A Prototype Forecast-Informed Reservoir Operation (FIRO) for Lake Conroe, TX

– Application of Riverware in Reservoir Operational Modeling

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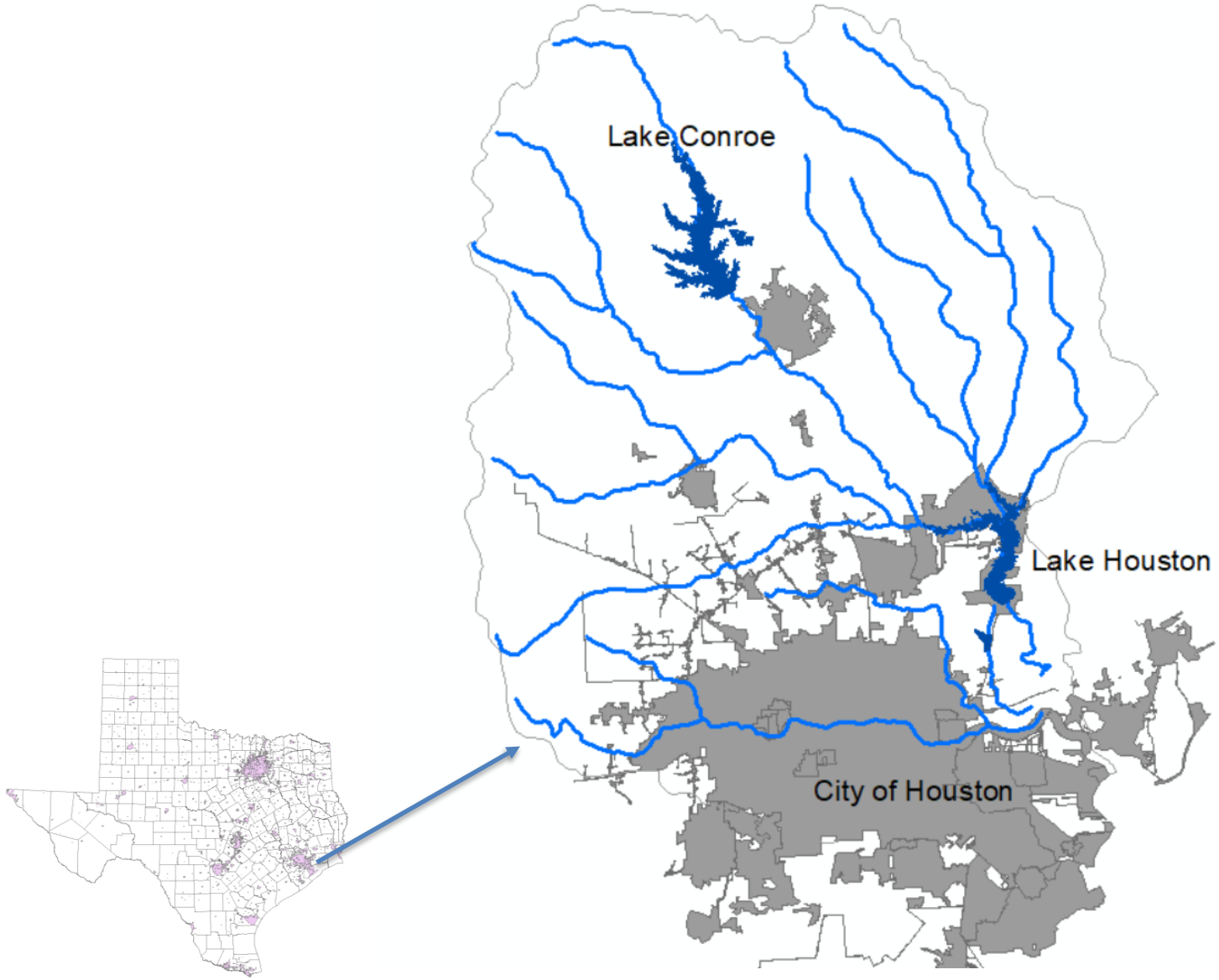
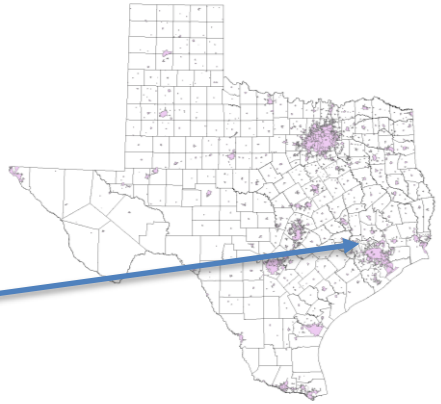
Water Availability Program
Surface Water Division

Lake Conroe

- Built in 1973; and jointly owned the San Jacinto River Authority (SJRA) and the City of Houston; it is operated by SJRA for water supply purpose.
- Added flood control operation after Hurricane Harvey.
- Total conservation capacity is 411,022 acre-feet at top of conservation pool at 201 feet msl.

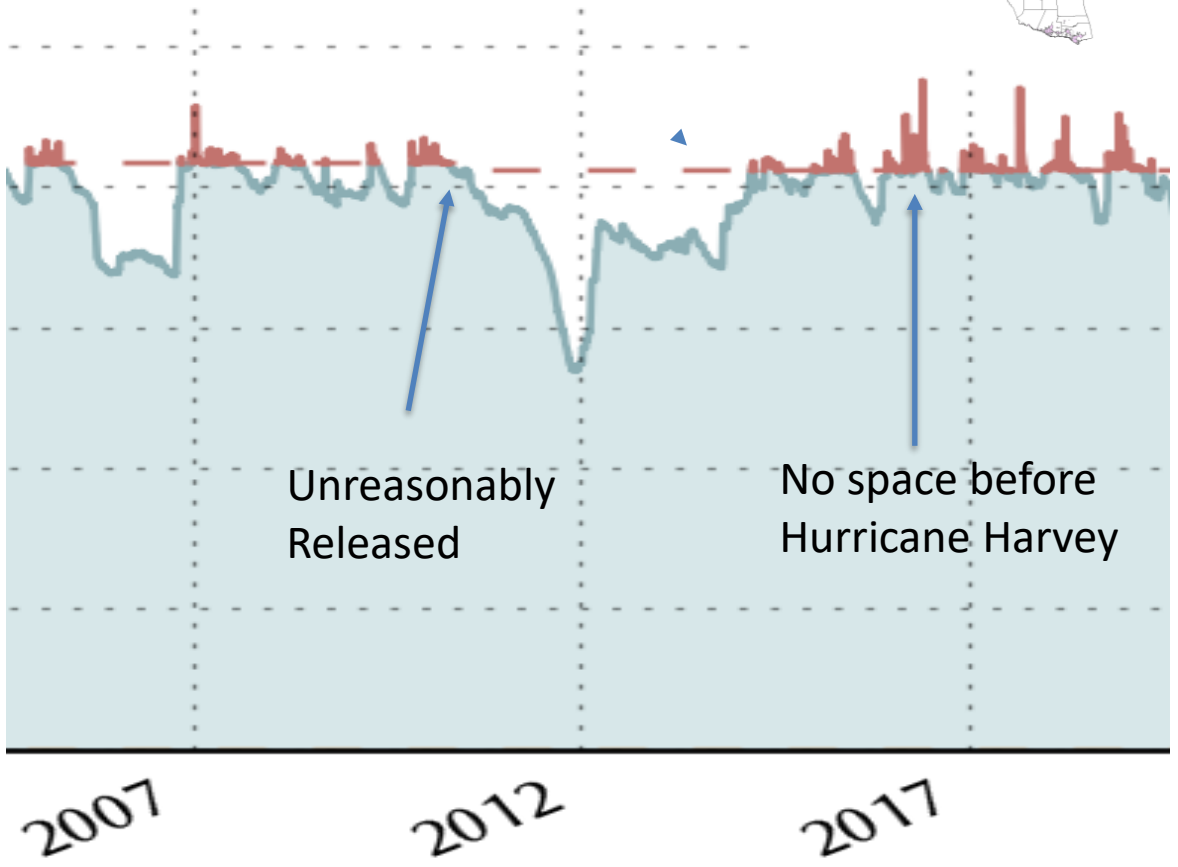


Background and Motivation



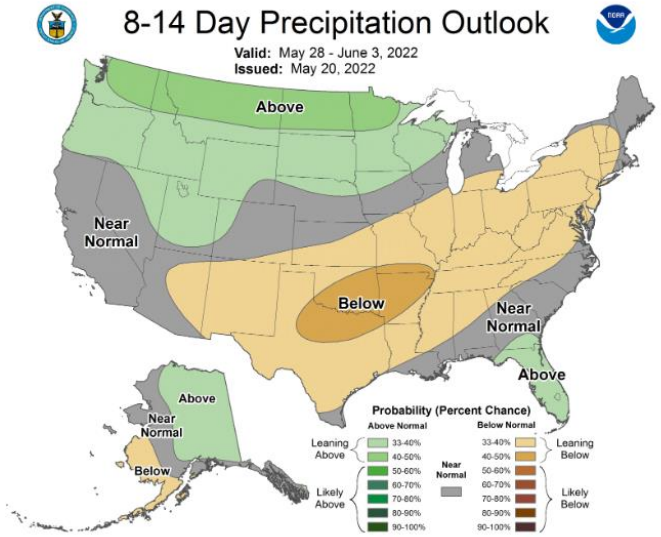
- Forecast-informed reservoir operations (FIRO) is a reservoir-operations strategy that uses … weather and water forecasts to inform decision making to selectively **retain or release** water from reservoirs to optimize water supply reliability and … to enhance flood-risk reduction. (drought.gov)

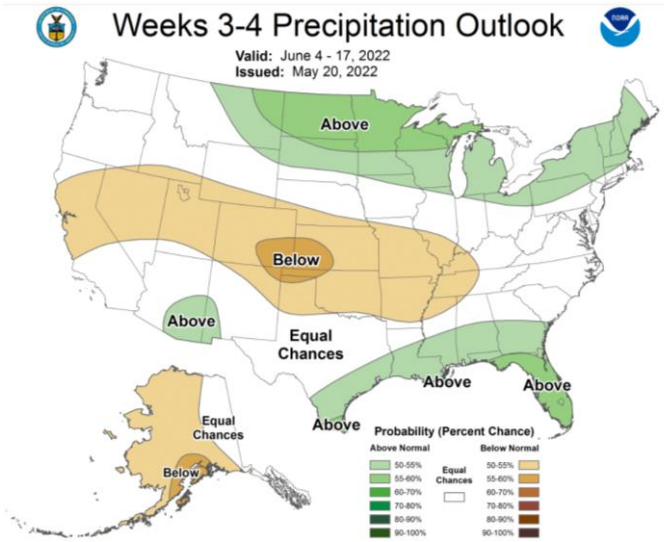
- Lake Conroe is selected as the prototype because it is a water supply reservoir that must consider flood control operations, post Hurricane Harvey.

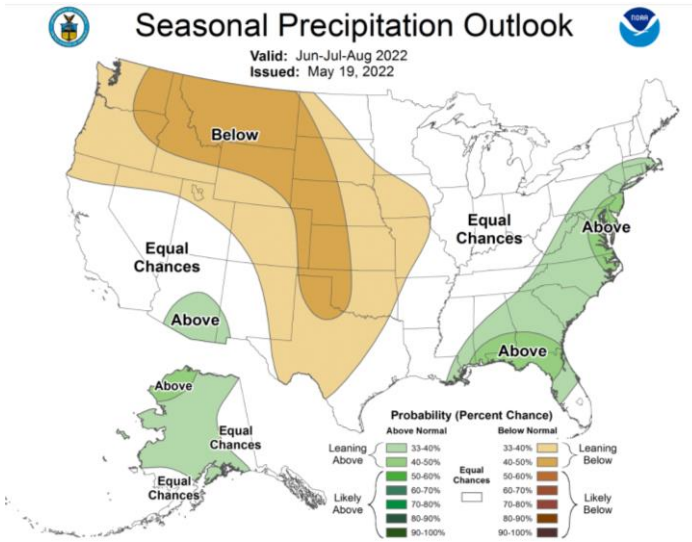


NOAA's Forecasts and Outlooks

- **Quantitative Precipitation Forecast (QPF)** for 7 days (6-hrs per file and total 28 grib2 files – retrieved by python scripts) https://www.wpc.ncep.noaa.gov/qpf/qpfloop_6hr_d17.html
- **Outlooks:**



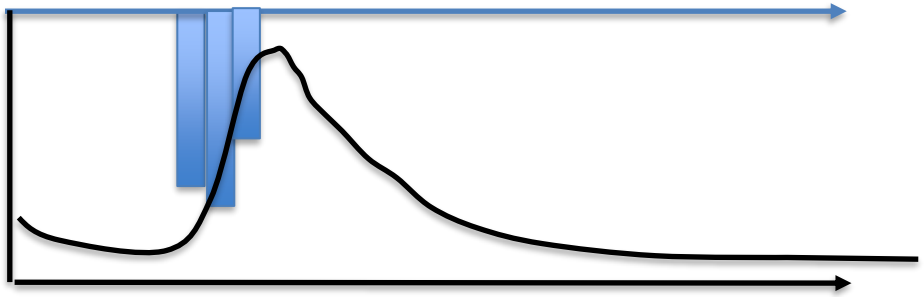




Methodology I of our prototype FIRO

Precipitation:

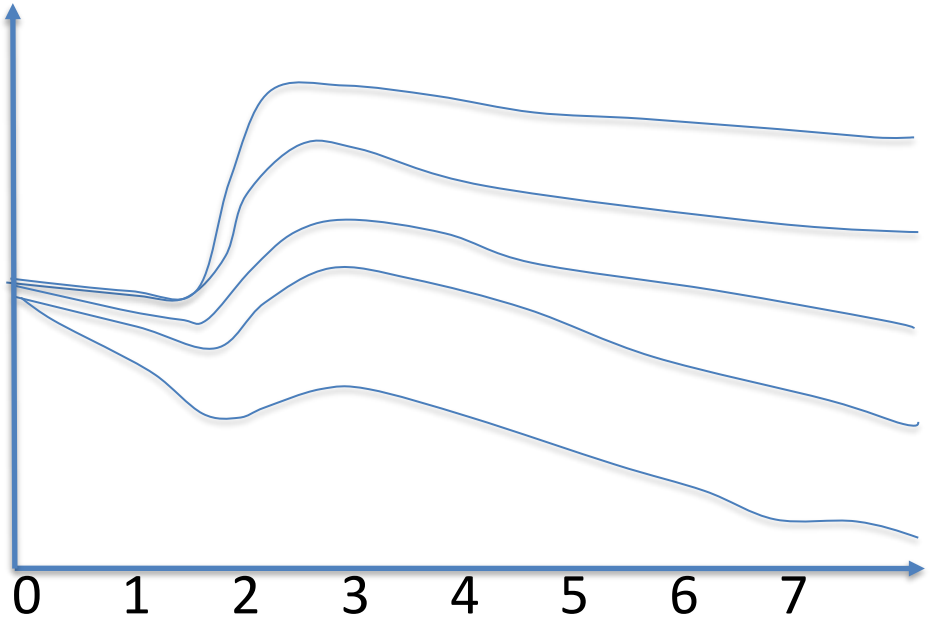
Reservoir Inflow:
(HEC-HMS)



Using short-term forecast (QPF)

Reservoir Storage:

(Riverware)



Timeline (day):

Using Longer Forecast (Outlooks):

Very Dry future

Dry future

Normal future

Wet future

Very wet future

Less release

More release

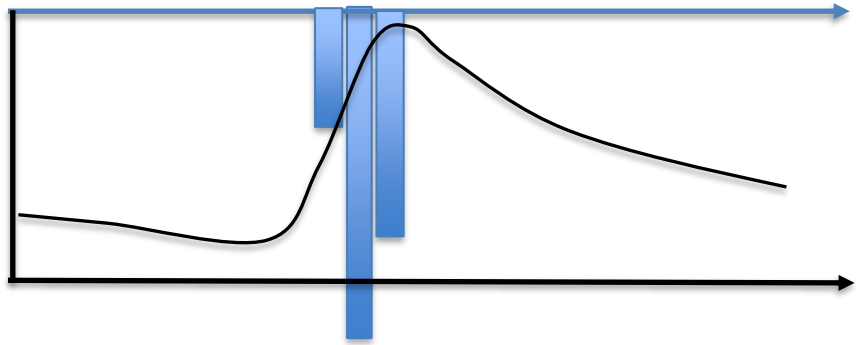
The short-term operation is not only driven by short-term forecasts (QPF), but also the operational target is determined by the longer-term forecast (various CPC's Outlooks).

Methodology II of our prototype FIRO

Precipitation:

Using short-term forecast (QPF)

Reservoir Inflow:
(HEC-HMS)

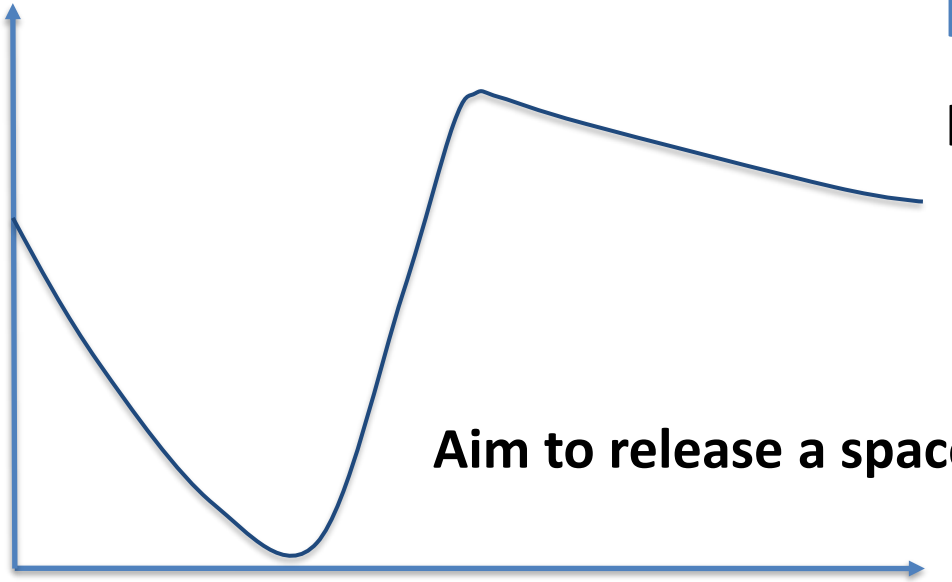


Pre-release for flood control

Hurricane is coming in 3 days

Reservoir Storage:

(Riverware)



Aim to release a space of 75% of forecasted storm water

Timeline (day): 0 1 2 3 4 5 6 7

Data, toolsets, and workflow

Contrail rain data

NOAA WPC QPF data

NOAA CPC Outlooks data

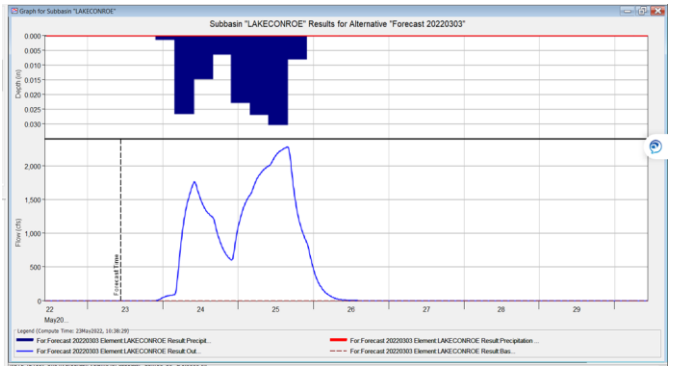
Python scripts

HEC-DSS

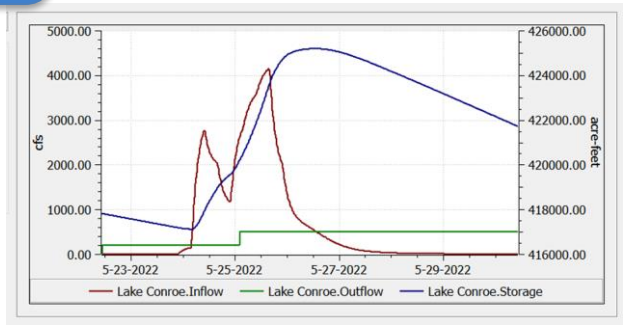
HEC-RTS

HEC-HMS

Riverware

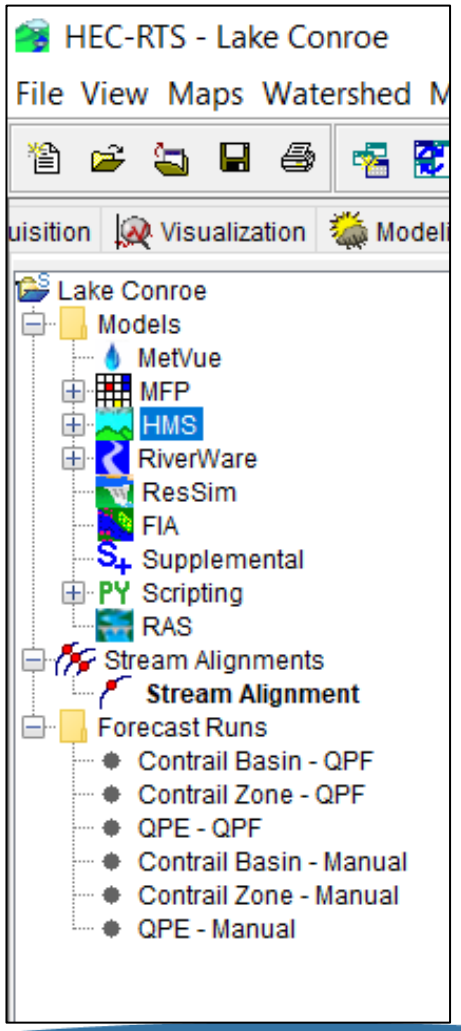


FIRO outputs
(Release guide)

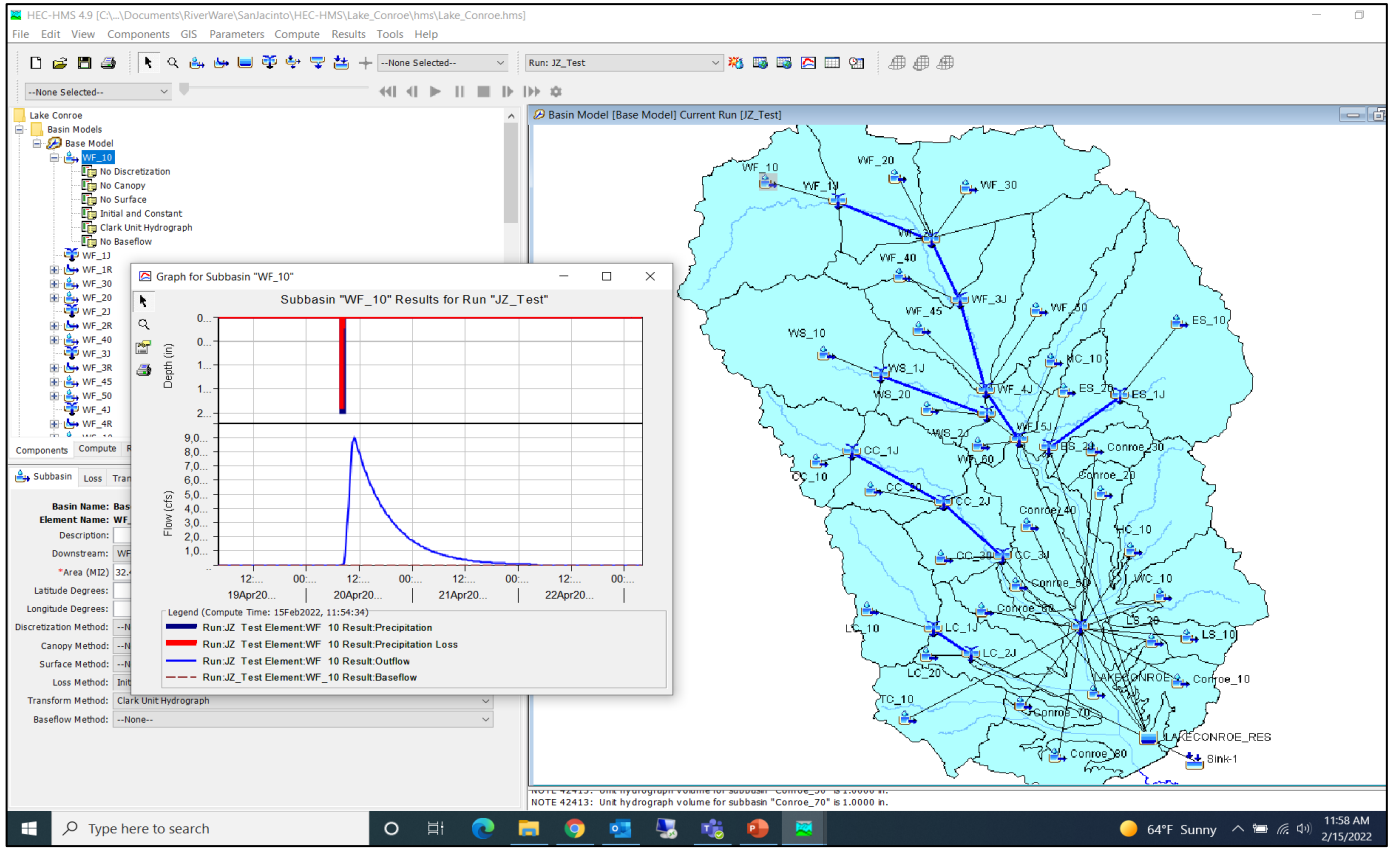


HEC-RTS and HEC-HMS for Conroe watershed

- Funded by TWDB
- Created by Halff Associates
- Used by SJRA and TWDB

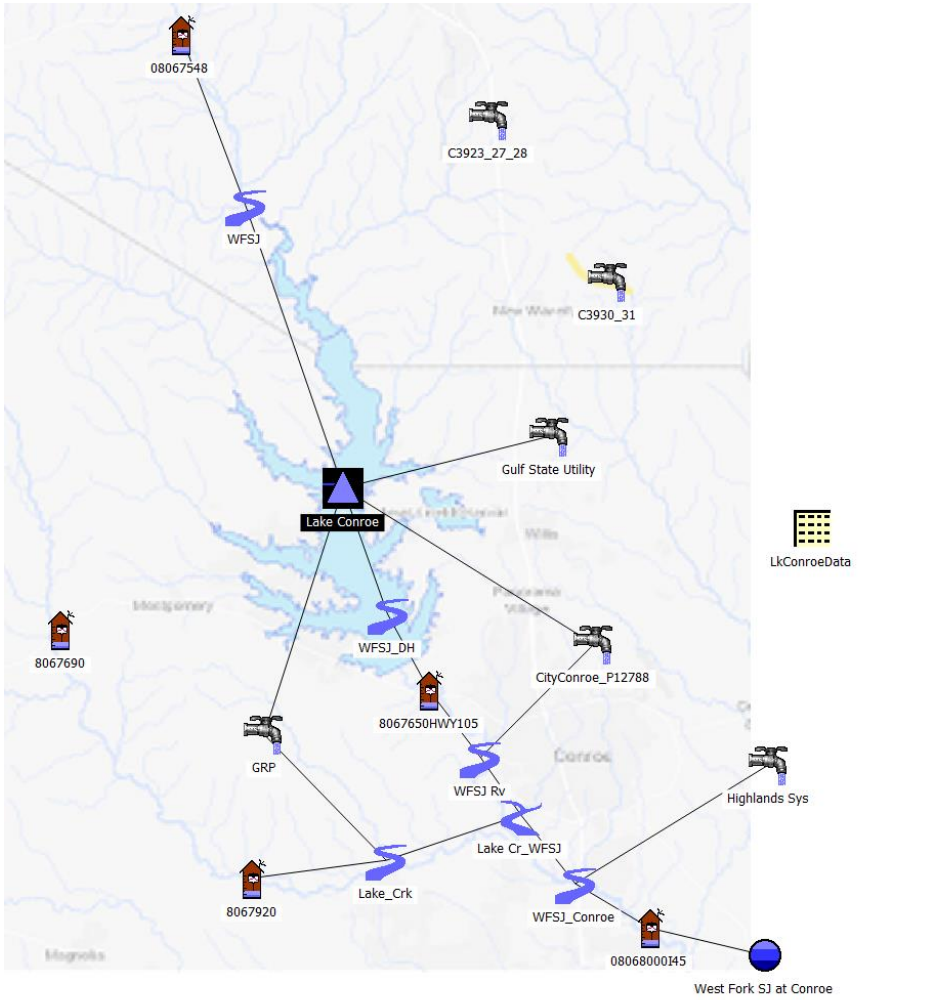


HEC-HMS model for Lake Conroe Watershed



RiverWare model for Lake Conroe

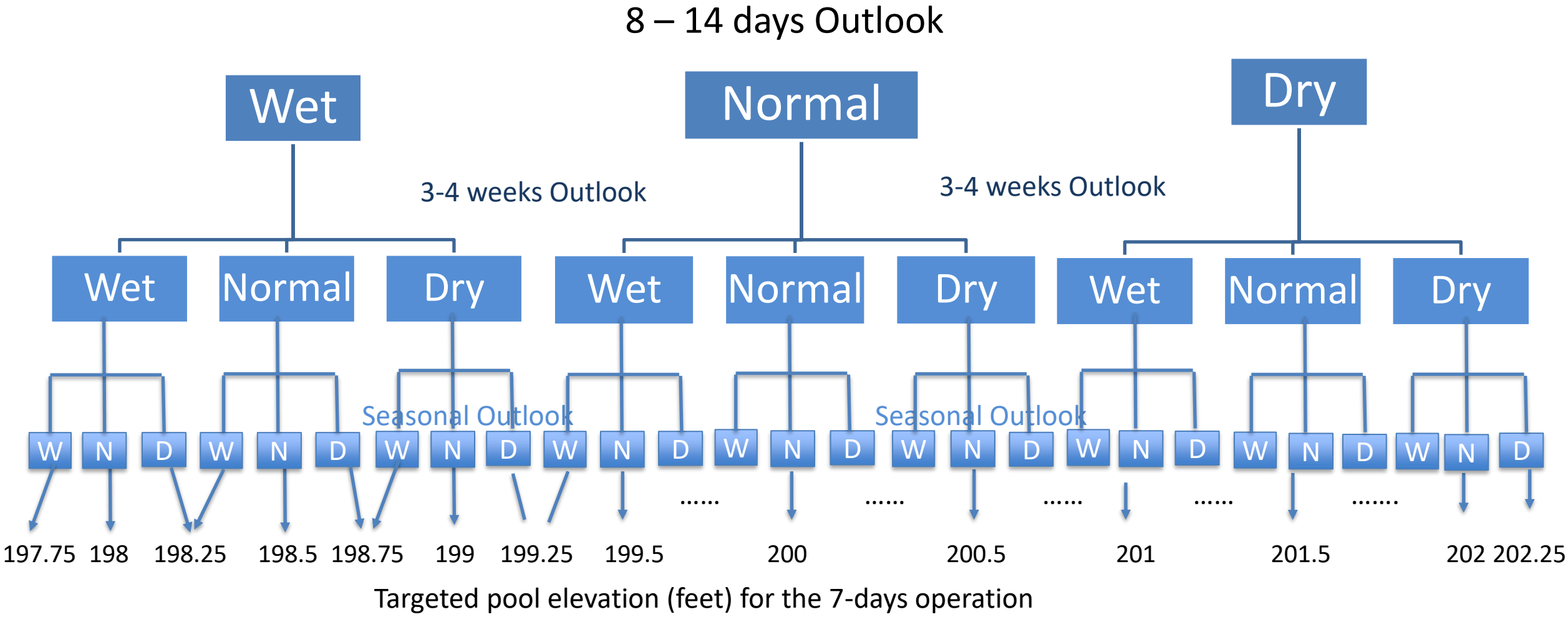
- Covers entire watershed and includes:
  5 reaches, 1 reservoirs, 1 confluences, and 6 diversions
- Uses latest reservoir hydrographic survey - 2020 rating curve
- 15-minute timestep



Contrail rainfall and QPF data fetching

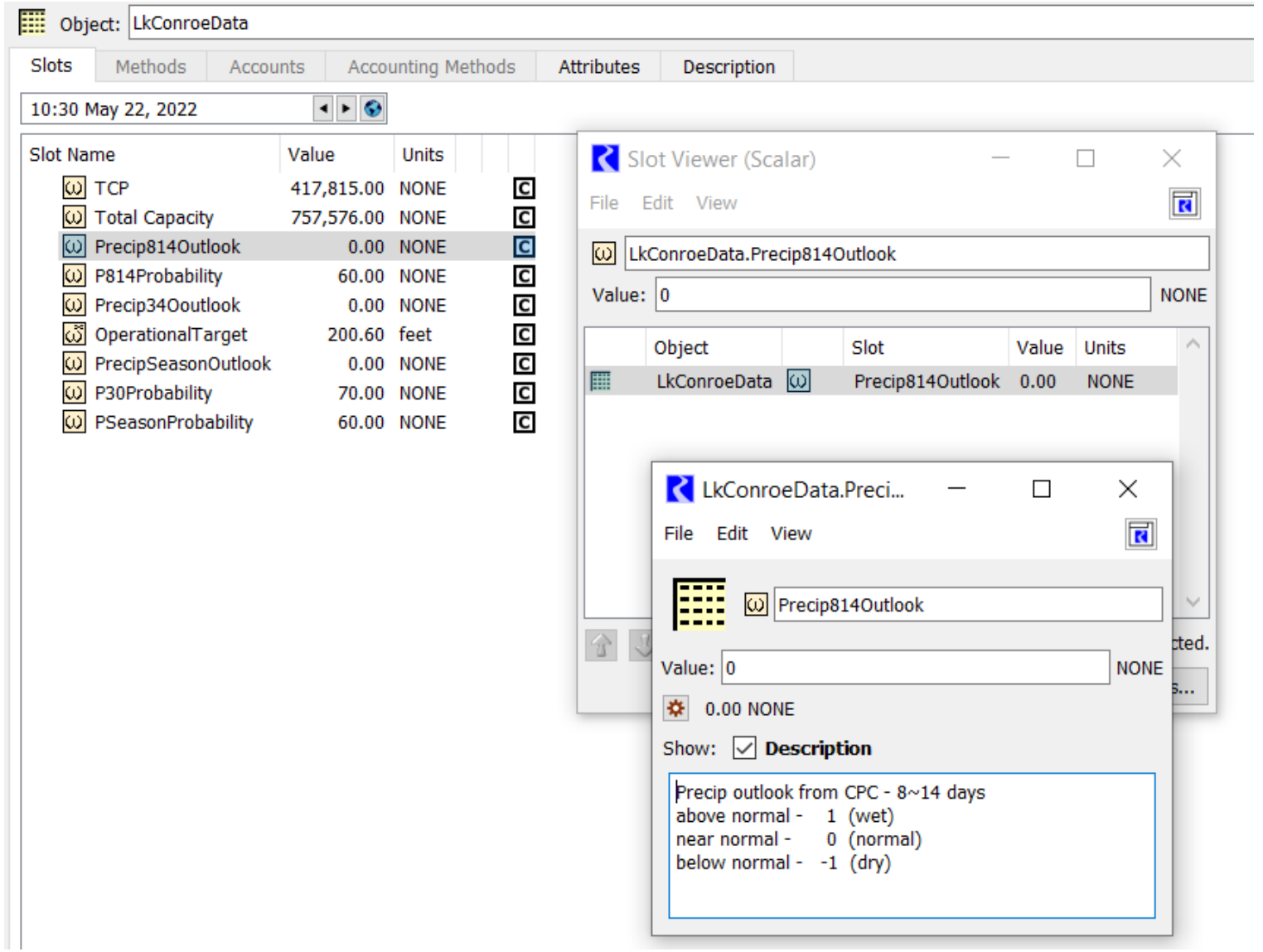
- Past 24 hours rainfall data are retrieved through Contrail API.
- 6-hour NOAA-NWS-WFC Quantitative Precipitation Forecast (QPF) for next 7 days aredownloaded into HEC-DSS.
- Data are disaggregated into 15-minute intervals to feed the HEC-HMS model.
- Past 24-hour streamflow at location upstream of the lake is also retrieved for HEC-HMS model warm-up.
- All done using python scripts.

Algorithm for determining operational target



Note: All wet and dry must have a probability (percent chance) above 50%, otherwise, it is deemed as normal.

Data object in Riverware for **Operational Target** rule to be written by Scalar Slot with Expression, executed before simulation.



Rule implementation in Riverware model

Rule for Operational target:

OperationalTarget

Evaluation Time: Beginning of run

```
IF ( LkConroeData . "Precip814Outlook" [ ] > 0.00 AND LkConroeData . "P814Probability" [ ] > 50.00 ) THEN
   IF ( LkConroeData . "Precip34Ooutlook" [ ] > 0.00 AND LkConroeData . "P30Probability" [ ] > 50.00 ) THEN
      IF ( LkConroeData . "PrecipSeasonOutlook" [ ] > 0.00 AND LkConroeData . "PSeasonProbability" [ ] > 50.00 ) THEN
         197.75 "ft"
      ELSE IF ( LkConroeData . "PrecipSeasonOutlook" [ ] < 0.00 AND LkConroeData . "PSeasonProbability" [ ] > 50.00 ) THEN
         198.25 "ft"
      ELSE
         198.00 "ft"
      END IF
   ELSE IF ( LkConroeData . "Precip34Ooutlook" [ ] < 0.00 AND LkConroeData . "P30Probability" [ ] > 50.00 ) THEN
      IF ( LkConroeData . "PrecipSeasonOutlook" [ ] > 0.00 AND LkConroeData . "PSeasonProbability" [ ] > 50.00 ) THEN
         198.75 "ft"
      ELSE IF ( LkConroeData . "PrecipSeasonOutlook" [ ] < 0.00 AND LkConroeData . "PSeasonProbability" [ ] > 50.00 ) THEN
         199.25 "ft"
      ELSE
         199.00 "ft"
      END IF
   ELSE
      IF ( LkConroeData . "PrecipSeasonOutlook" [ ] > 0.00 AND LkConroeData . "PSeasonProbability" [ ] > 50.00 ) THEN
         198.75 "ft"
      ELSE IF ( LkConroeData . "PrecipSeasonOutlook" [ ] < 0.00 AND LkConroeData . "PSeasonProbability" [ ] > 50.00 ) THEN
         198.25 "ft"
```

Rule for release:

Outflow_Rule

3 Outflow_Rule

```
IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] > LkConroeData . "OperationalTarget" [ ] ) THEN
   IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 198.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 0.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 198.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 198.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 200.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 198.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 199.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 500.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 199.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 199.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 1,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 199.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 200.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 2,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 200.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 200.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 3,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 200.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 201.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 4,500.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 201.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 201.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 6,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 201.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 202.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 8,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 202.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 202.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 10,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 202.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 203.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 12,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 203.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 203.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 16,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 203.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 204.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 20,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 204.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 204.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 25,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 204.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 205.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 30,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 205.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 205.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 35,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 205.50 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 206.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 40,000.00 "cfs"
   ELSE IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] >= 206.00 "ft" AND Lake Conroe . "Pool Elevation" [ @"t - 1" ] < 206.50 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 50,000.00 "cfs"
```

Large storm (Hurricane) pre-release

- Pre-release or lowering of pool elevation is determined by forecasted total inflow on the **third** day from current day.
- The release rate and lowering level depend on amount of forecasted total inflow.
- The release time is before the third day's peak time of the inflow.
- This pre-release operation is the highest priority (No.1 rule).

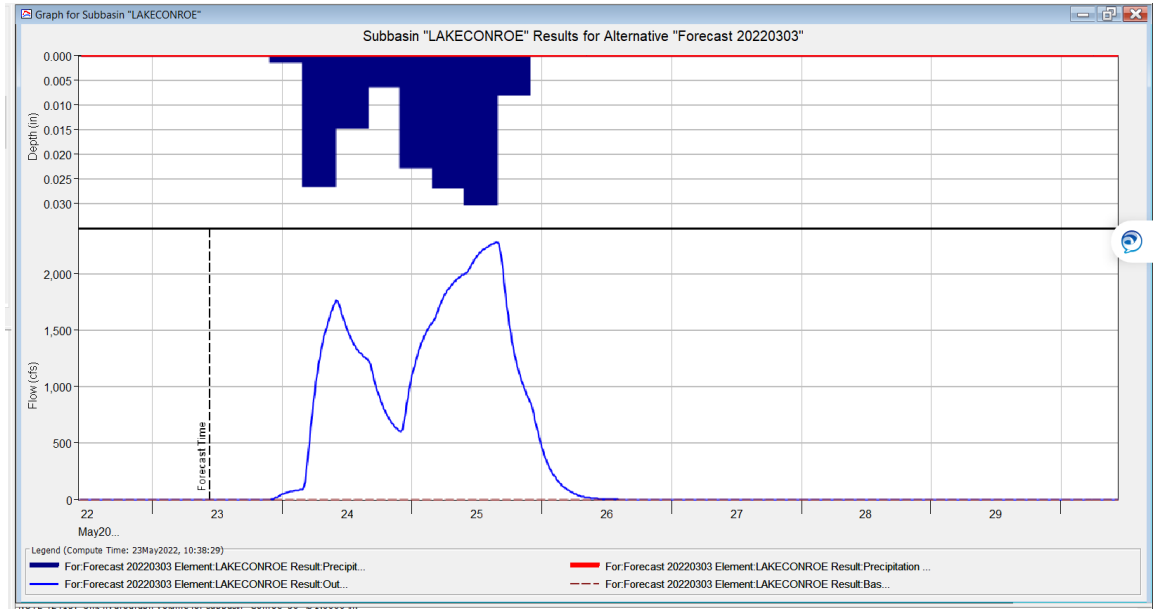
S R 1 Hurricane_Prerelease

```
IF ( LkConroeData . "Third_Day_Inflow" [ ] >= 500,000.00 "acre-ft" AND @"t" <= PeakTime ( Lake Conroe . "Inflow" , @"Start Timestep" + 3.00 "day" , @"Start Timestep" + 4.00 "day" ) ) THEN
   IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] > 198.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 10,000.00 "cfs"
   END IF
ELSE IF ( LkConroeData . "Third_Day_Inflow" [ ] < 500,000.00 "acre-ft" AND LkConroeData . "Third_Day_Inflow" [ ] >= 300,000.00 "acre-ft" AND @"t" <= PeakTime ( Lake Conroe . "Inflow" , @"Start Timestep" + 3.00 "day" , @"Start Timestep" + 4.00 "day" ) ) THEN
   IF ( Lake Conroe . "Pool Elevation" [ @"t - 1" ] > 199.00 "ft" ) THEN
      Lake Conroe . "Outflow" [ @"t" ] = 5,000.00 "cfs"
   END IF
ELSE
   Lake Conroe . "Outflow" [ @"t" ] = 0.00 "cfs"
END IF
```

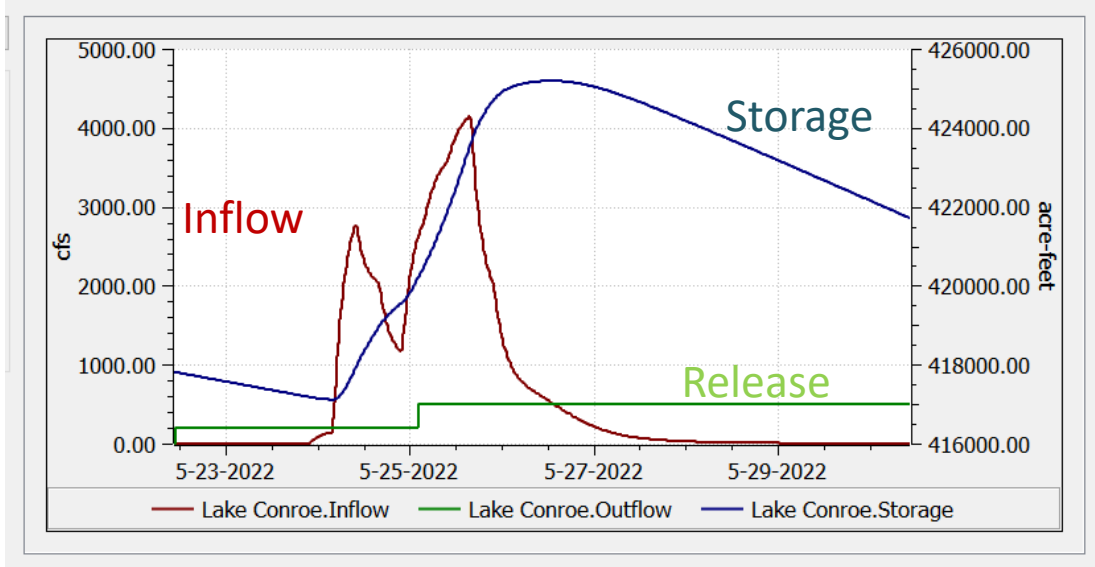
Result of simulations (May 22-30, 2022)

Regular runs set every 7 days. Flood prevention runs set every 6 hrs or every day depending on situation.

HEC-HMS output:



RiverWare output for Lake operation:



Little release due to normal outlooks

Key take aways

- Riverware is ideally suited for FIRO-type reservoir operational modeling and simulation.

- Easy operation with HEC-RTS and easy ingest of data from HEC-HMS.
  - I like DMI, many pre-made functions, many levels of rules (before run, after run, priorities), ……

- More efforts are needed to transform the prototype to a formal model.
  - lake owner diversion data, other input data (i.e., HRRR), timestep improvement, model calibration,…..

Acknowledgment

- Heartfelt thanks to Riverware Support Team (David Neumann, Mitch Clement, ….)! Without your help, I may never be able to reach this far.

Questions?

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