

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

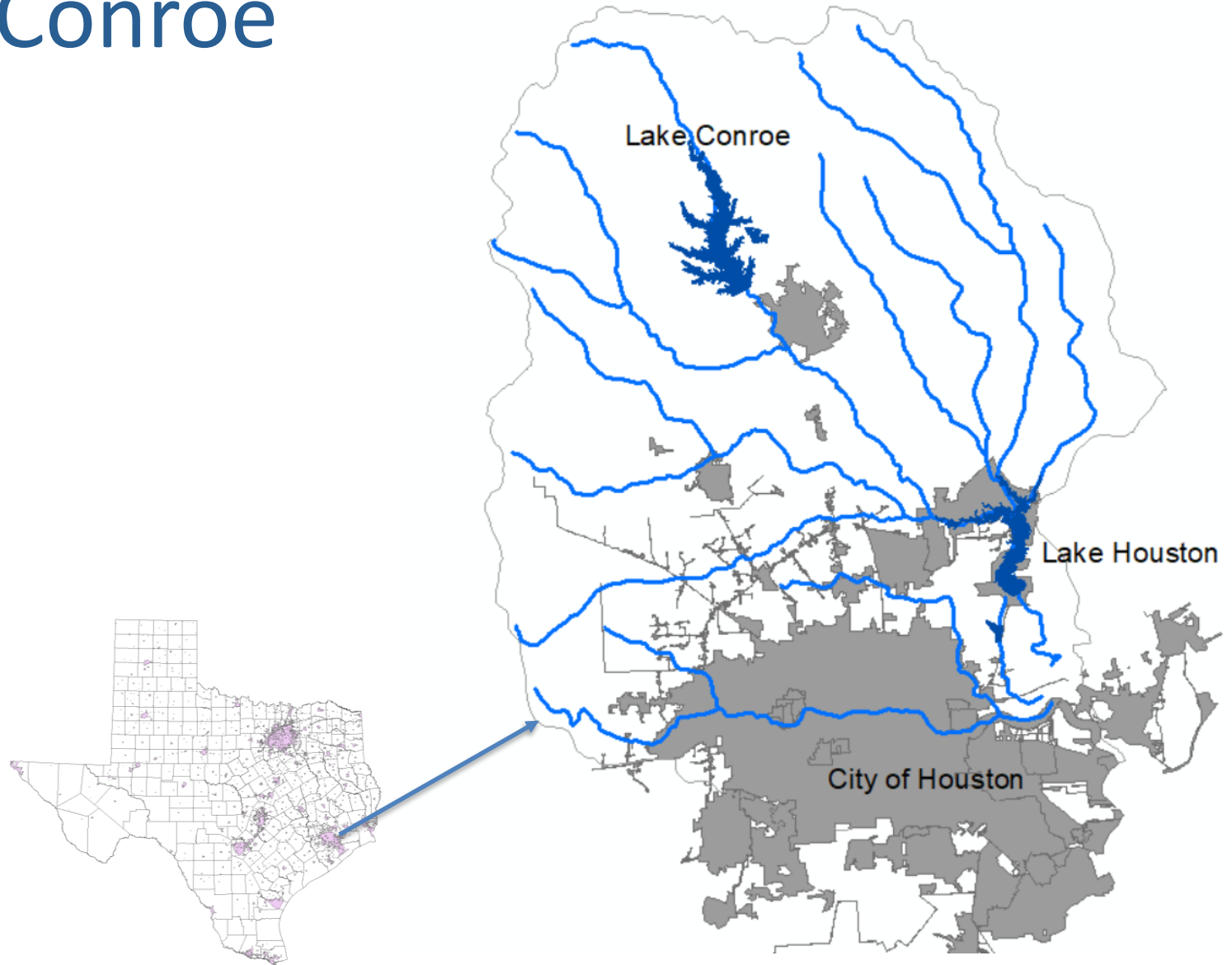
– Application of Riverware, NOAA/WPC QPFs and CPC Outlooks in Reservoir Operational Modeling

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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; 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.



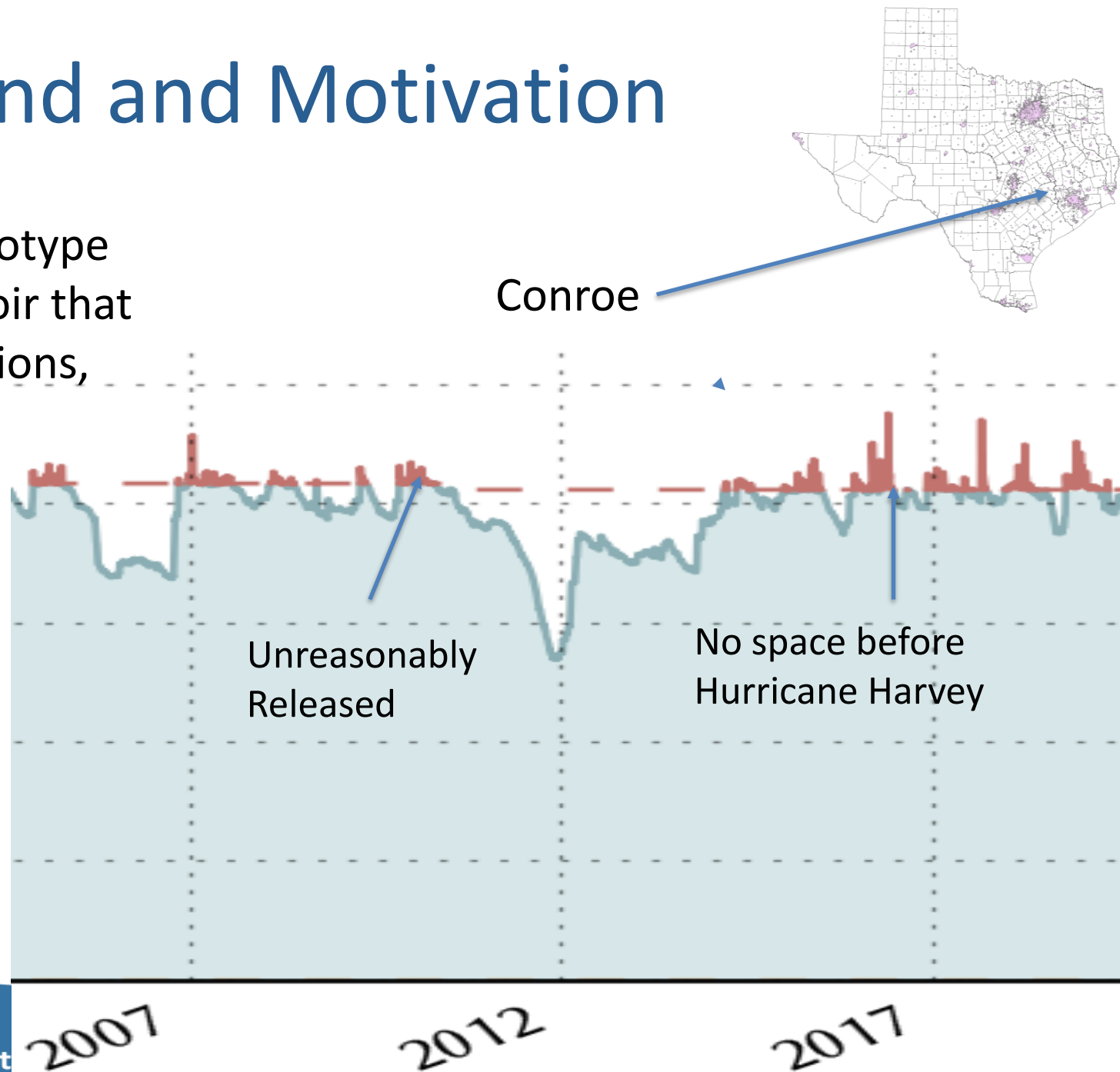
Background and Motivation

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

- Approved seasonal pools:

- April-May: 201'->200.5'
- August: 201'-200.5'
- September: 200'
- All other time: 201'

- Is it good enough?

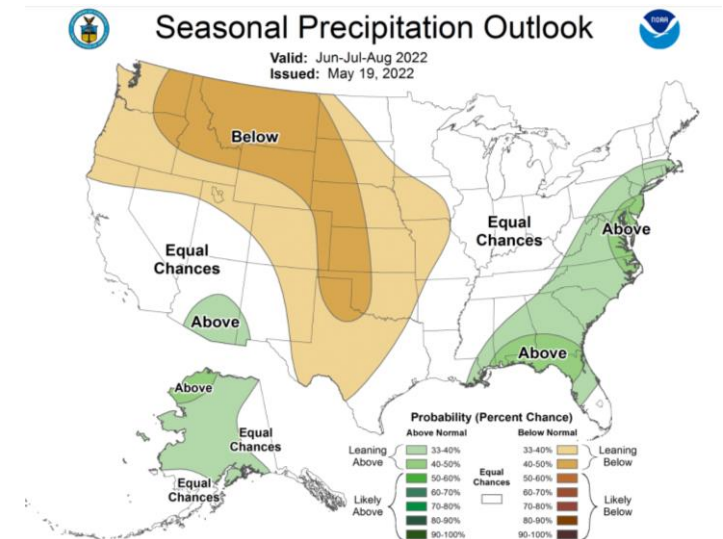
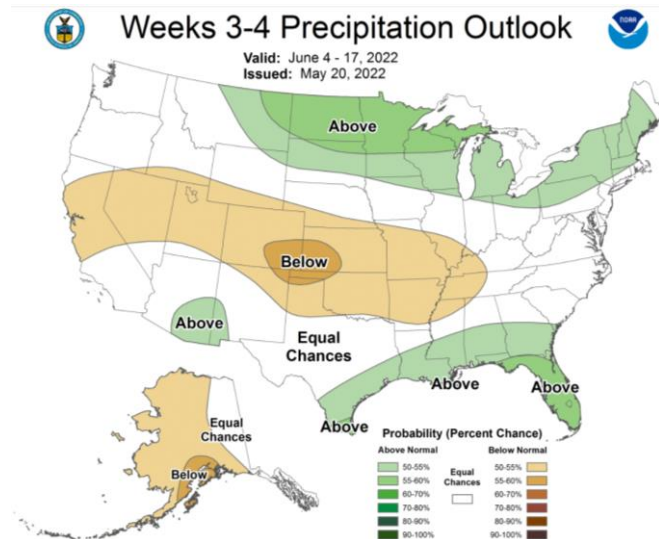
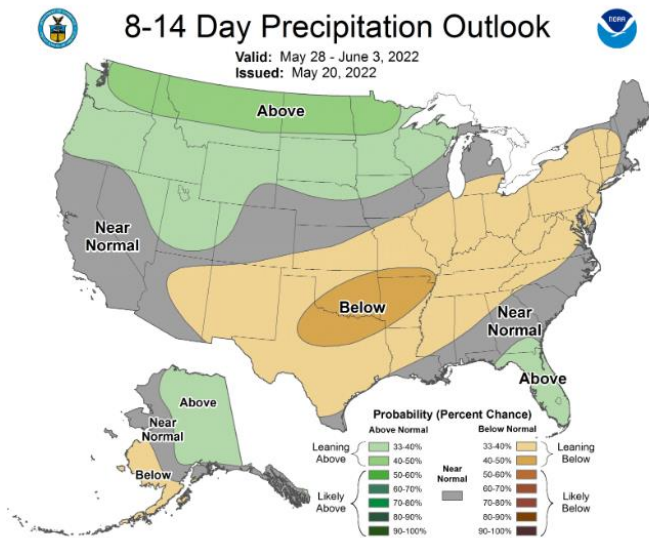


NOAA's Forecasts and Outlooks

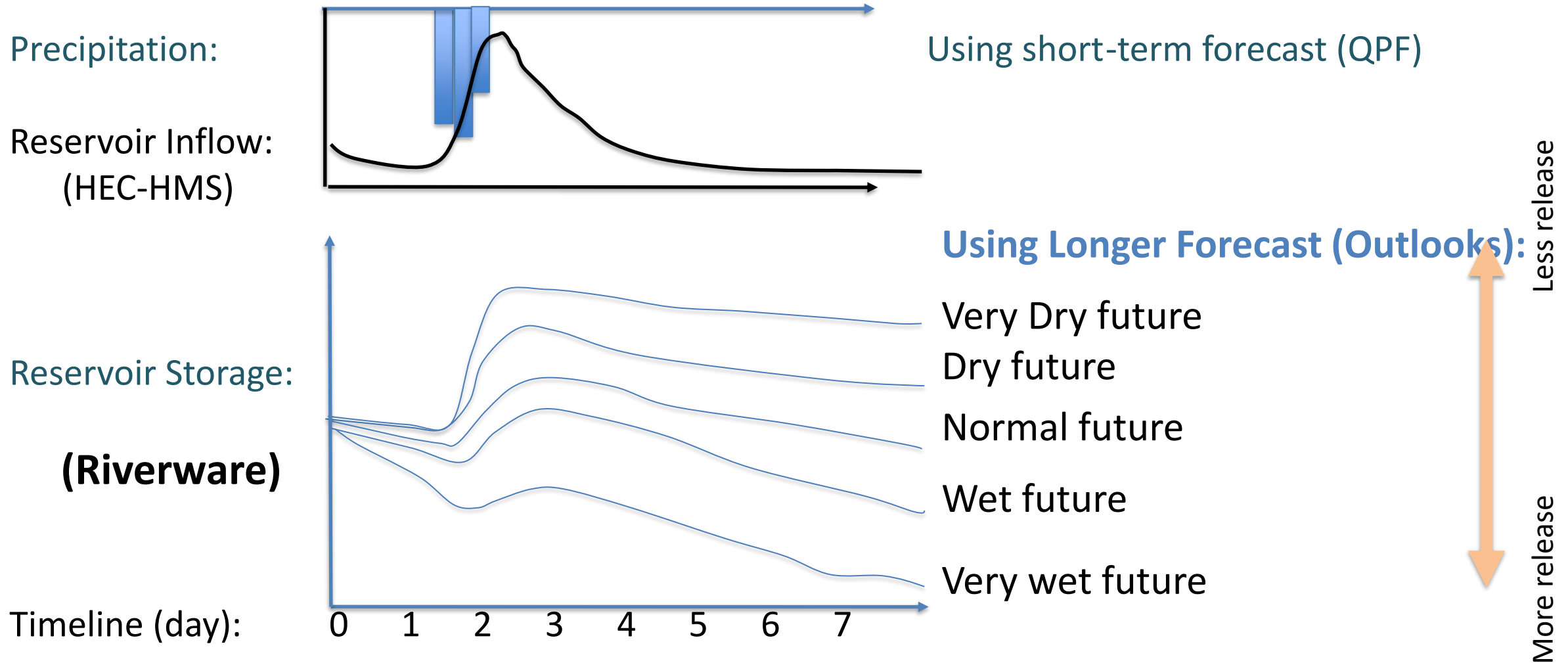
- **Quantitative Precipitation Forecast (QPF)** for 7 days (6-hrs per file and total 28 grib2 files – retrieved by python scripts)

https://www.wpc.ncep.noaa.gov/qpf/qpfloop_6hr_d17.html

- **Outlooks:**



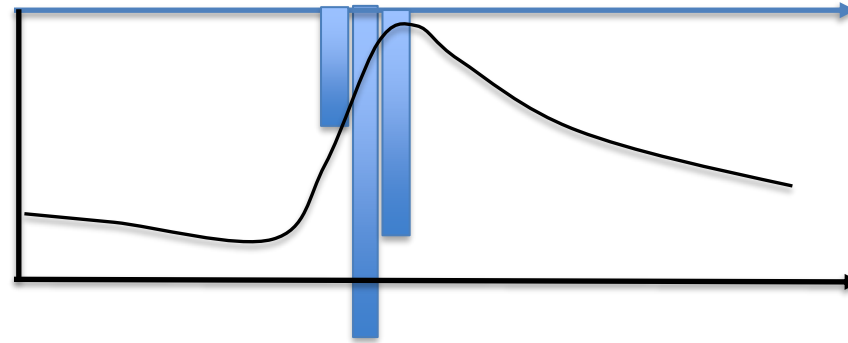
Methodology I of our prototype FIRO



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 Outlooks).

Methodology II of our prototype FIRO

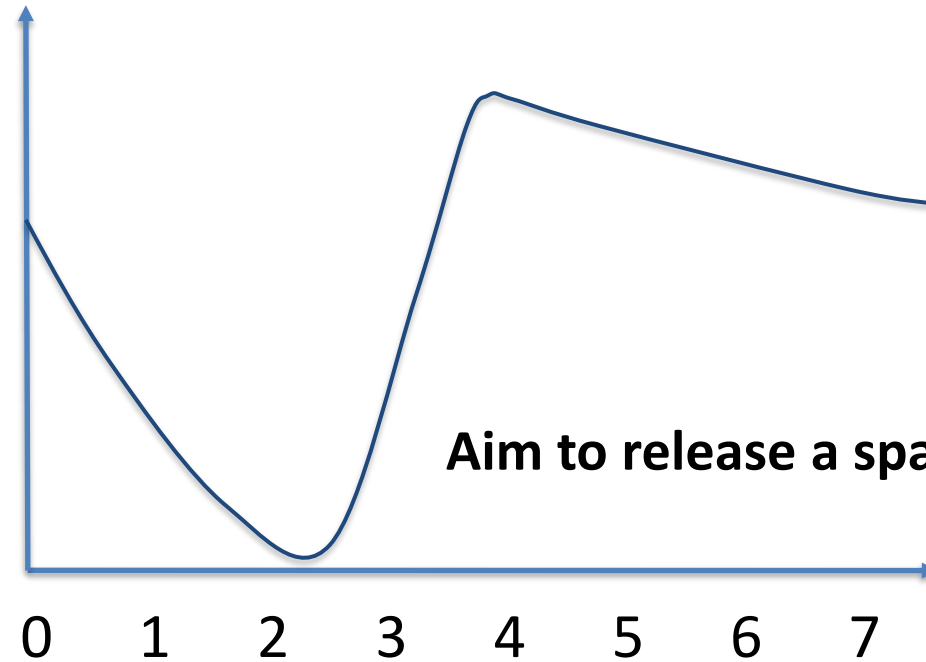
Precipitation:



Using short-term forecast (QPF)

Reservoir Inflow:
(HEC-HMS)

Reservoir Storage:
(Riverware)



Pre-release for flood control

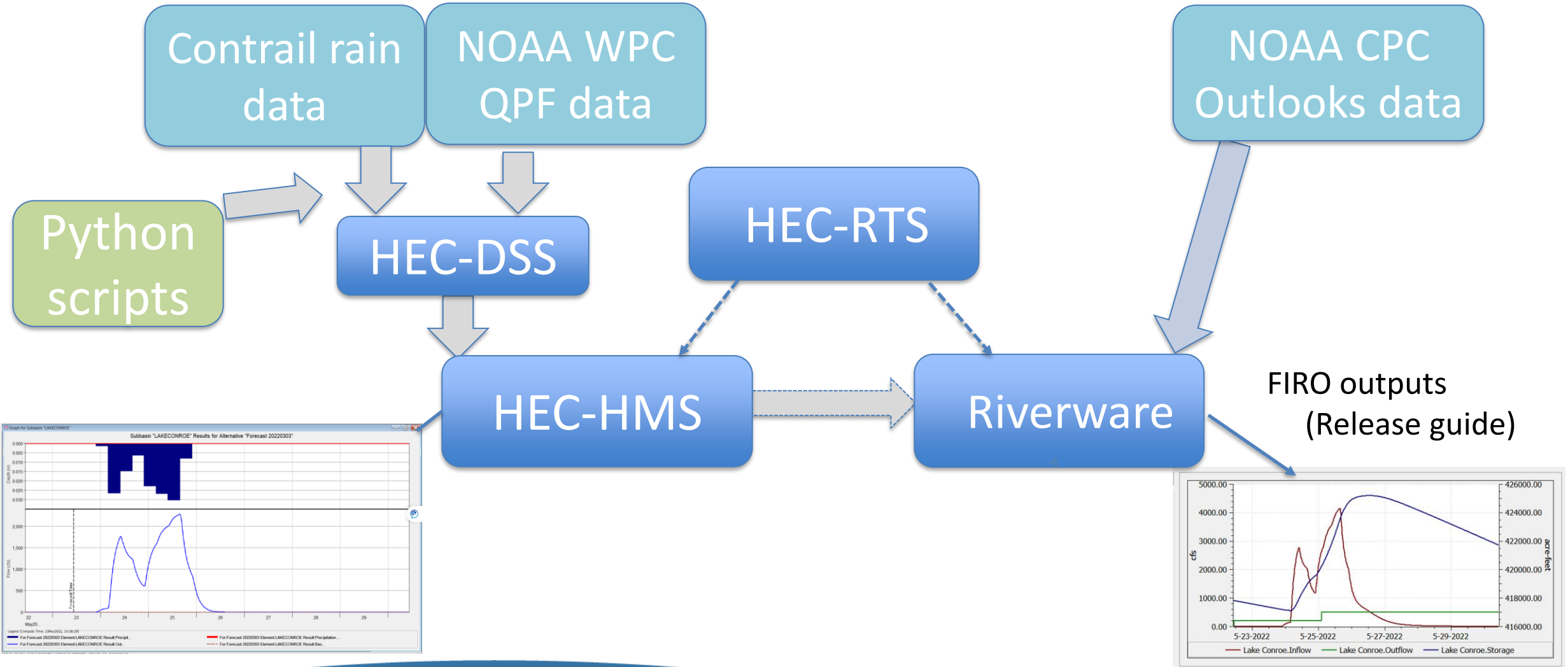
Hurricane is coming in 3 days

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

Timeline (day):

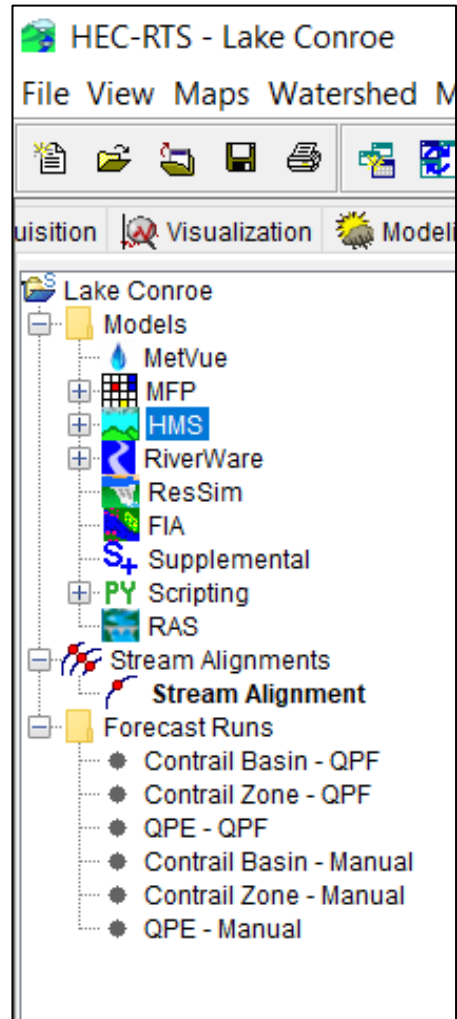
0 1 2 3 4 5 6 7

Data, toolsets, and workflow

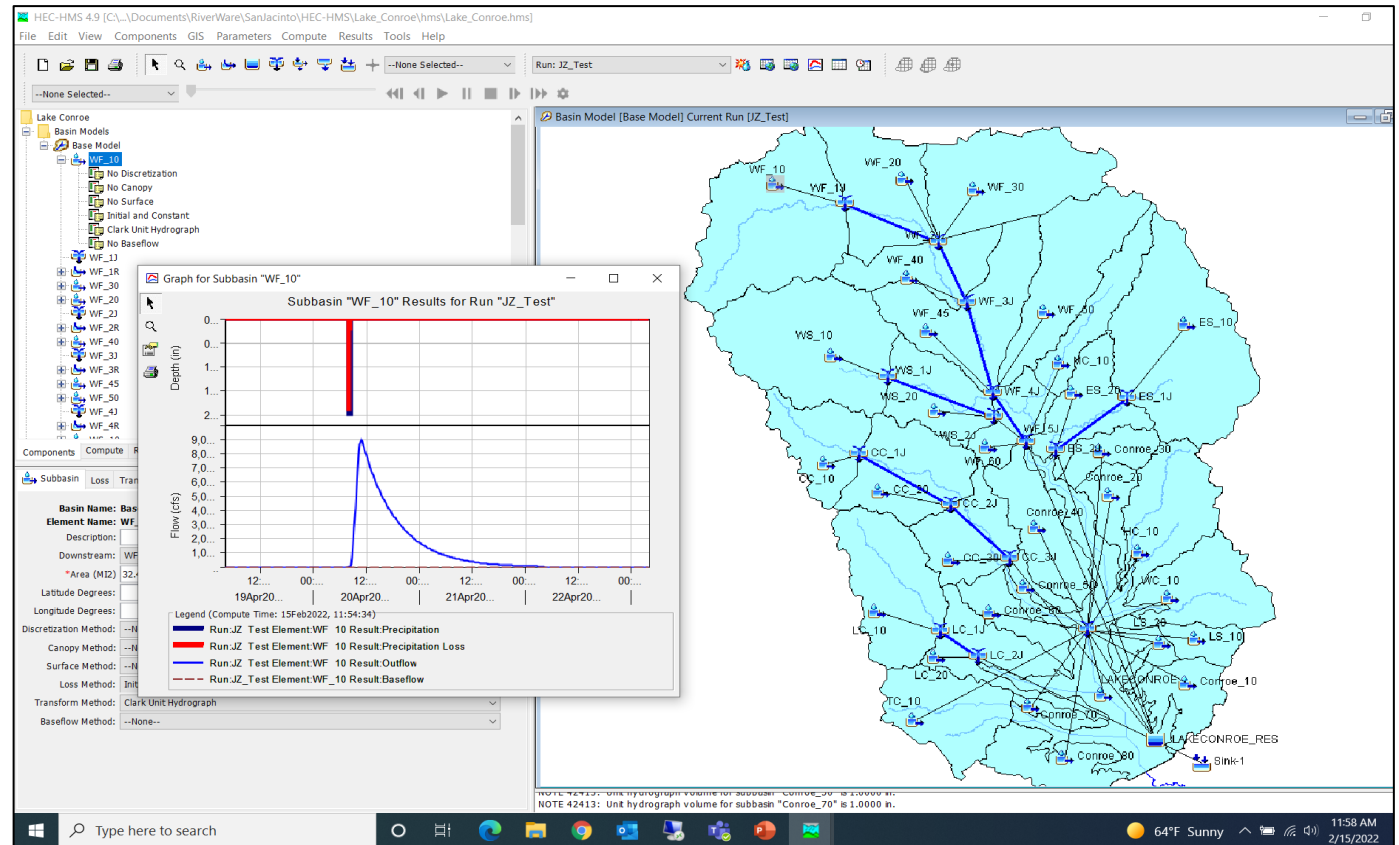


HEC-RTS and HEC-HMS for Conroe watershed

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

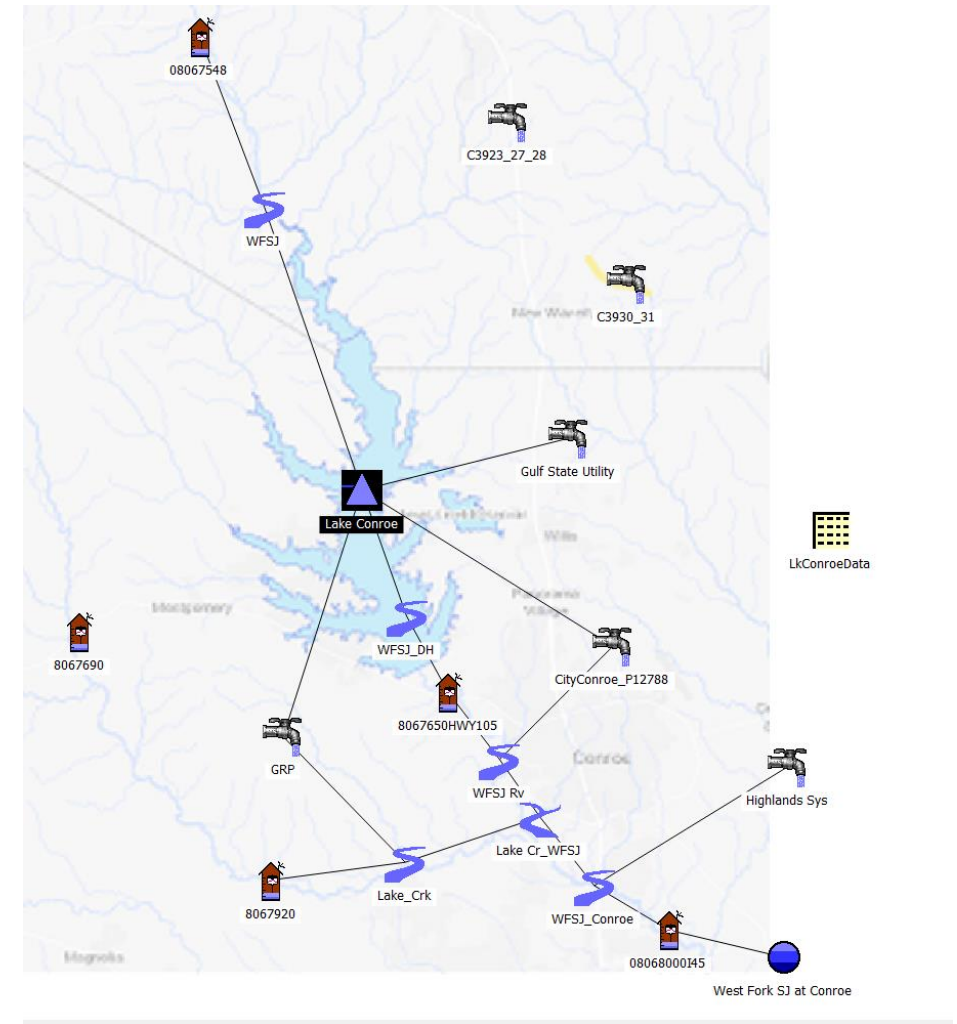


HEC-HMS model for Lake Conroe Watershed



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

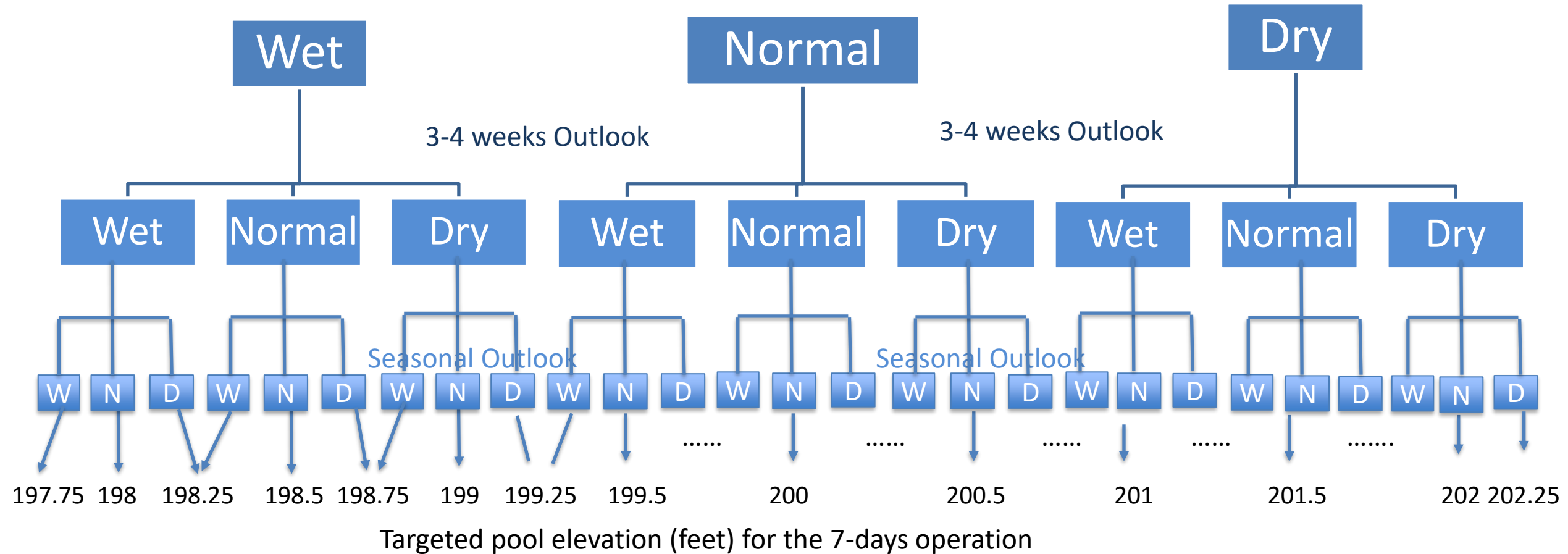


Contrail rainfall and QPF data fetching

- Past 24 hours rainfall data are retrieved through Contrail API.
- 6-hour NOAA-NWS-WFC Quantitative Precipitation Forecast (QPF) for next 7 days are downloaded 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

8 – 14 days Outlook



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

Data object
in Riverware
for dynamic
**Operational
Target** to
be determined
by the outlooks

The screenshot displays the Riverware software interface. The main window shows the 'Object: LkConroeData' with tabs for Slots, Methods, Accounts, Accounting Methods, Attributes, and Description. The 'Slots' tab is active, showing a list of slots with their values and units. The 'Precip814Outlook' slot is highlighted. A 'Slot Viewer (Scalar)' window is open, showing the 'LkConroeData.Precip814Outlook' slot with a value of 0.00 and units of NONE. A third window, titled 'LkConroeData.Preci...', is also open, showing the 'Precip814Outlook' slot with a value of 0.00 and units of NONE. This window also displays a description of the outlook: 'Precip outlook from CPC - 8~14 days' with a legend: 'above normal - 1 (wet)', 'near normal - 0 (normal)', and 'below normal - -1 (dry)'.

Slot Name	Value	Units
TCP	417,815.00	NONE
Total Capacity	757,576.00	NONE
Precip814Outlook	0.00	NONE
P814Probability	60.00	NONE
Precip34Outlook	0.00	NONE
OperationalTarget	200.60	feet
PrecipSeasonOutlook	0.00	NONE
P30Probability	70.00	NONE
PSeasonProbability	60.00	NONE

Slot Viewer (Scalar)

File Edit View

LkConroeData.Precip814Outlook

Value: 0.00 NONE

Object	Slot	Value	Units
LkConroeData	Precip814Outlook	0.00	NONE

LkConroeData.Preci...

File Edit View

Precip814Outlook

Value: 0.00 NONE

0.00 NONE

Show: ☒ Description

Precip outlook from CPC - 8~14 days
above normal - 1 (wet)
near normal - 0 (normal)
below normal - -1 (dry)

Rule implementation in Riverware model

Codes: -determining Operational_target:

```
OperationalTarget

Evaluation Time: Beginning of run

IF ( LkConroeData . "Precip814Outlook" [ ] > 0.00 AND LkConroeData . "P814Probability" [ ] > 50.00 ) THEN
  IF ( LkConroeData . "Precip340outlook" [ ] > 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 . "Precip340outlook" [ ] < 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
```

Rules for release:

```
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"
```

Run before the model simulation

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).

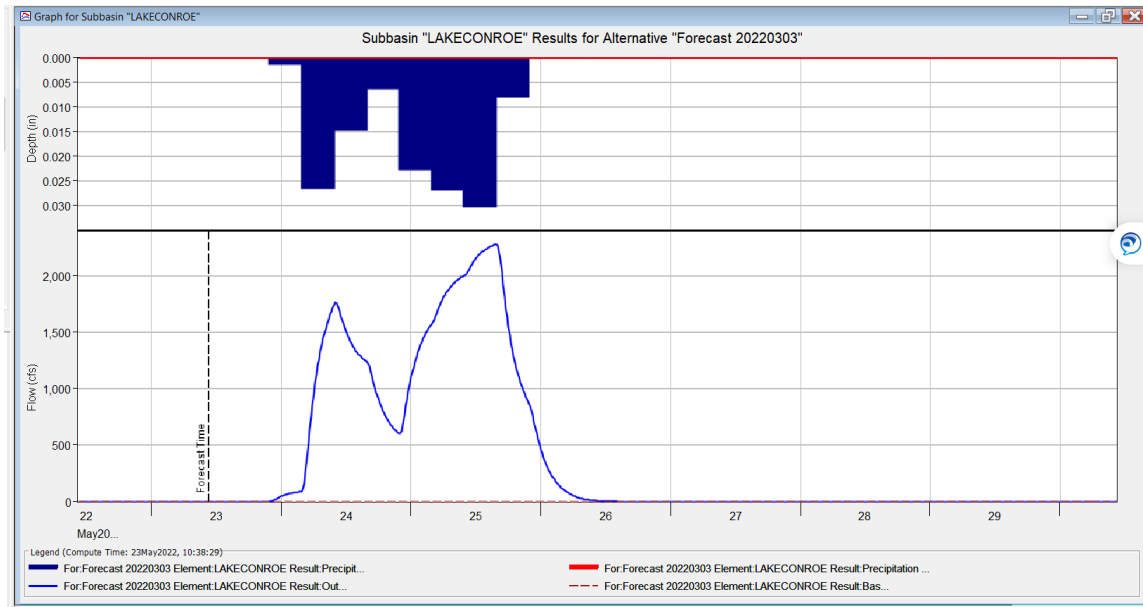
  1 Hurricane_Prerelease

```
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)

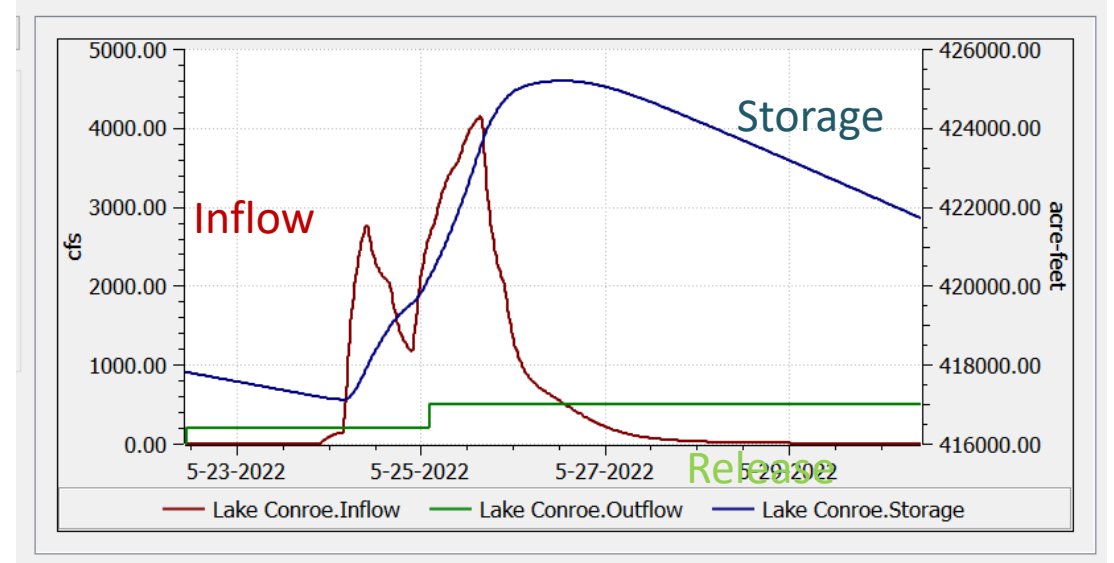
Regular runs set every 7 days. Flood prevention runs set every 6 hrs or every day depending on situation.

HEC-HMS output:



Little release due to normal outlooks

RiverWare output for Lake operation:



Key take aways

- Reservoir operation can be DIRECTLY and AUTOMATICALLY informed by NOAA's QPF and Outlooks by our methodology.
- HEC-RTS, HEC-HMS and RiverWare can work together for this purpose. RiverWare is outstanding and versatile for FIRO.
- QPF appears reasonable, but it would be the best for QPF in variable timesteps, 1-, 2-, 3-, and 6-hr for 0-6, 6-24, 24-48, 48-168 hours, respectively.
- More efforts are needed from the prototype to a formal/pilot model. (lake owner' data, other input data (i.e., HEFS forecasts), timesteps, model calibration)

Questions?

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