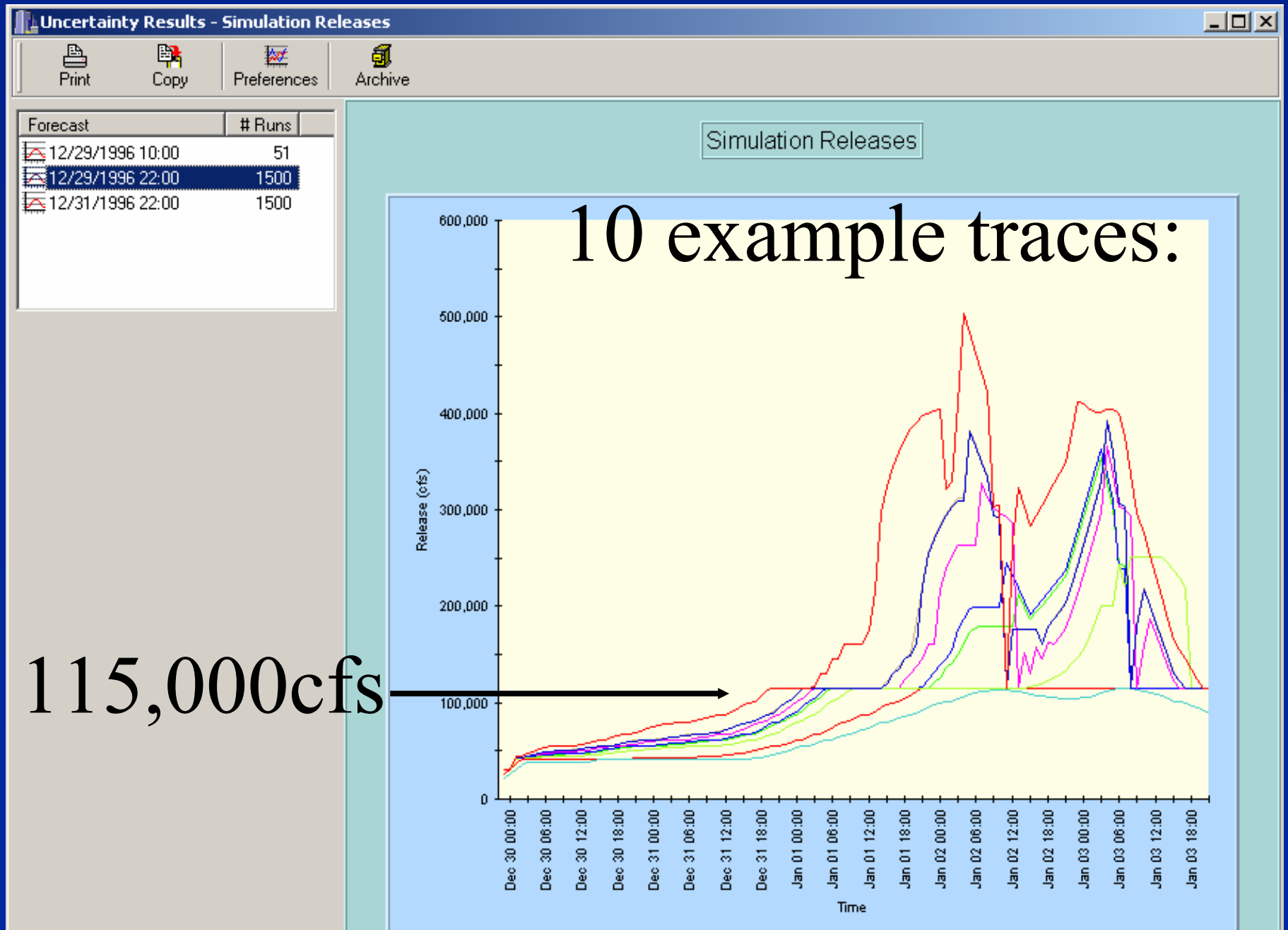
Forecast Lead Times



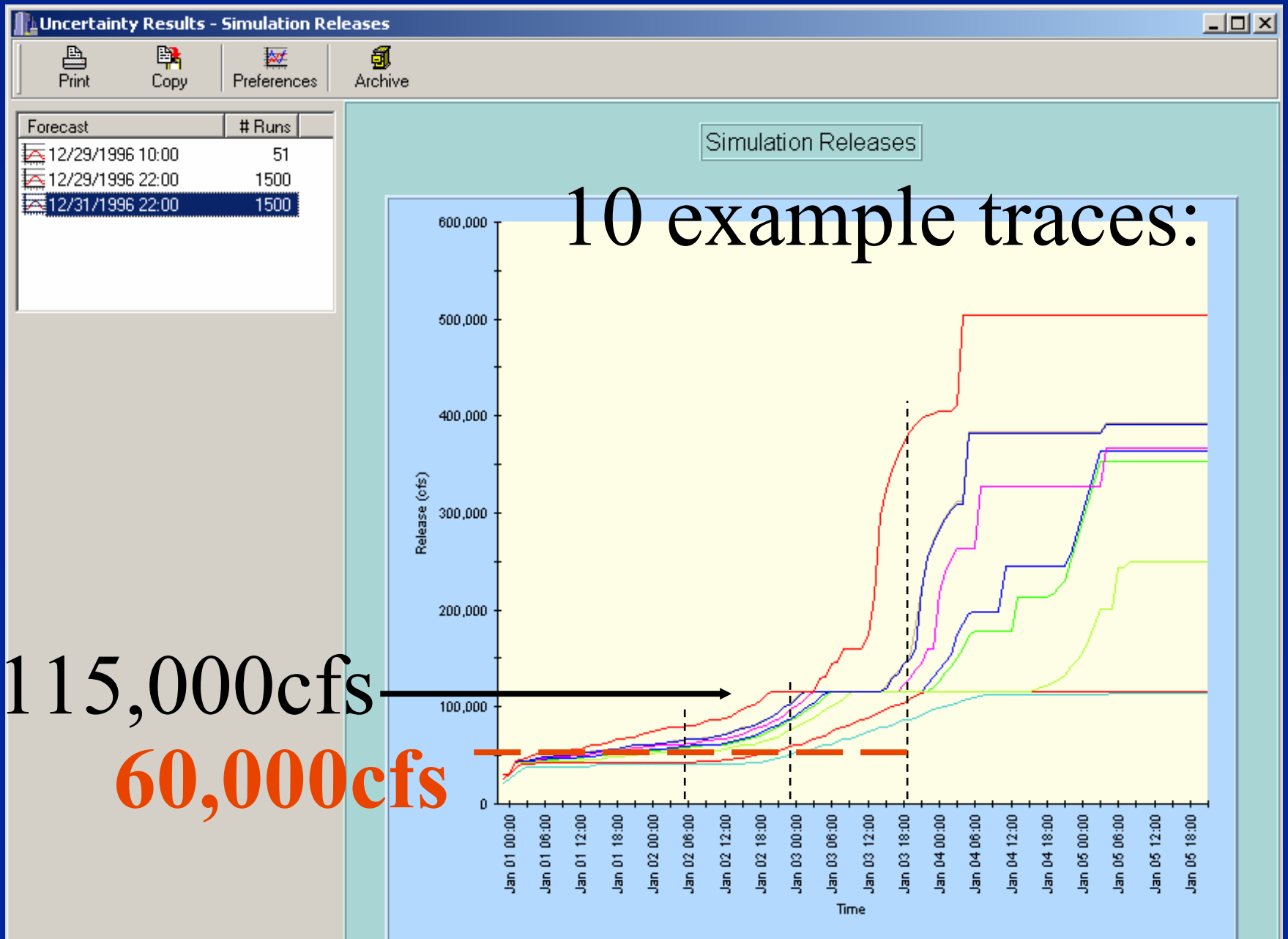
Forecast Lead Times



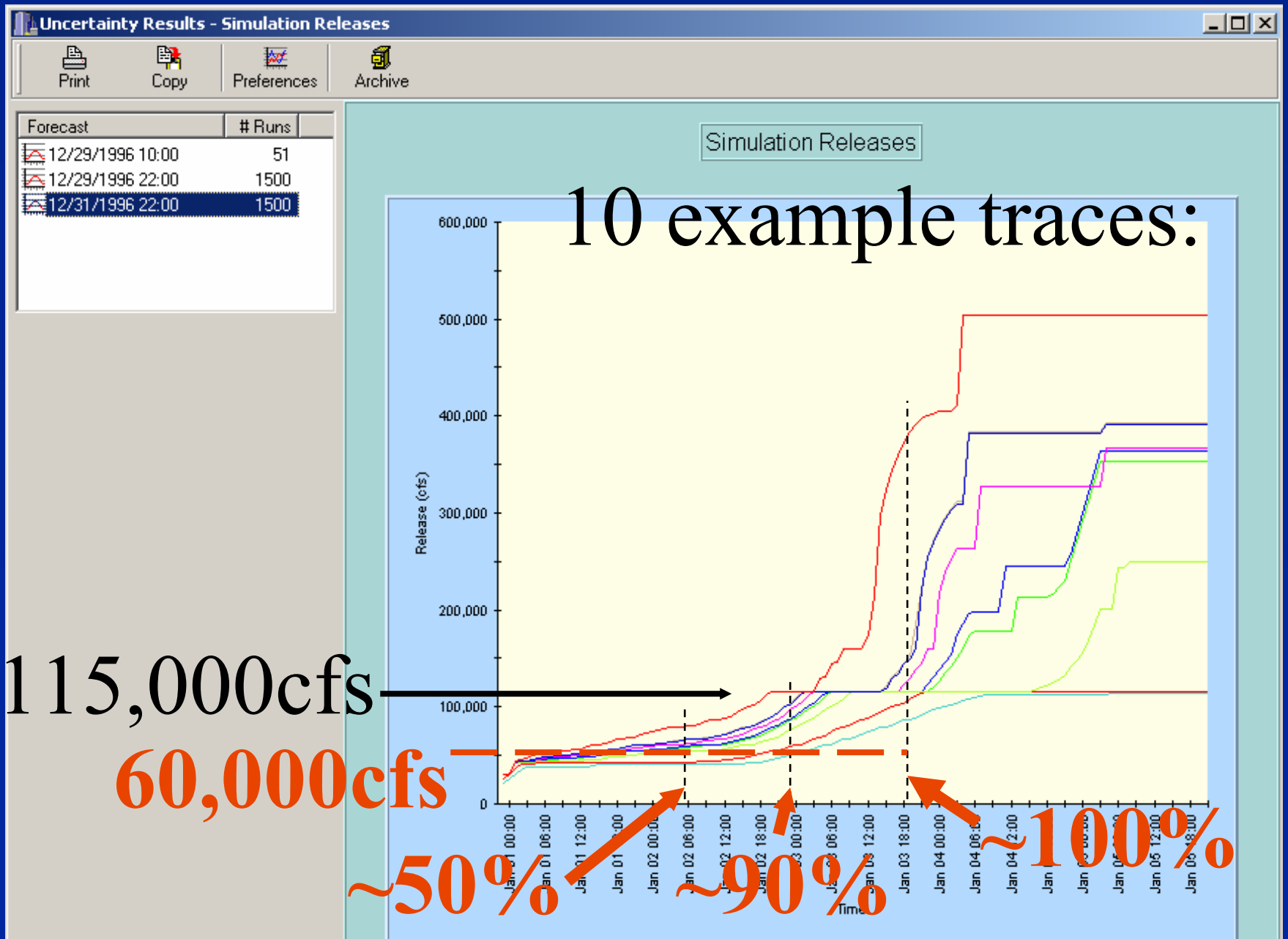
Simulated Instantaneous Forecast Releases X cfs



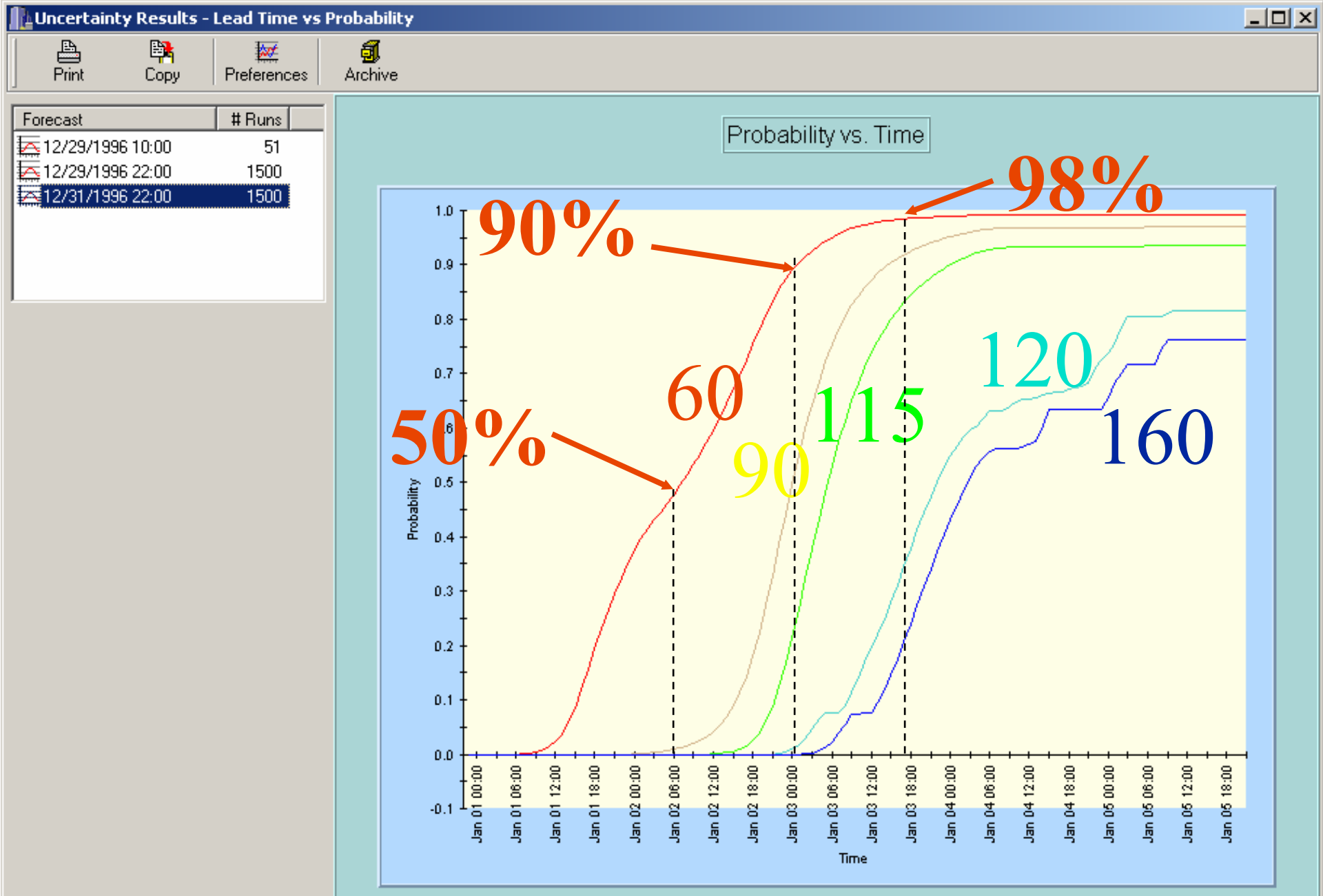
Simulated Maximum Forecast Releases X cfs



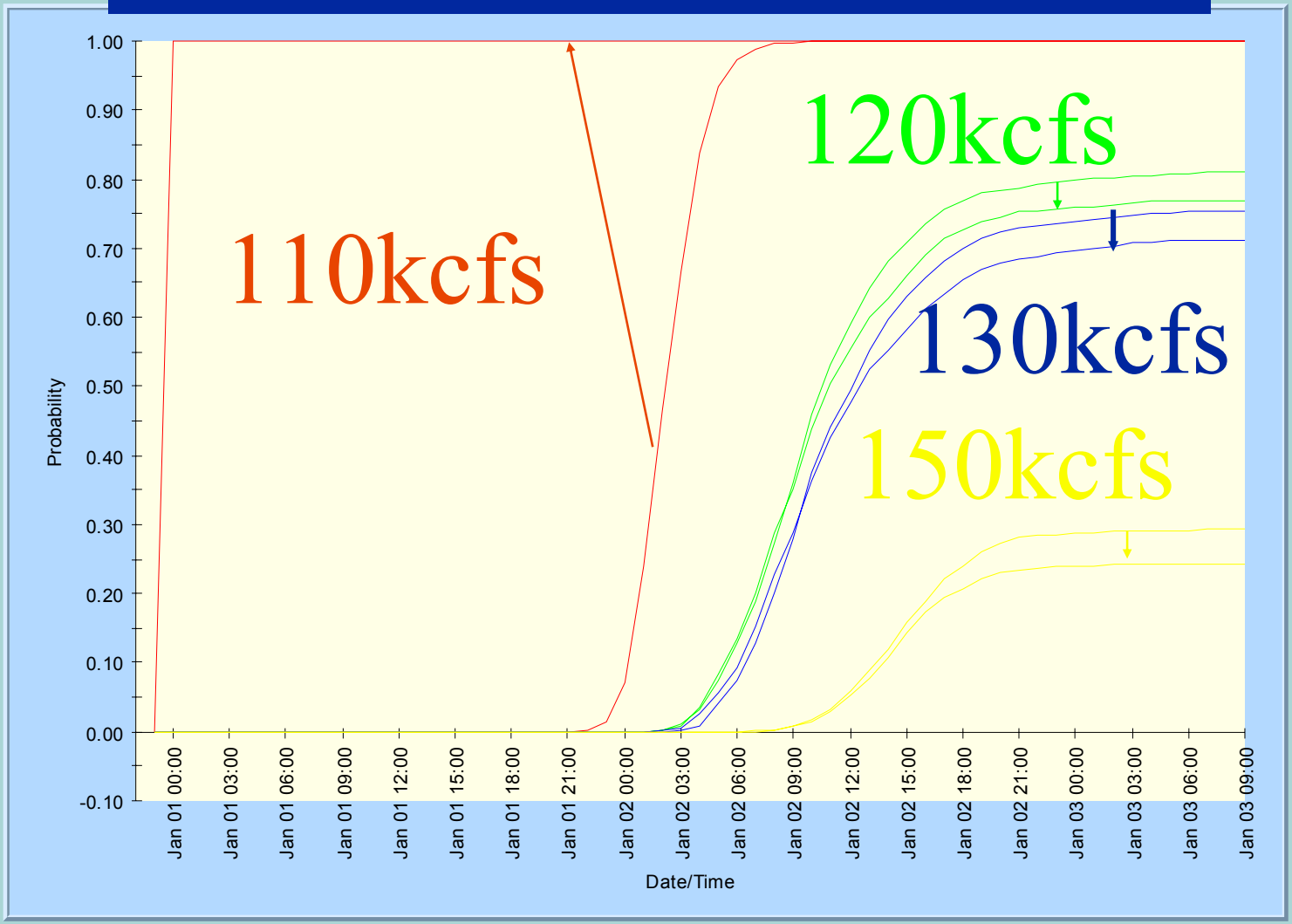
Simulated Maximum Forecast Releases X cfs



Prob. P of Max. Rel. exceeding X cfs by Time T



Pre Release Illustration



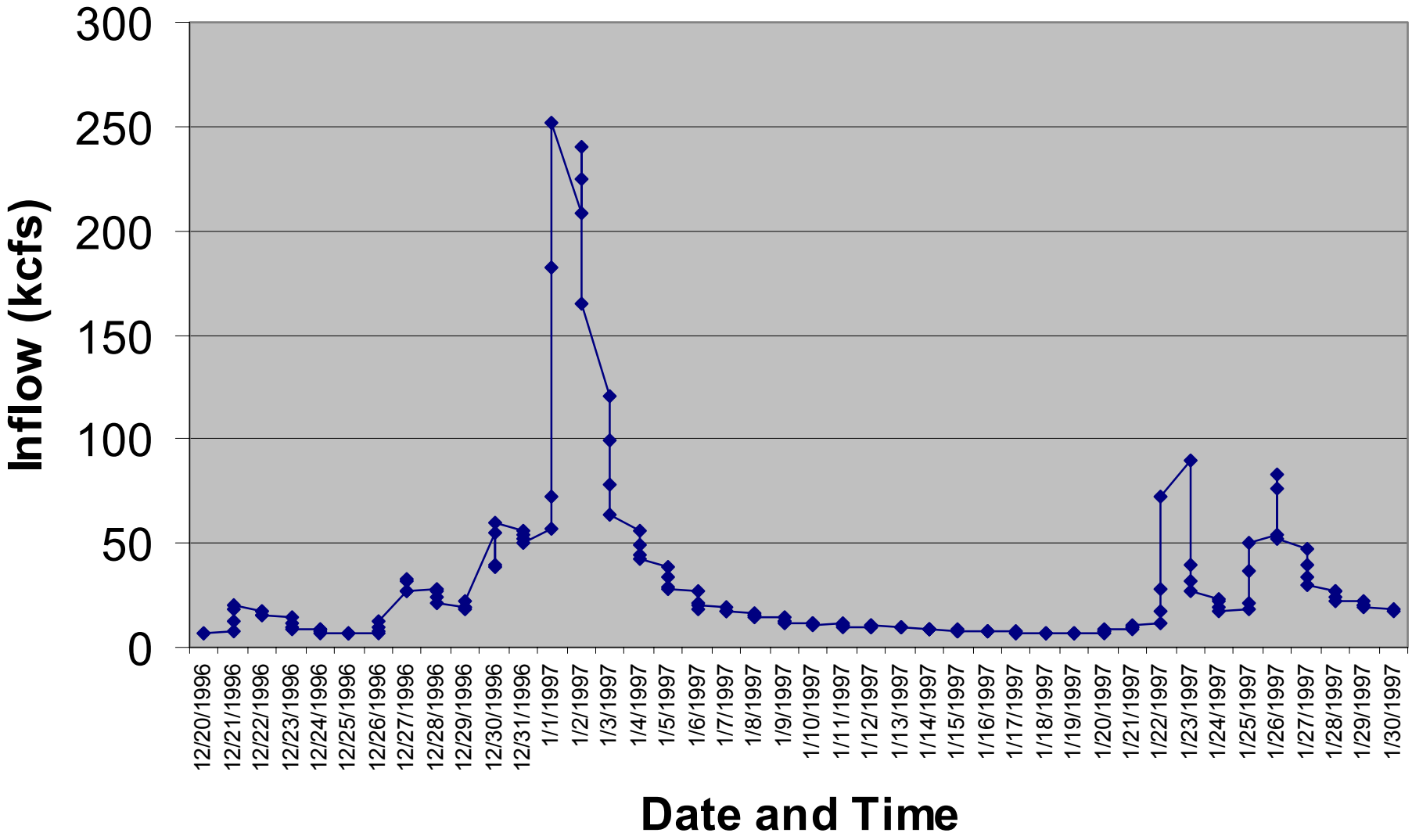
Init St 700k (Max) (110)
Init St 700k (Max) (120)
Init St 700k (Max) (130)
Init St 700k (Max) (150)

PreRel Init St 700k (Max) (110)
PreRel Init St 700k (Max) (120)
PreRel Init St 700k (Max) (130)
PreRel Init St 700k (Max) (150)

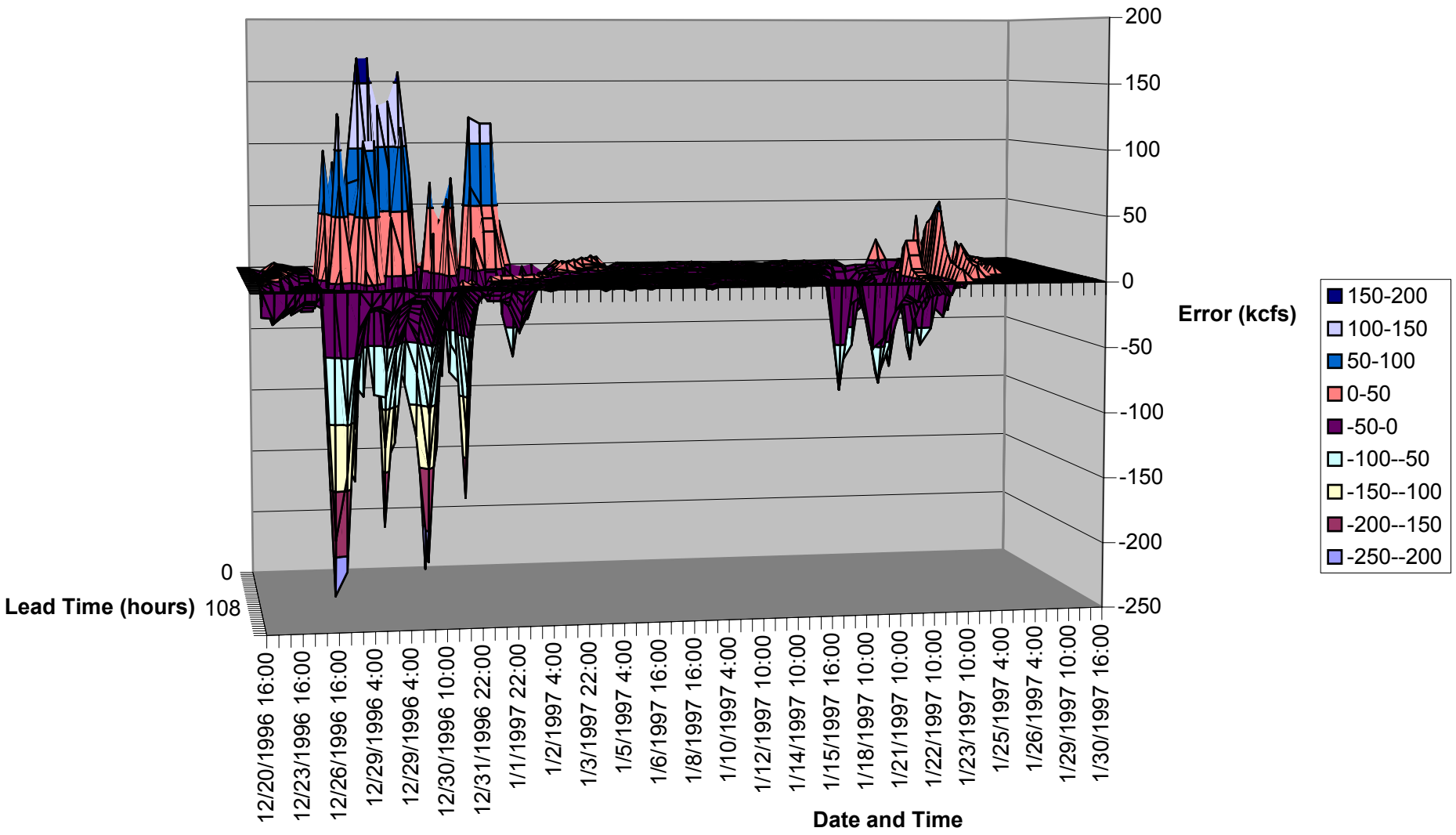
3) Inflow Forecast Error Generator

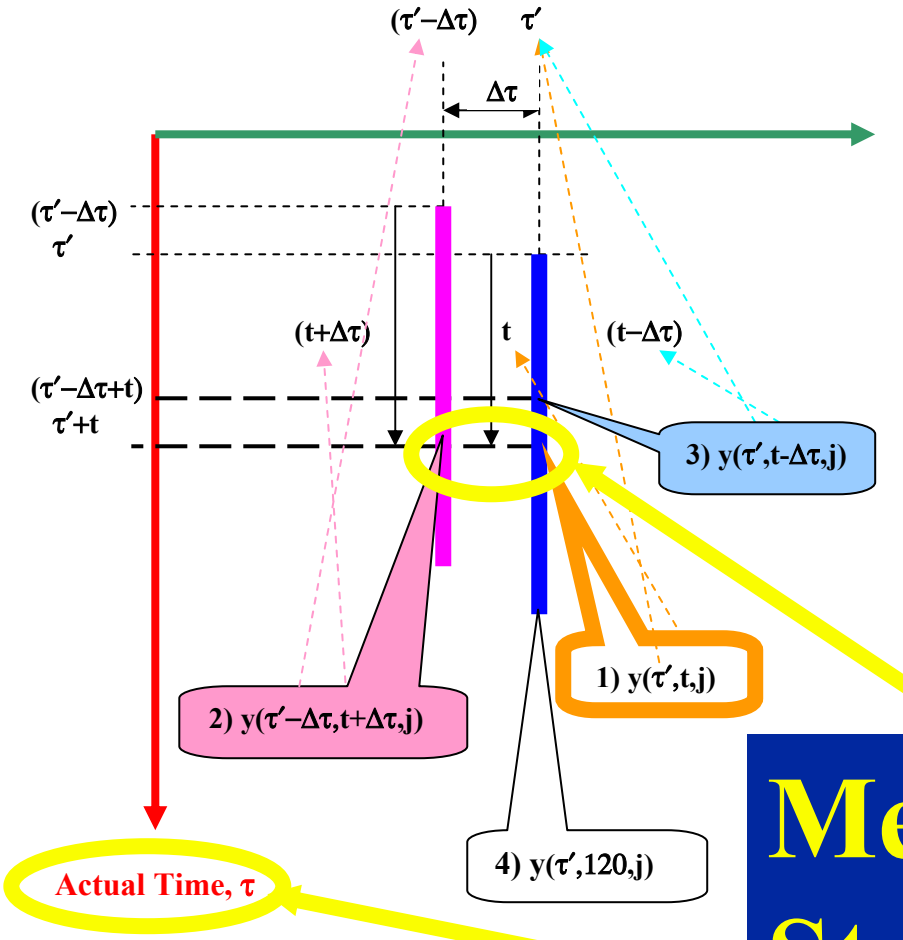
Forecast Error = Forecast Inflow – Observed Inflow

Observed Folsom Inflows



Forecast Errors

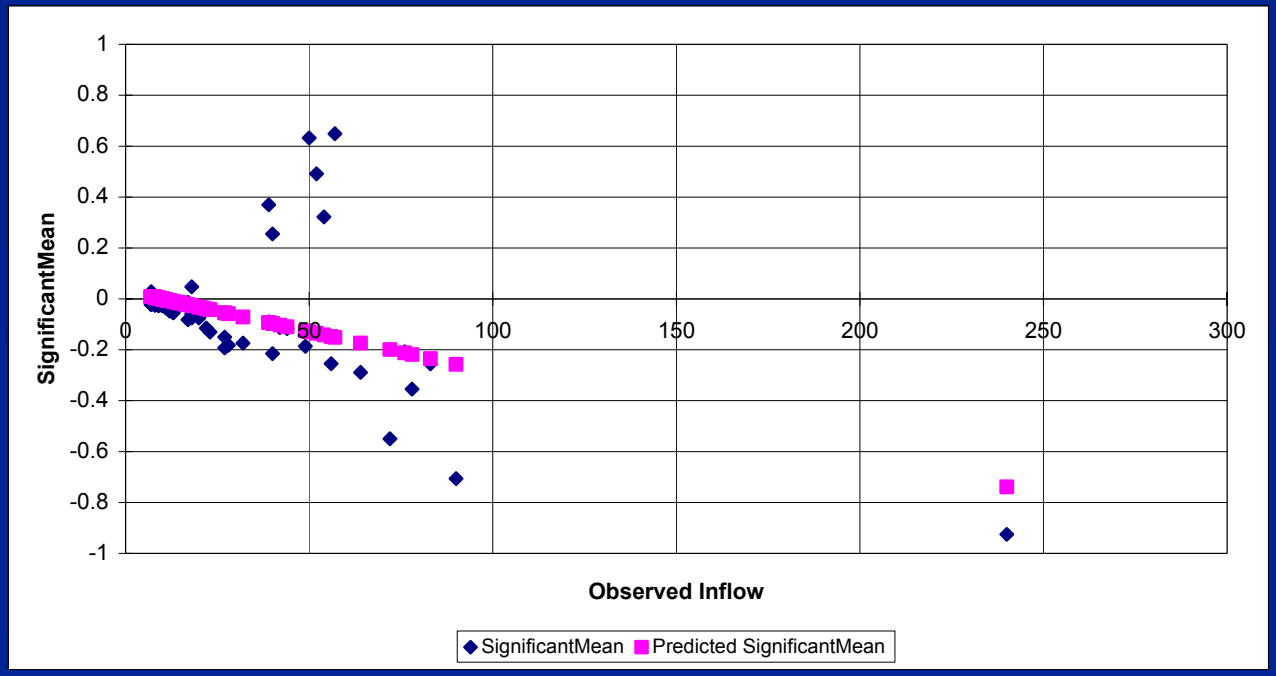


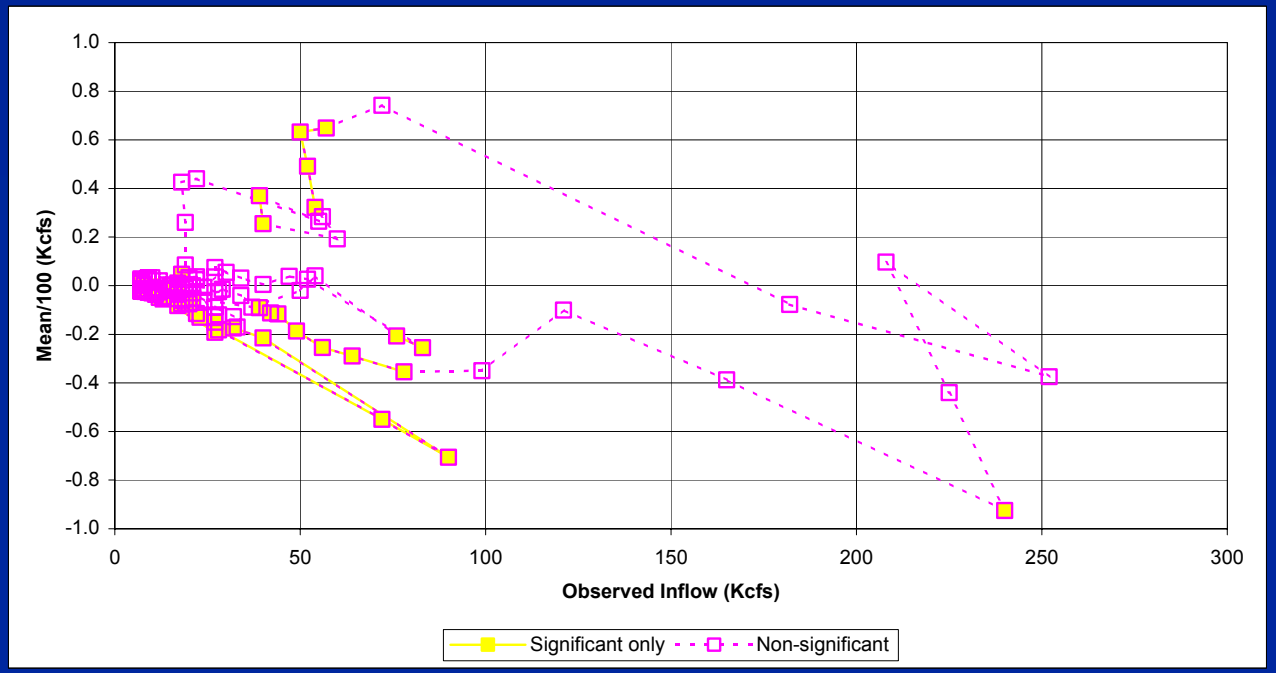


Successive Forecasts

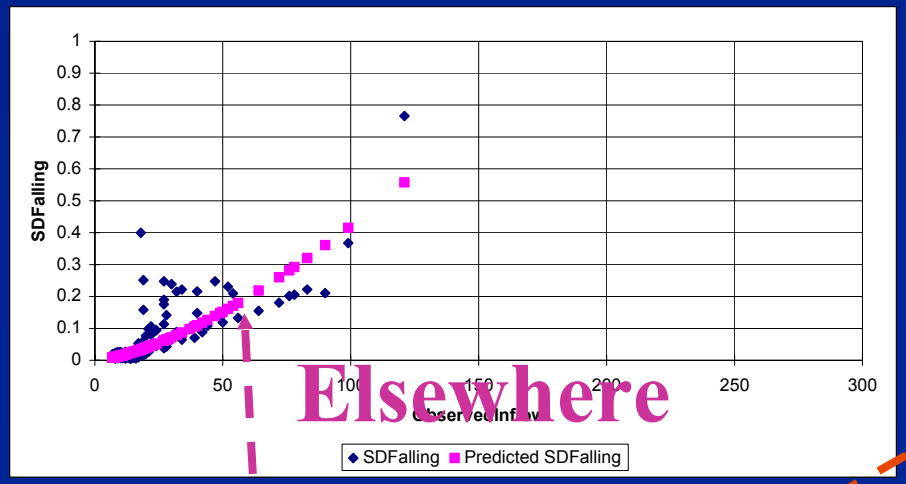
Mean
Std Dvtn
Skewness

Mean Forecast Error

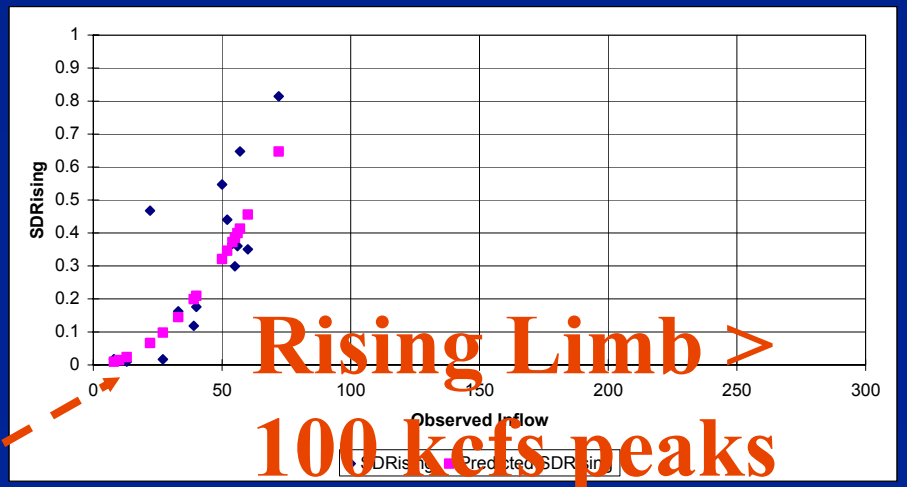




Standard Deviation of Forecast Error



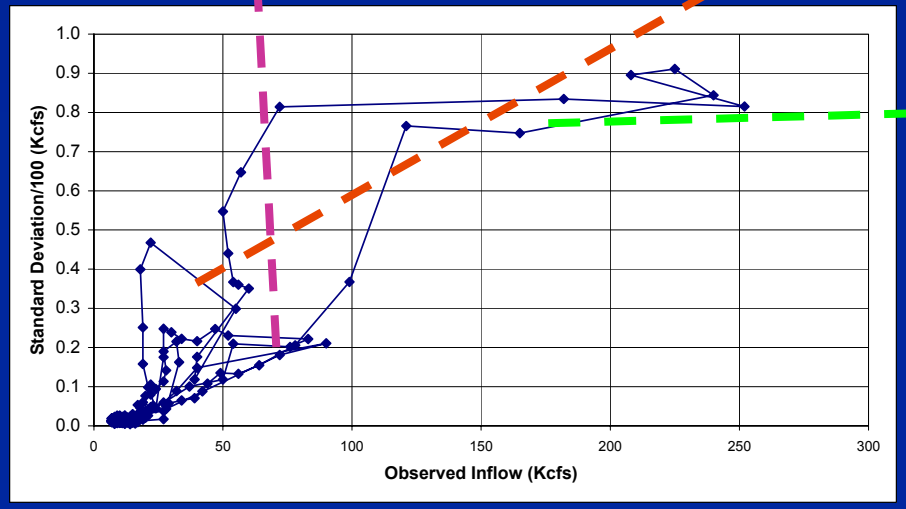
Combine less than 100 cfs peaks with the falling limb

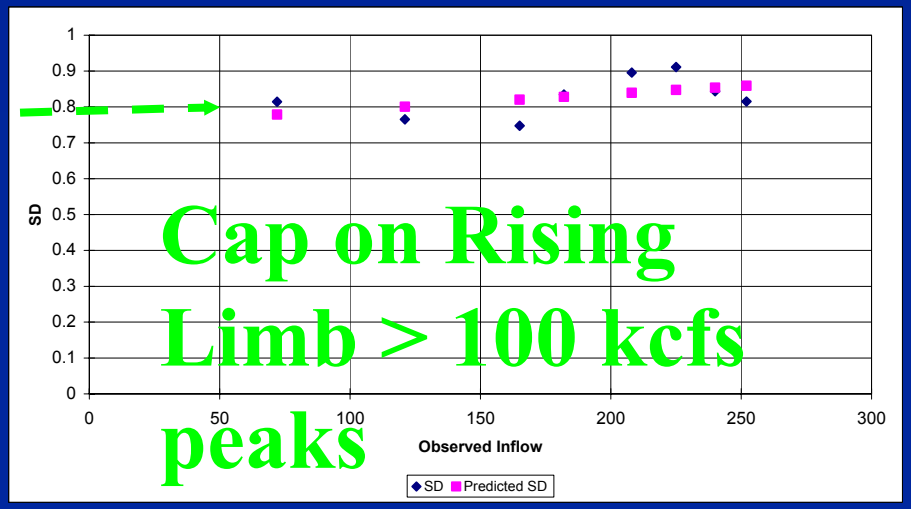


Rising limb for only >100kcfs peak

Elsewhere

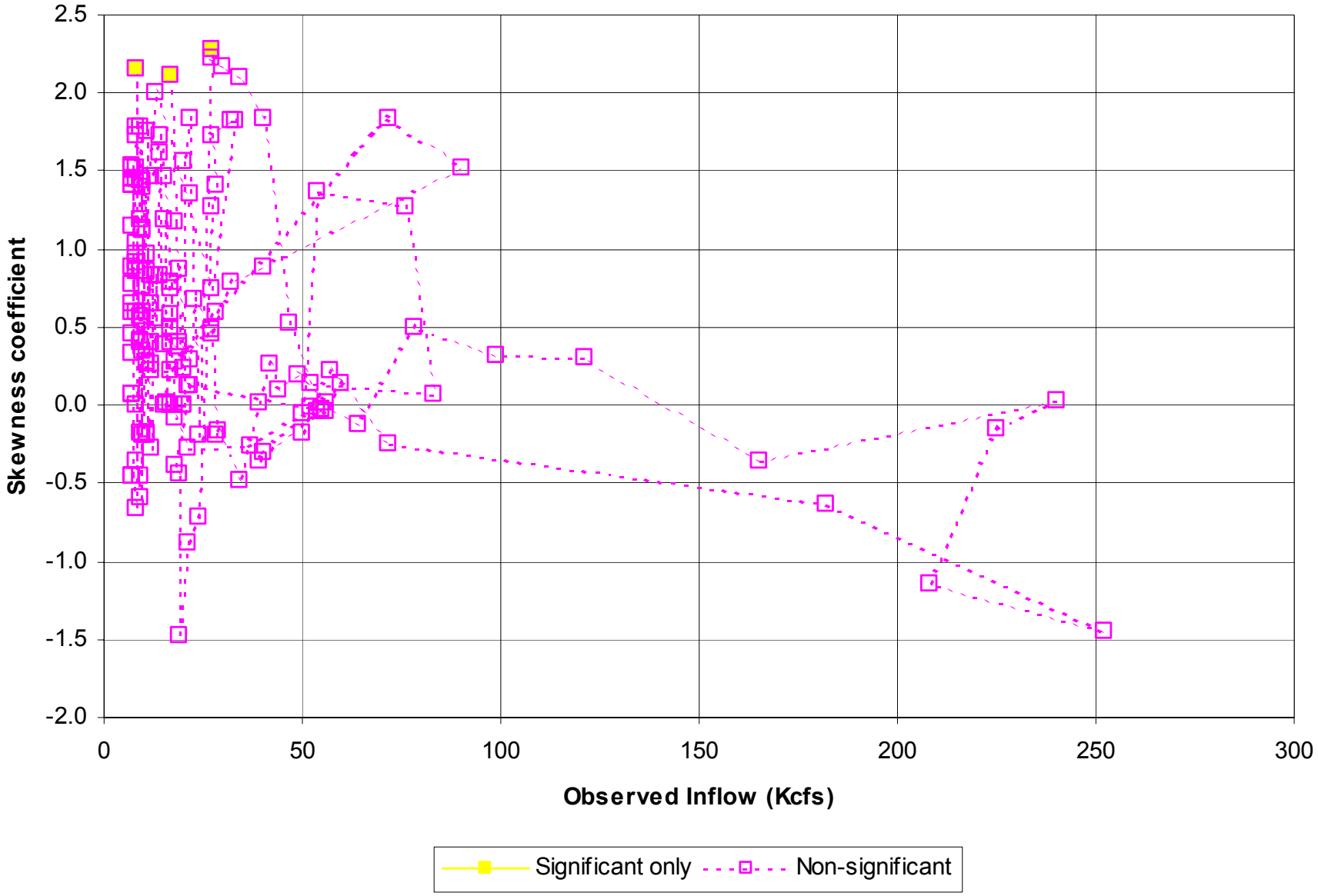
Rising Limb > 100 kcfs peaks

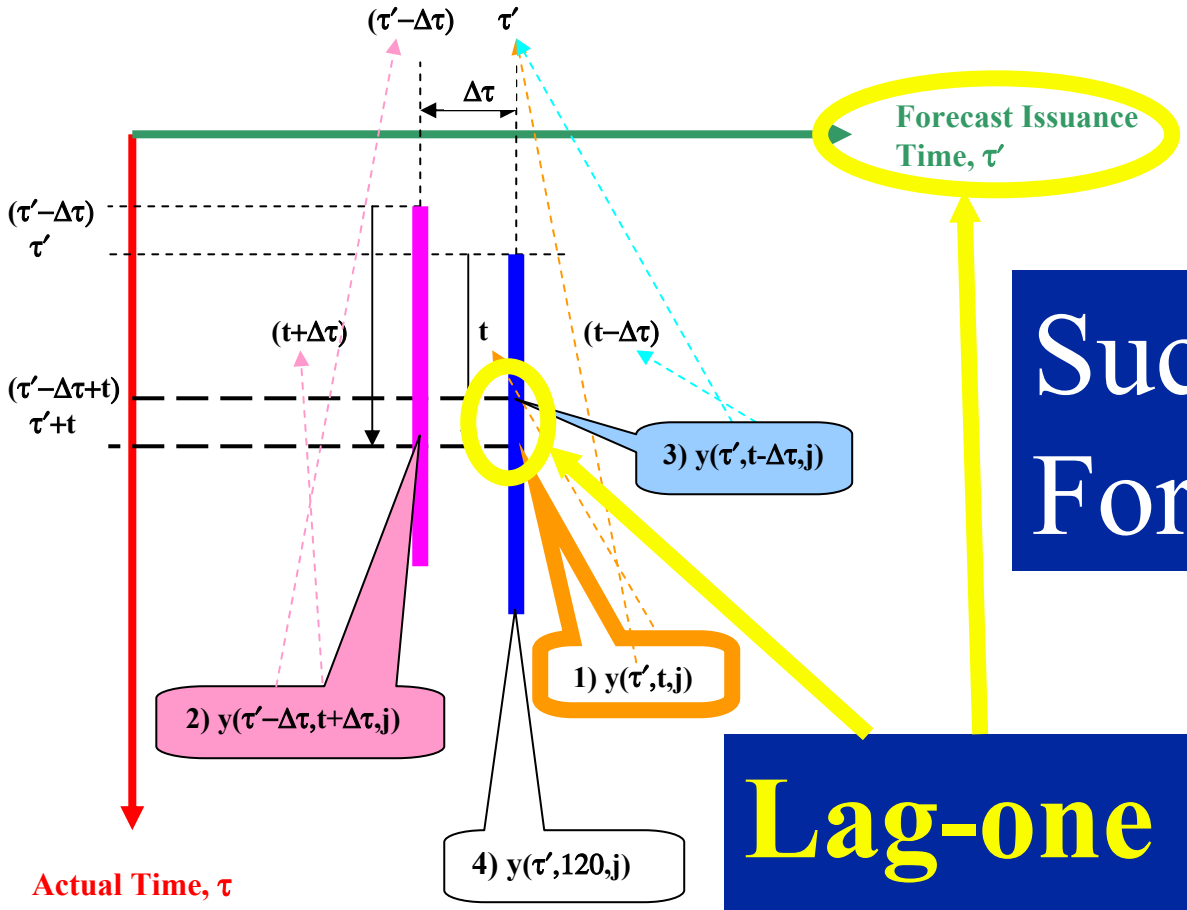




Cap on Rising Limb > 100 kcfs peaks

Skewness of Forecast Errors



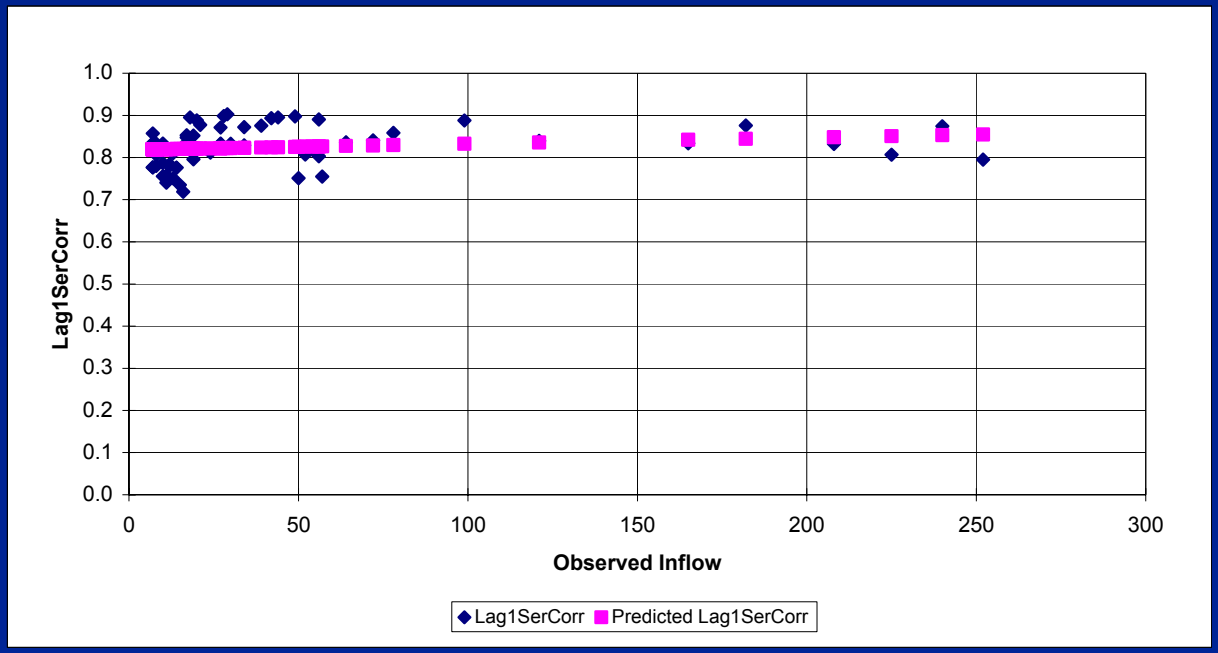


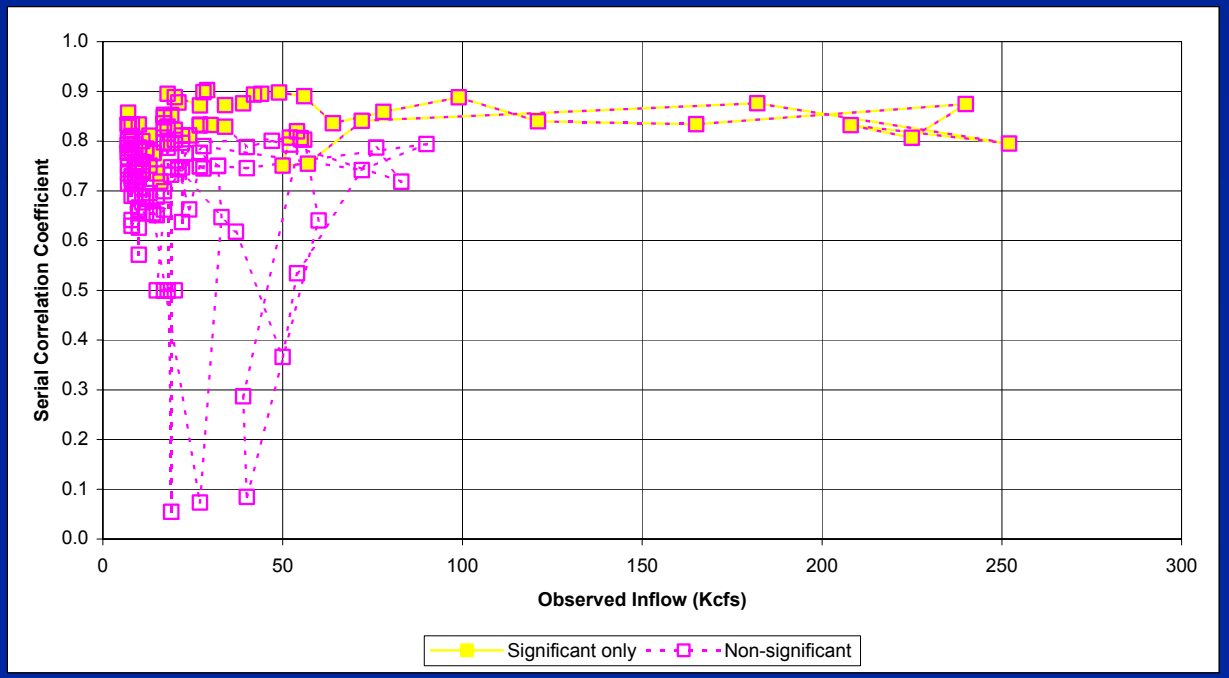
Successive Forecasts

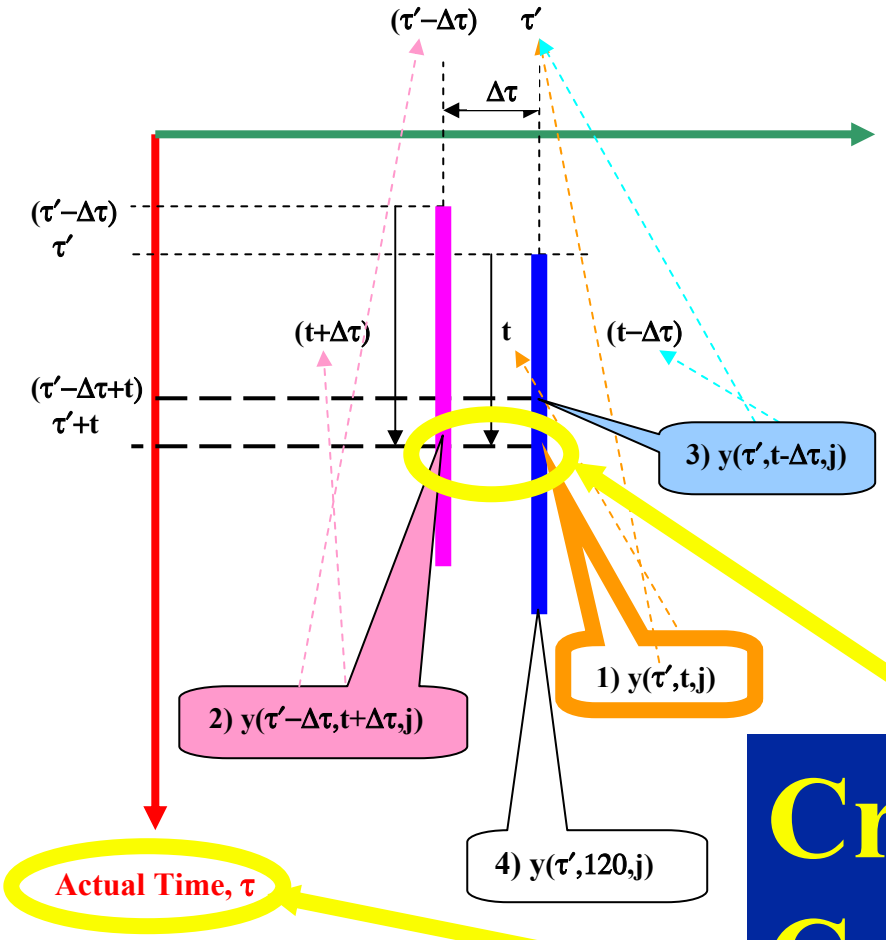
Lag-one Serial Correlation

Lag-one Serial Correlation

between Forecast Errors in successive 6-hour forecast flows in same forecast





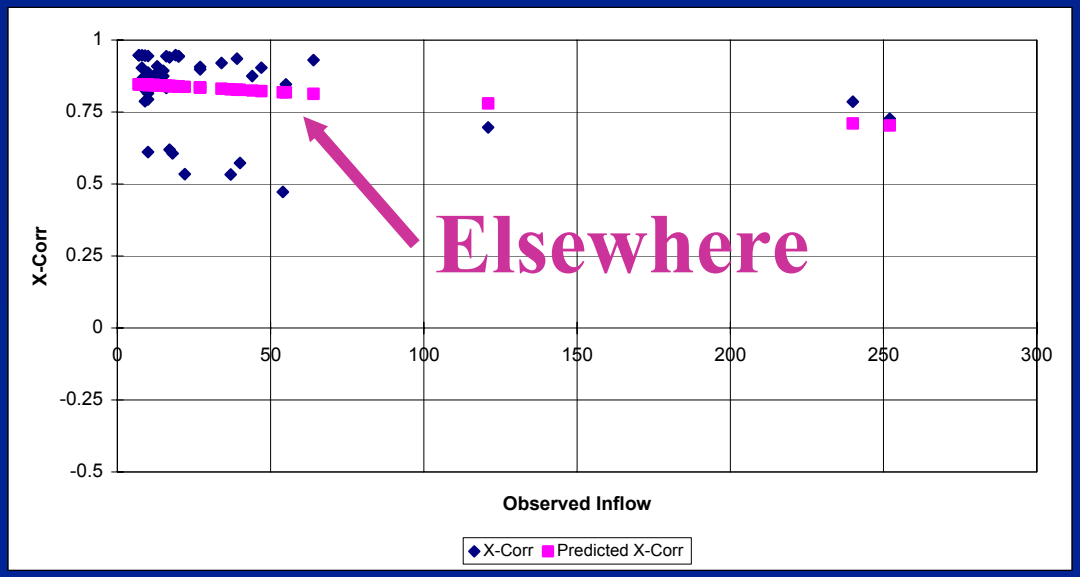


Successive Forecasts

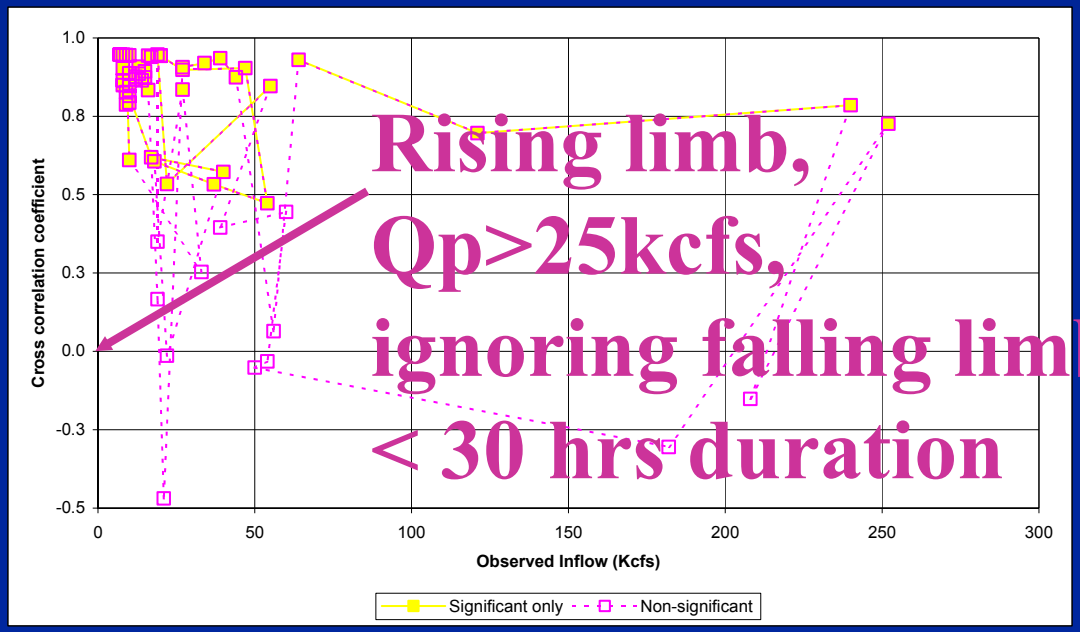
Cross Correlation

Cross Correlation

between Forecast Errors at same actual time for Successive Forecasts issued at 6-hour spacing



Mean = 0.8760 Falling



4) Forecast Based Operations

PRELIMINARY GENERALIZED ADVANCED RELEASE RULE

Formulated with

Joe Countryman

MBK Engineers, Sacramento, CA

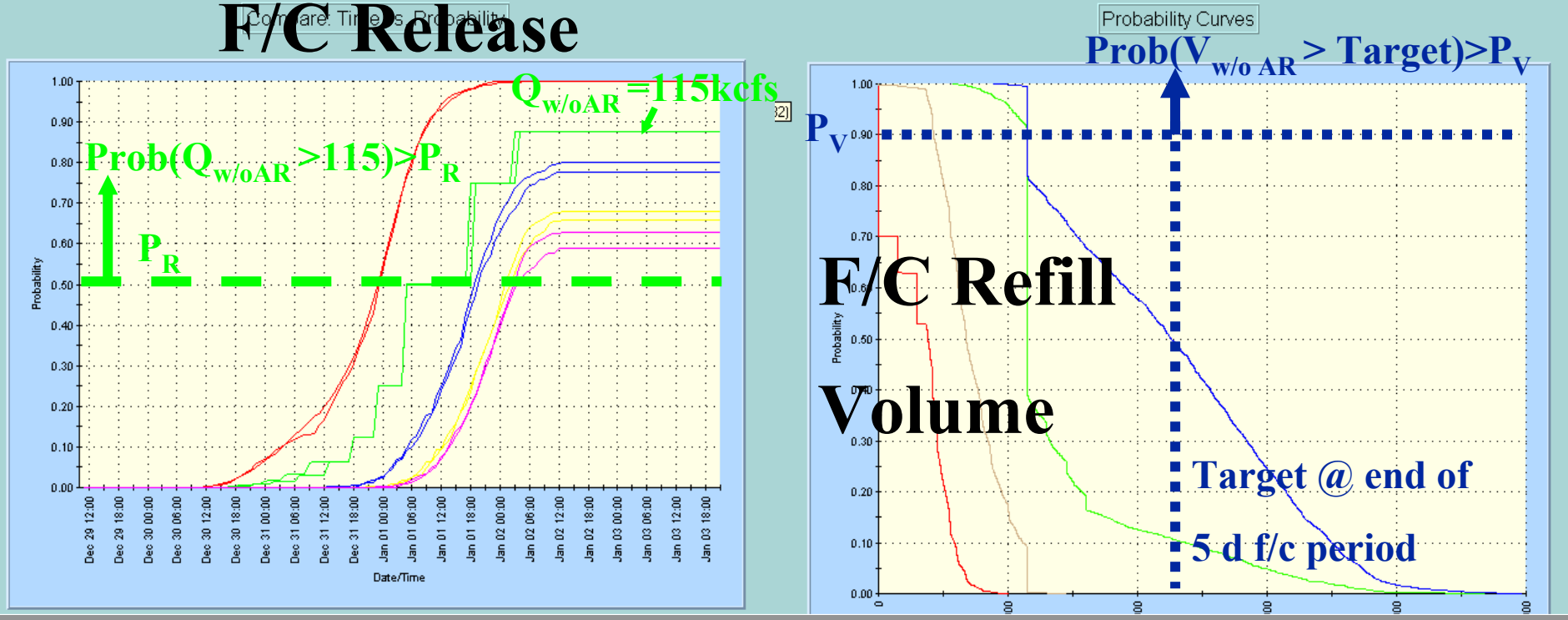
and **Beth Faber**

Corps/HEC, Davis, CA

Preliminary Generalized Advanced Release Rule

- ON Trigger
- Magnitude of Advance Release
- OFF Trigger

ON Trigger – *main features*



OR

[Prob(Q_{IN} >300(variable)kcfs)>P_{QIN} < 0.5), Q_{IN} *is* ***peak inflow*** *for 5d f/c*

OR

Prob(V_{IN} >1,000 kacft) >P_{VIN}, V_{IN} *is* ***inflow volume*** *for 5d f/c*

Magnitude of Advance Release

1) Iterate AR such that refill prob and release probs w/AR meet release and refill prob targets
   - How to weight release & refill prob targets?

OR

2) Use initial estimate w/o iteration

Magnitude of Advance Release

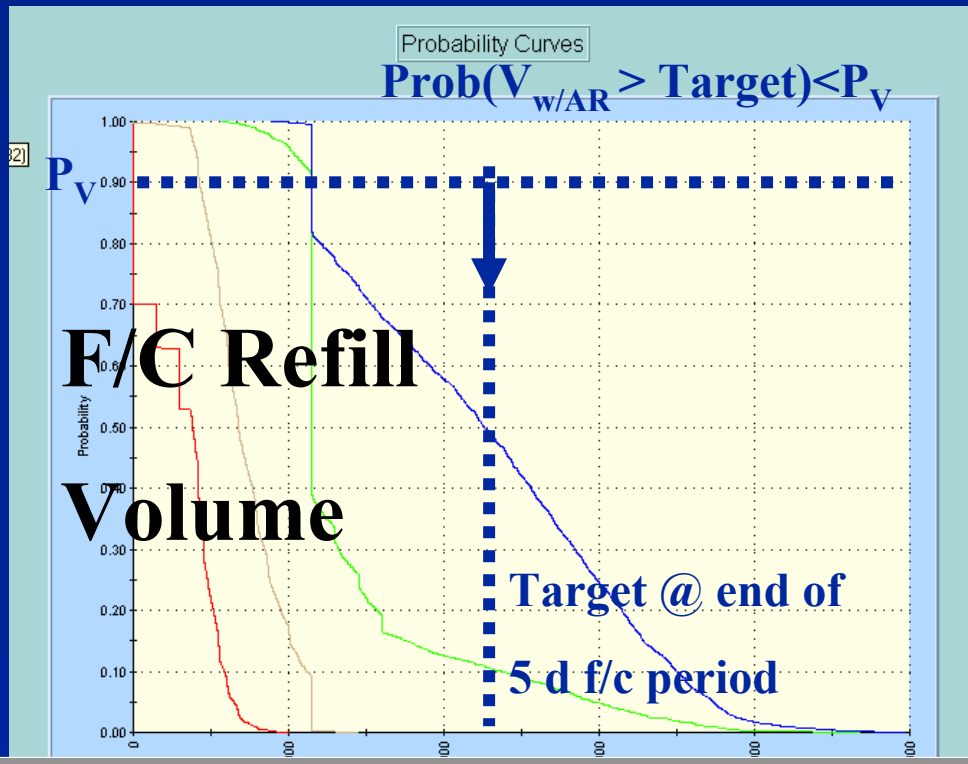
Initial estimate

a) Qin + 50 (variable, probably ≤50) kcfs,
   - Max 115 kcfs
   - F&WS constraint (probably not binding)
   - Until 5d f/c inflow > 150 kcfs
   - Follow this above 25 kcfs

OR

b) Start with inflow based on meeting target volume, P_V

OFF Trigger – *main features*



OR

Prob(Qin < 200(variable)kcfs) =P'_{Qin}, *Qin* = ***peak inflow*** *for 5d f/c*

AND

Prob(Vin < 500(variable)kacft) =P'_{Vin}, *Vin* = ***inflow volume*** *for 5d f/c*

5) Status

What has been accomplished since last year?

- Completed Inflow Generation Algorithms
- Verified Inflow Generation codes
- Tested Inflow Generation algorithms
- Added interactive (pseudo real time) planning mode for simulation exercises with emergency managers
- Added framework AR rule testing
- Formulated of generalized AR rule
- Operational Version software maintenance
- Delivery and training for COM – USBR/Denver

What can be done to improve RRFM-U?

- Improve Specification of Uncertainties:
  - Planning mode – Inflow Forecast Errors
    - Reconstruction of historical forecasts based on current forecast technology
  - Operational mode – Precipitation Forecast Errors
    - Formalize subjective uncertainty estimation procedure
    - Improve precipitation forecasts
- Refine Inflow Generation Algorithms
  - Using improved uncertainty specifications
  - Better and more efficient convergence
- Extend H Street routing to 160 kcfs

What is needed to expand RRFM-U applications?

Develop Applications Protocols for:

1) Community emergency management
   - SAFCA/ARFCD
2) Advanced Release Rule Development
   - CORPS
3) *Power station safety and dam safety*
   - *USBR EAP*

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http://www.engineering.usu.edu/uwrl/www/faculty/bowles.html