Hydropower modeling improvements: Historical and ongoing work

US DOE / National Lab team
Presented by Greg Brinkman
Feb 6, 2020

The purpose of this slide deck is for technical review; all results are preliminary and not to be distributed. This work was authored by the National Renewable Energy Laboratory, with funding provided by a partnership between the U.S. DOE, NRCan, and SENER. The views expressed herein do not necessarily represent the views of the study funders.

Motivation

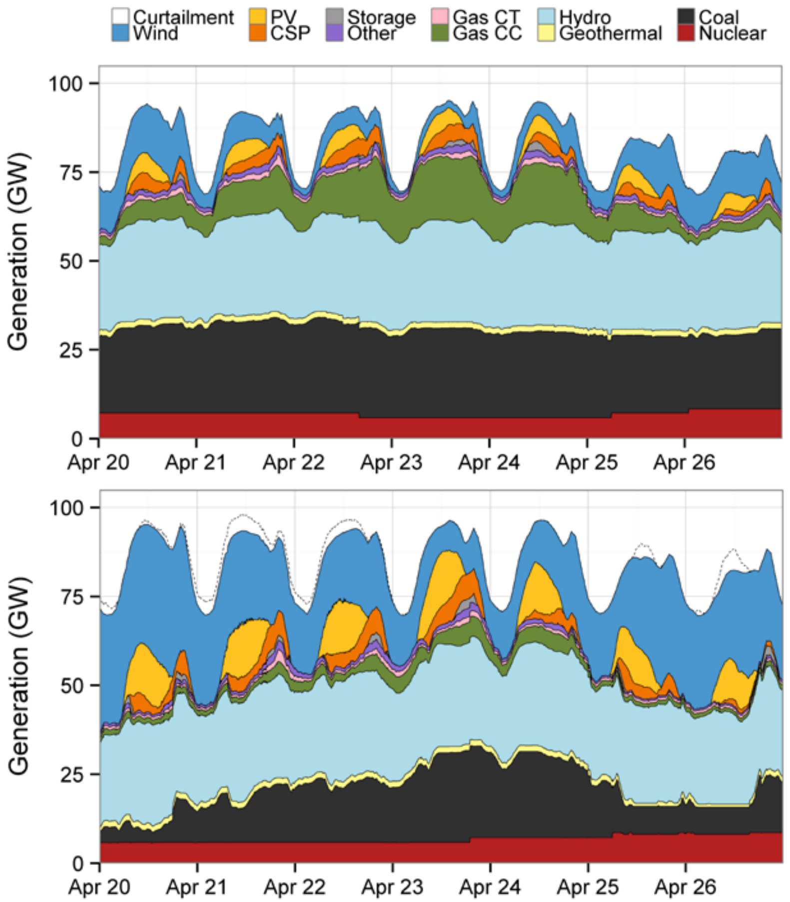
- Iteration between river systems model (RiverWare) and power systems model (PLEXOS) demonstrated significant difference between standard grid modeling assumptions and more informed version in current and future grids.
- Ibanez et al 2014: https://www.sciencedirect.com/science/article/pii/S0360544214008391

Demonstration case

- Electric system: Western Interconnection
  - o BAU scenario: 9.4% wind, 3.6% solar
  - o HiWind scenario: 25% wind, 8% solar
- Hydro system: Columbia River Basin
  - o BPA's "Big Ten"
  - o 85% of hydro in the interconnect
- One spring week
  - o April 20-27
- Simulation of system integrated:
  - o PLEXOS – power systems operation
  - o RiverWare – river systems (and dam) operation

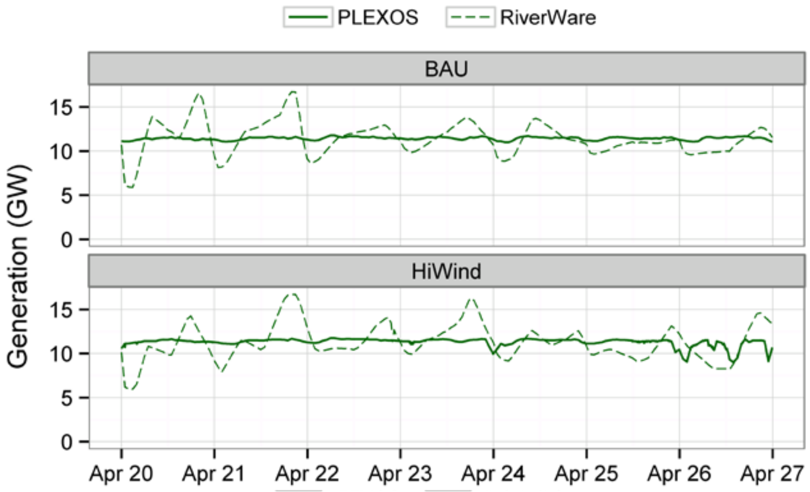
Results: PLEXOS

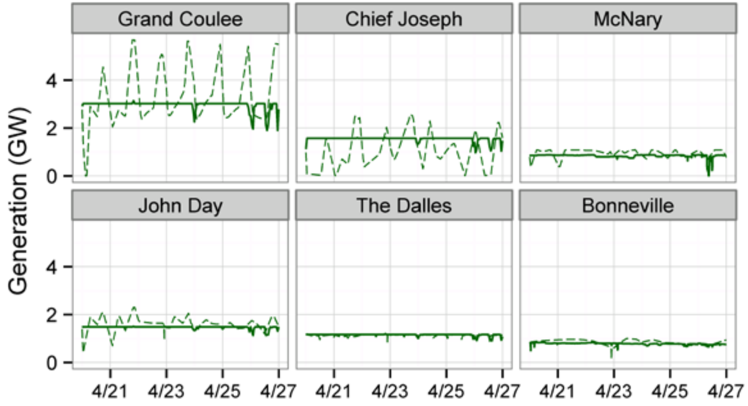
- BAU
  - Hydro, gas CC follow load
  - CTs used to balance
- HiWind
  - Cycling coal
  - Gas CC backed down
  - VG curtailed



Results

- Compare PLEXOS (solid lines) and RiverWare (dashed lines) hydro profiles
    - o RiverWare: more variation in total generation
    - o Bigger effect in individual dams





Results: System cost and prices

- BAU: $4m (2%) reduction in total cost for one week
- Both: Decrease in average and extreme prices
- Standard grid modeling assumptions may be undervaluing hydro flexibility
- More time periods and scenarios should be studied to see if conclusion is robust

Total cost	PLEXOS (million $)	RiverWare (million $)	Reduction (million $, %)
BAU	223.0	218.9	4.17 (1.9%)
HiWind	155.2	154.2	0.98 (0.6%)

Avg. price	PLEXOS ($/MWh)	RiverWare ($/MWh)
BAU	40.5	38.3
HiWind	30.0	27.0

New US DOE (HydroWIRES) projects funded to focus on improvements

Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

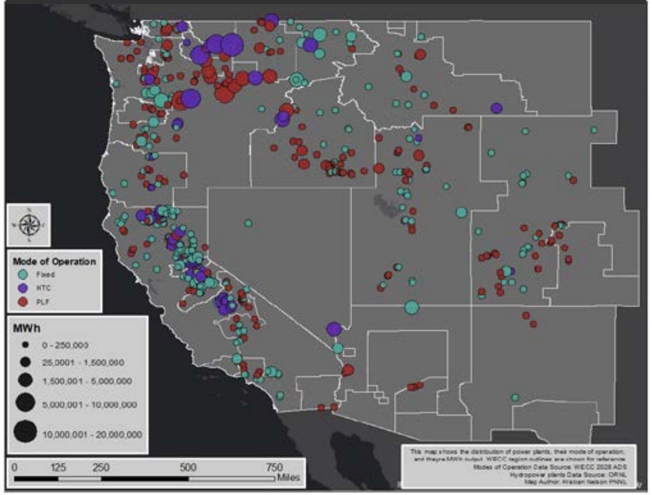
CADS WES

HydroWIRES U.S. DEPARTMENT OF ENERGY

A dynamic plant classification to improve the representation of hydropower flexibility in production cost models

N. Voisin, T. Veselka, T. Magee, L. Markel, M. Clement , K. Oikonomou, N. Samaan, S. Turner, E. Zagona

Hydropower plants in WECC 2028 ADS PCM & their modes of operation



Note: Canada and Mexico not mapped for simplicity

Over 50% of powered reservoirs needs to provide river services before matching hydropower services.

To mimic the constraints associated with water availability and river services, most commercial production cost models parameterize the hydropower plants flexibility with a plant classification:

- *Monthly* potential energy
- *Monthly* hourly minimum and maximum generation
- *Annual* ramping rates
- *Annual* mode of operations

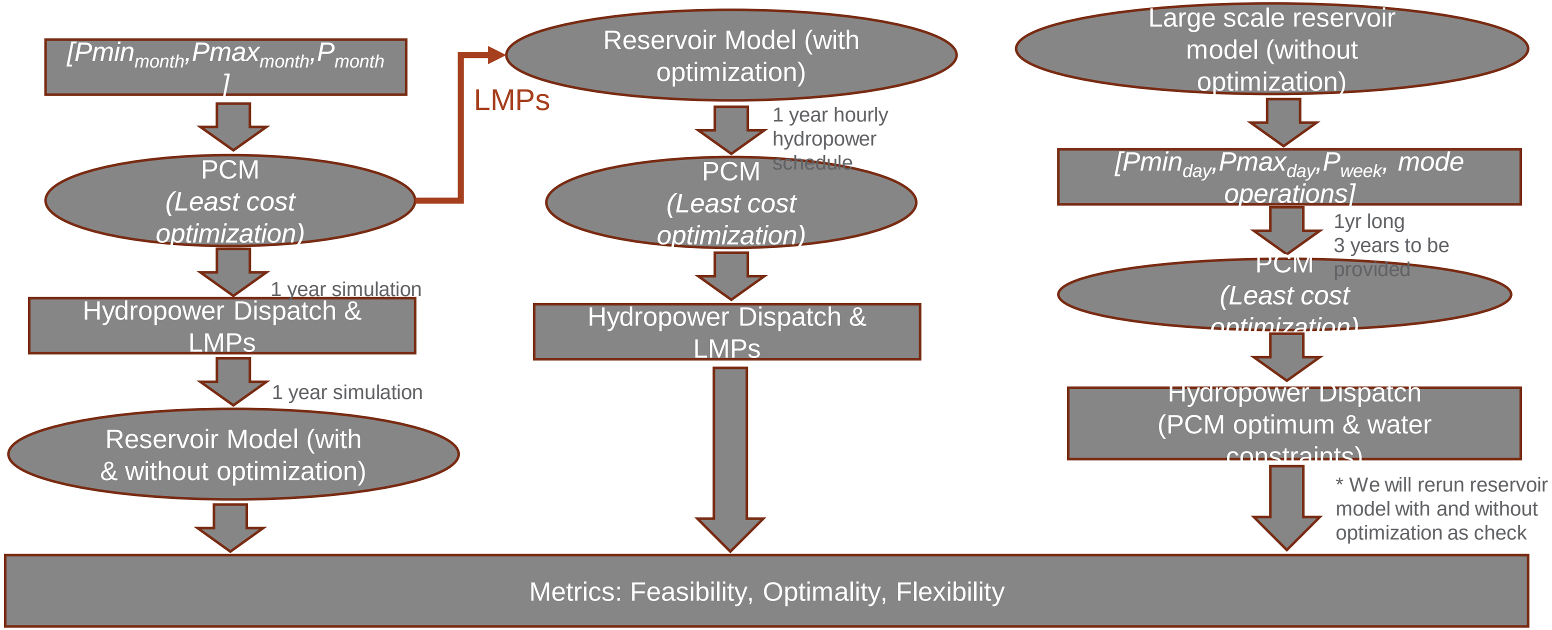
We use a series of large scale hydrologic and reservoir operations models to **represent hydropower flexibility at a sub-monthly time scale to support reliability and resources adequacy studies**.

A dynamic plant classification to improve the representation of hydropower flexibility in production cost models

Benchmark
(PCM optimum)

Water Optimum
*(*regional coverage only with 10 power plants)*

Dynamic plant classification
(PCM optimum with water feasibility constraints)



Domain: **Western US (1300 hydropower plants).** PCM: AURORA NWPCC set up, GridView WECC 2028 ADS CC

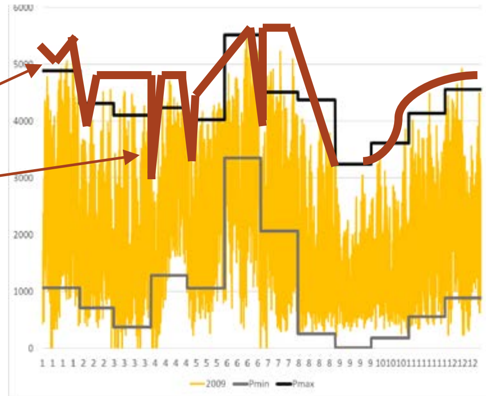
Anticipated outcome

An offline sub-monthly time scale plant classification in production cost models to support reliability and resources adequacy studies:

- Inter-annual variability in (Pmin-Pmax) and Monthly Energy Potential
- Sub-monthly variability associated with floods or evolving drought conditions
- Support the exploration of available hydropower flexibility needs under different generation portfolio, markets, regulation, etc
- Compatible with commercial production cost models (input datasets & PCM set ups)

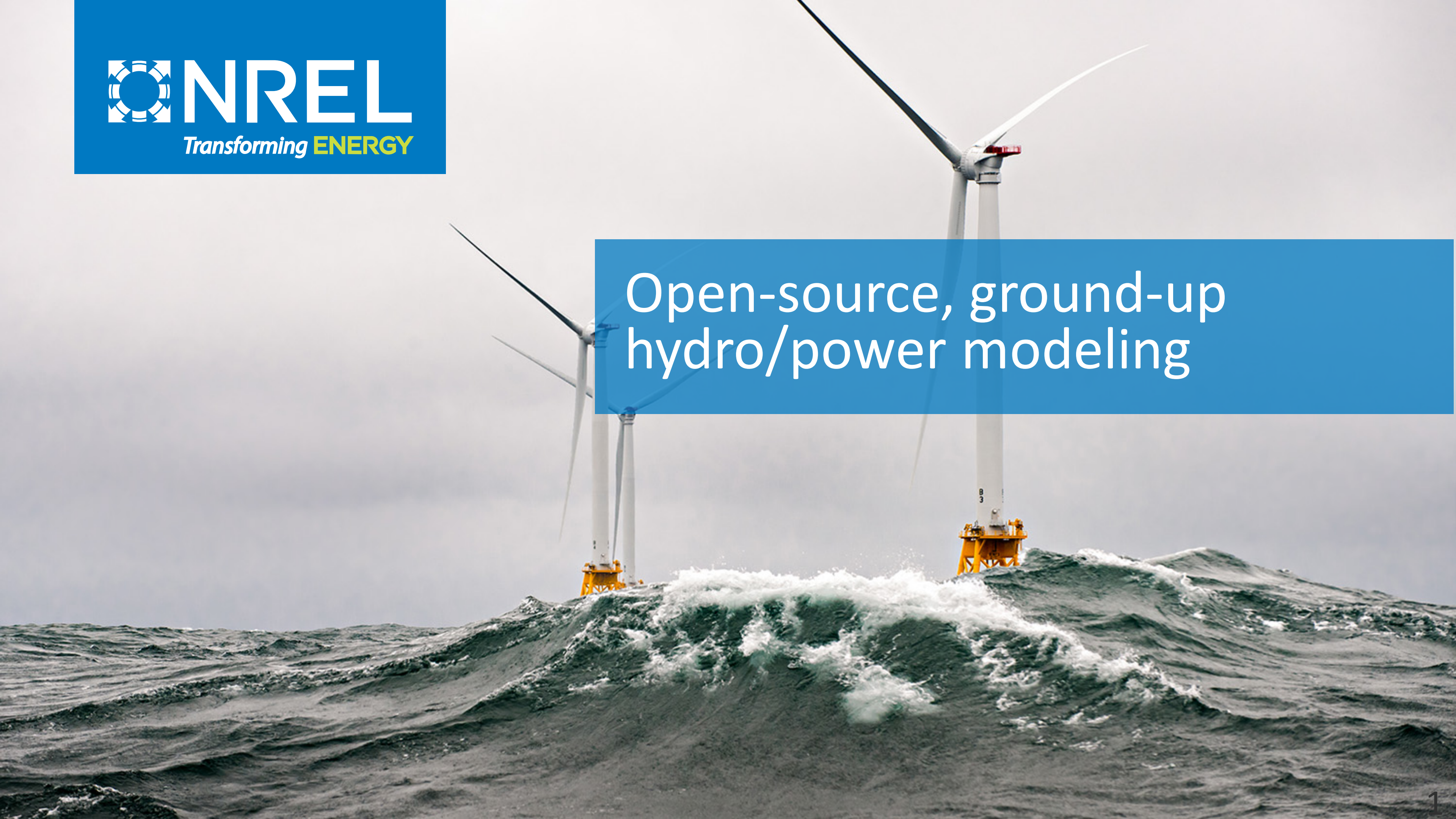
opportunities

constraints



2009 USACE hourly generation at Grand Coulee & existing Pmin & Pmax plant classification

Nathalie.Voisin@pnnl.gov



Open-source, ground-up hydro/power modeling

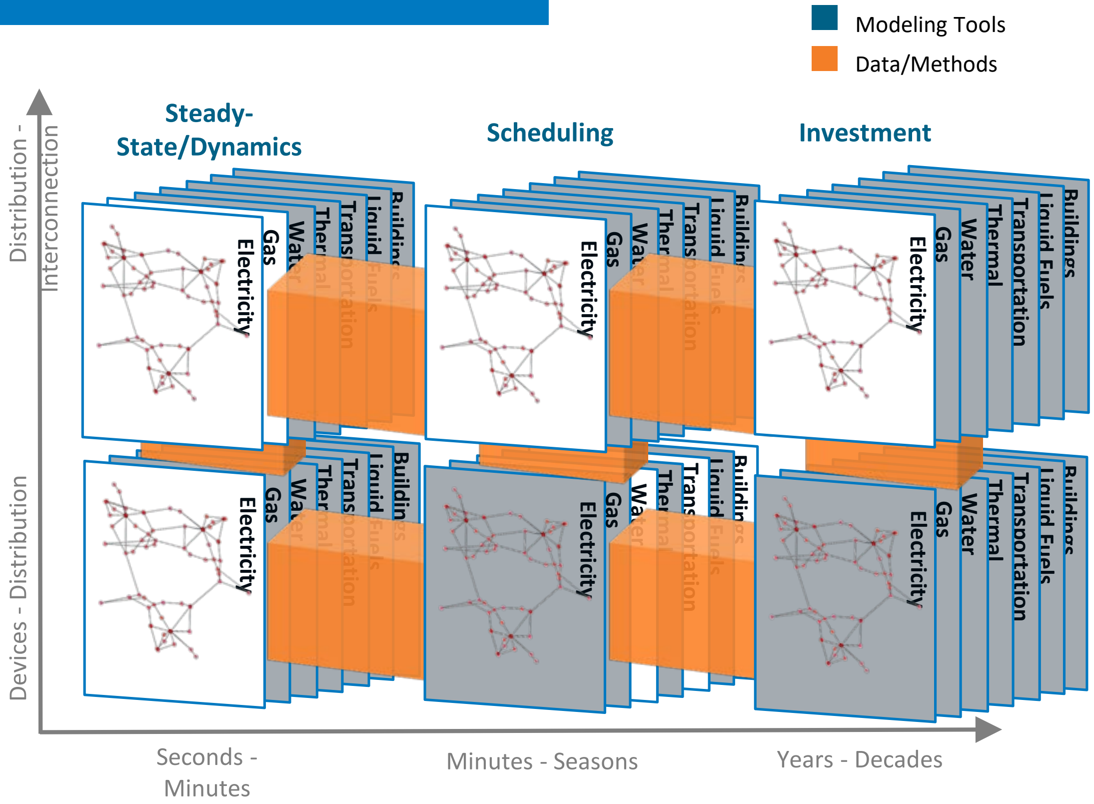
An Integrated Modeling Vision

Framework Design Objectives

Modularity and Accessibility – flexible and transparent problem creation that is easily extensible

Integration – coherency between models representing distinct phenomena

Scalability – address scales that matter through efficient problem simulation and parallelism



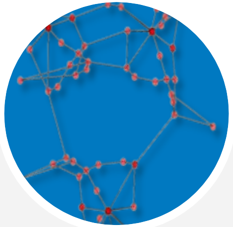
**Not representative of project deliverables*

SIIP Framework:

An example for electricity systems

Modular, interoperable, modeling components that define infrastructure modeling problems informed by system data

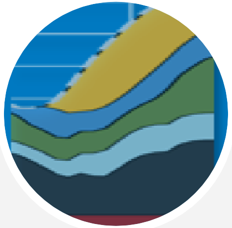
SIIP::Power



PowerSystems.jl

Rigorous data model that defines infrastructure systems

- Collects information required for device level modeling
- Includes parsing capabilities
- Exploits Julia's parametric dispatch for efficient code development
- Agnostic to simulations that will be performed



PowerSimulations.jl

Mathematical formulations and simulation assemblies

- Support for optimization and dynamic simulation models
- Modular problem assembly to enable rapid development and extension
- Includes standard simulations (e.g. UC/ED)
- Deep integration with PowerModels.jl (LANL) to enable non-linear power flow formulations

Two Hydro generation types can be applied to multiple formulations

- HydroFix

```
mutable struct HydroFix <: HydroGen
    name::String
    available::Bool
    bus::Bus
    activepower::Float64
    reactivepower::Float64
    tech::TechHydro
    "Services that this device contributes to"
    services::Vector{Service}
    ext::Dict{String, Any}
    _forecasts::InfrastructureSystems.Forecasts
    "power system internal reference, do not modify"
    internal::InfrastructureSystemsInternal
end
```

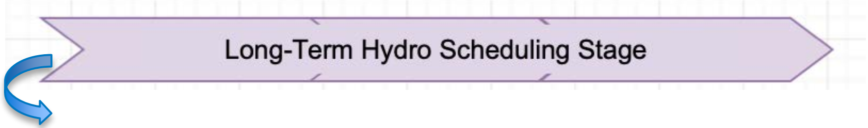
- HydroDispatch

```
mutable struct HydroDispatch <: HydroGen
    name::String
    available::Bool
    bus::Bus
    activepower::Float64
    reactivepower::Float64
    tech::TechHydro
    op_cost::TwoPartCost
    storage_capacity::Float64
    inflow::Float64
    initial_storage::Float64
    "Services that this device contributes to"
    services::Vector{Service}
    ext::Dict{String, Any}
    _forecasts::InfrastructureSystems.Forecasts
    "power system internal reference, do not modify"
    internal::InfrastructureSystemsInternal
end
```

- **Formulations**:
  - HydroFixed <: AbstractHydroFormulation
    - Net-load reduction
  - HydroDispatchRunOfRiver <: AbstractHydroDispatchFormulation
    - Dispatchable curtailment
  - HydroCommitmentRunOfRiver <: AbstractHydroUnitCommitment
    - Committable and dispatchable curtailment
  - HydroDispatchReservoirFlow <: AbstractHydroDispatchFormulation
    - Dispatchable subject to energy in reservoir
  - HydroCommitmentReservoirFlow <: AbstractHydroUnitCommitment
    - Committable and dispatchable subject to energy in reservoir
  - HydroDispatchReservoirStorage <: AbstractHydroDispatchFormulation
    - Dispatchable subject to energy in reservoir and storage target
  - HydroCommitmentReservoirStorage <: AbstractHydroUnitCommitment
    - Committable and dispatchable subject to energy in reservoir and storage target

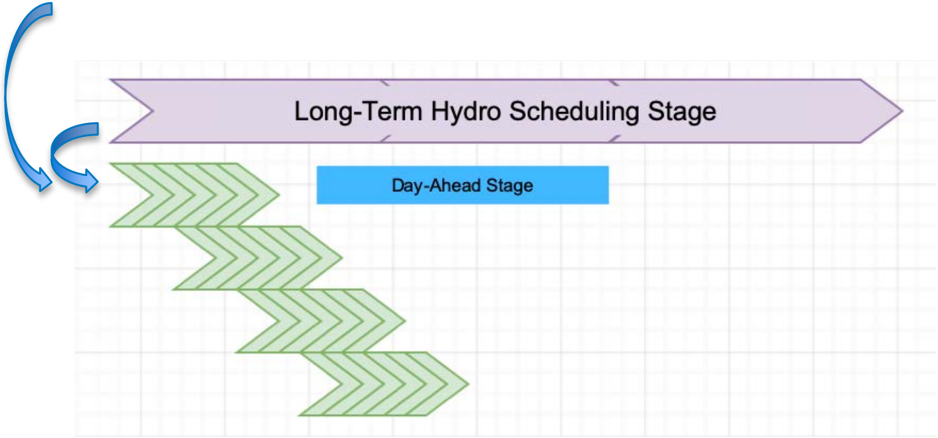
Simulation sequences can be adjusted to represent forecast availability and uncertainty

1. Long Term Hydro Scheduling Stage.



2. Information is fed forward between stages (e.g. hydro-energy limits).

3. Day-ahead market clearing stage constrains hydro dispatch integral to energy limit for the synchronized periods.



4. We can simulate the availability of updated forecasts and realized inflows by adjusting the simulation sequence.

SIIP Framework:
An example for water systems

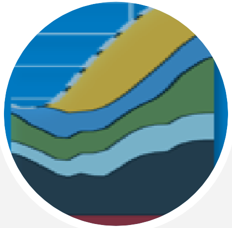
Modular, interoperable, modeling components that define infrastructure modeling problems informed by system data

SIIP::Water

WaterSystems.jl

Rigorous data model that defines infrastructure systems

- Collects information required for device level modeling
- Includes parsing capabilities from EPANET.inp file format
- Exploits Julia’s parametric dispatch for efficient code development
- Agnostic to simulations that will be performed



WaterSimulations.jl

Mathematical formulations and simulation assemblies

- Optimal pump scheduling for municipal water supply systems
- Modular problem assembly to enable rapid development and extension
- Scalable formulations to enable high-fidelity large-system simulations
- Multi-level integration with PowerSimulations.jl for exploration of Electric-Water coordination

SIIP::POWER

[PowerSystems.jl]

[PowerSimulations.jl]

SIIP::WATER

[WaterSystems.jl]

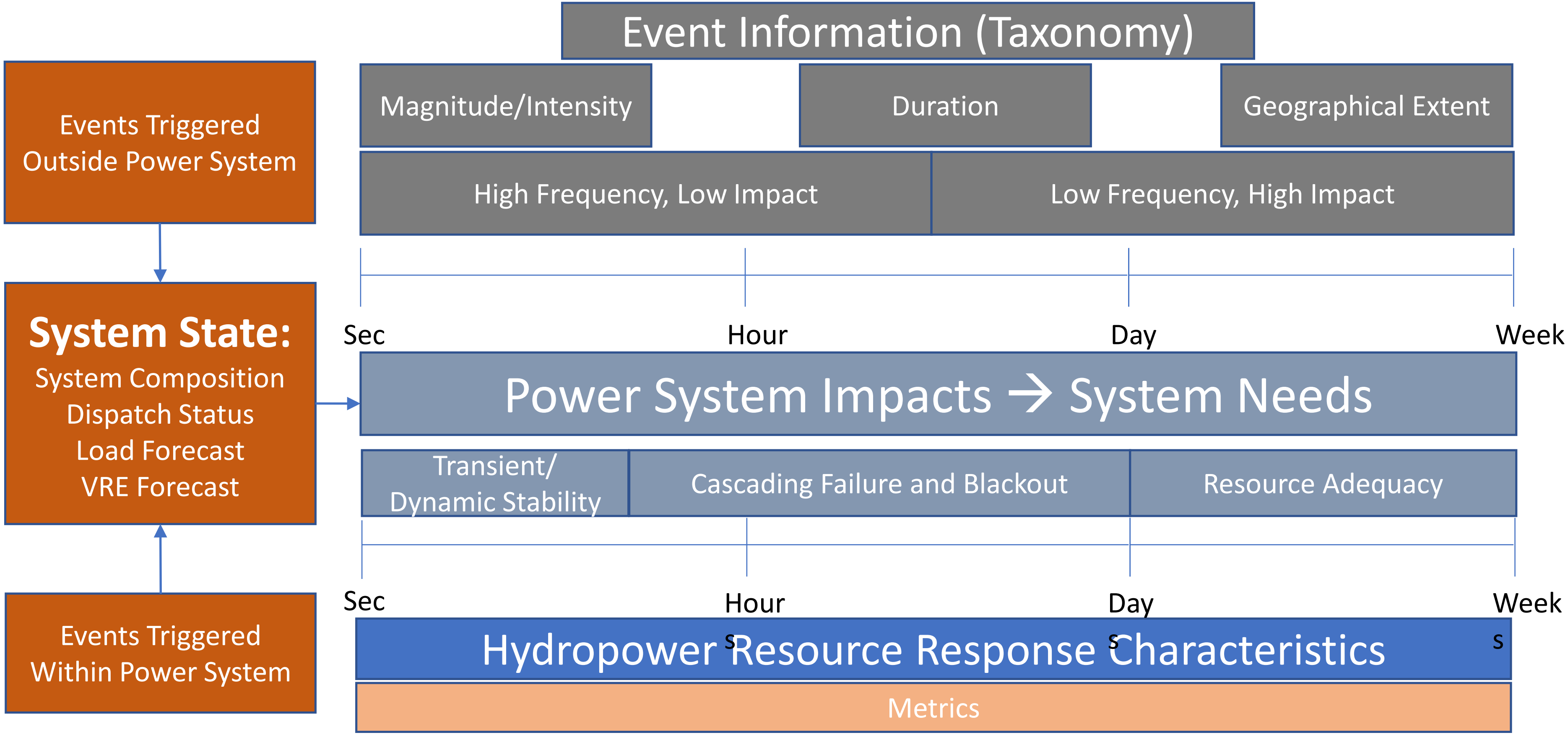
[WaterSimulations.jl]

Please contact **clayton.barrows@nrel.gov** with questions

www.nrel.gov

NREL Transforming ENERGY

Understanding the Role of Hydropower in Ensuring Reliable and Resilient Grid Operations



NREL
Transforming ENERGY

Questions?

gregory.brinkman@nrel.gov