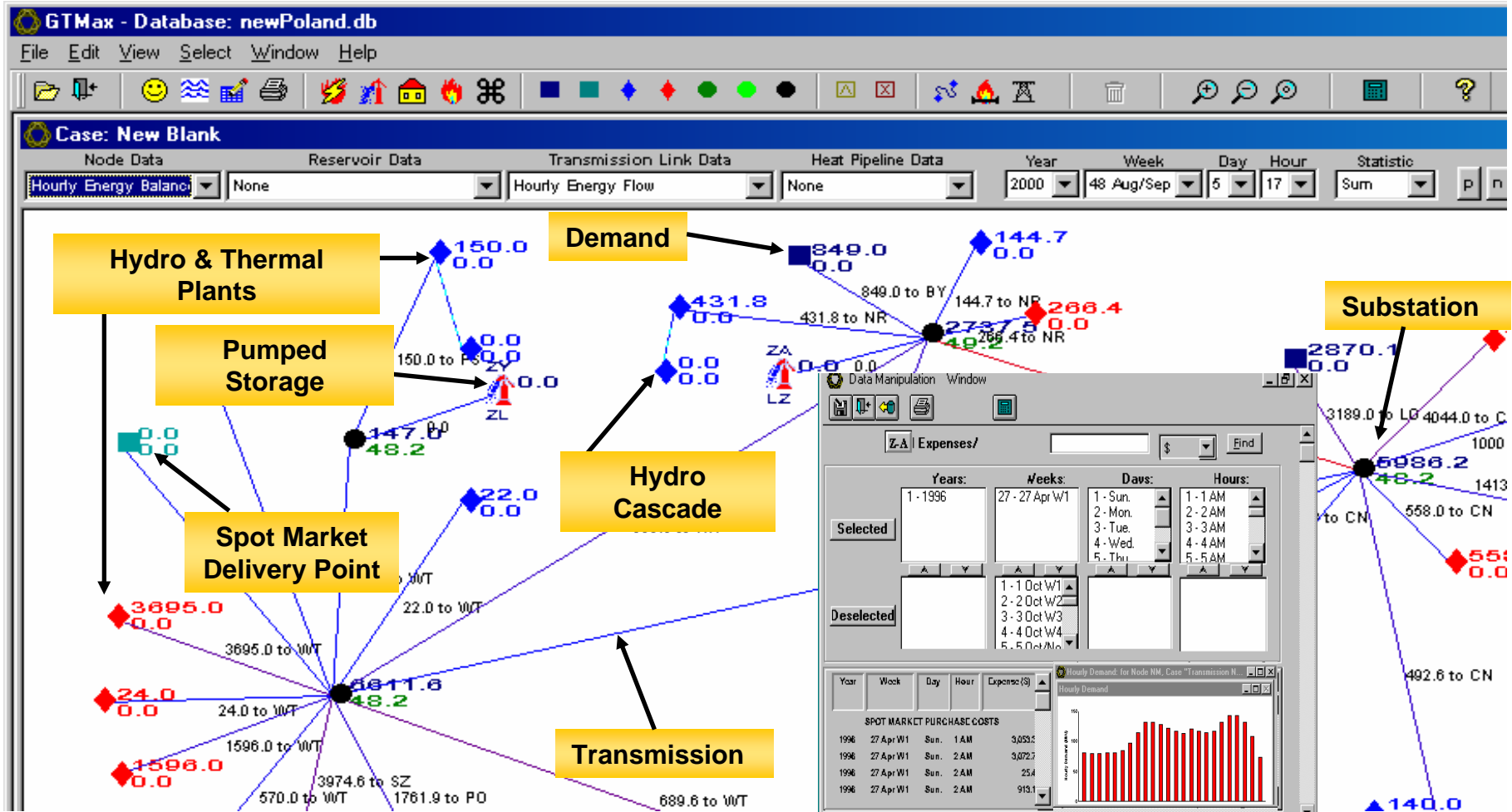


***GTMax:
An Analytical Tool for
Power System Operations***

GTMax Uses a Network Representation



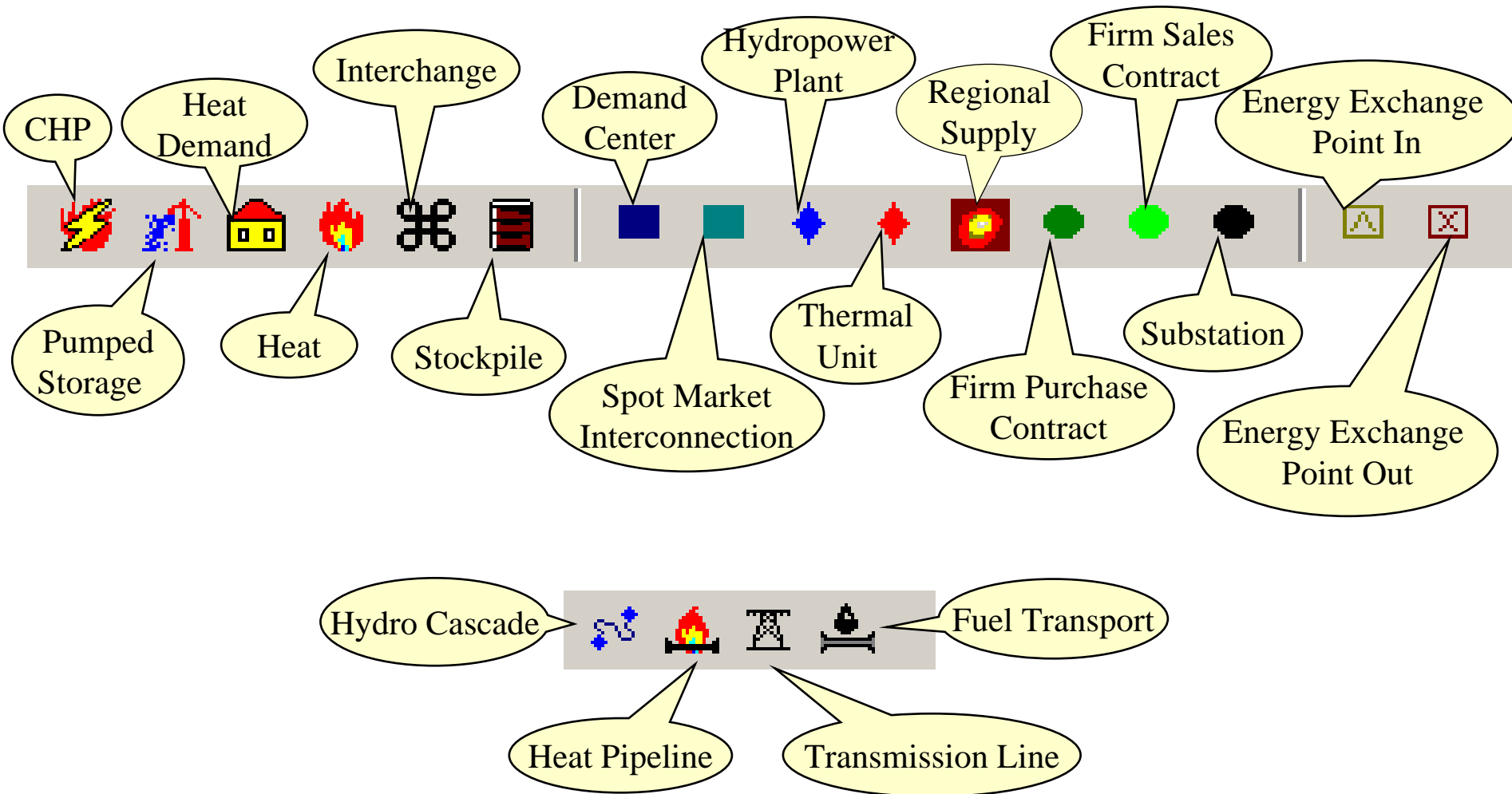
A Network Is Constructed From Objects that Represent Electricity Demand, Supply, and Transmission Systems

- **Some objects represent power plants, consumers, contracts, and markets**
- **Other objects represent the transport of electricity, water, or fuel**
- **Once an object is created, the user inputs information that describes the attributes and limitations of the physical entity it represents**
- **Data inputs are applied at various time horizons including annual, weekly, daily, and hourly**
- **The user also inputs information about the interconnected system**

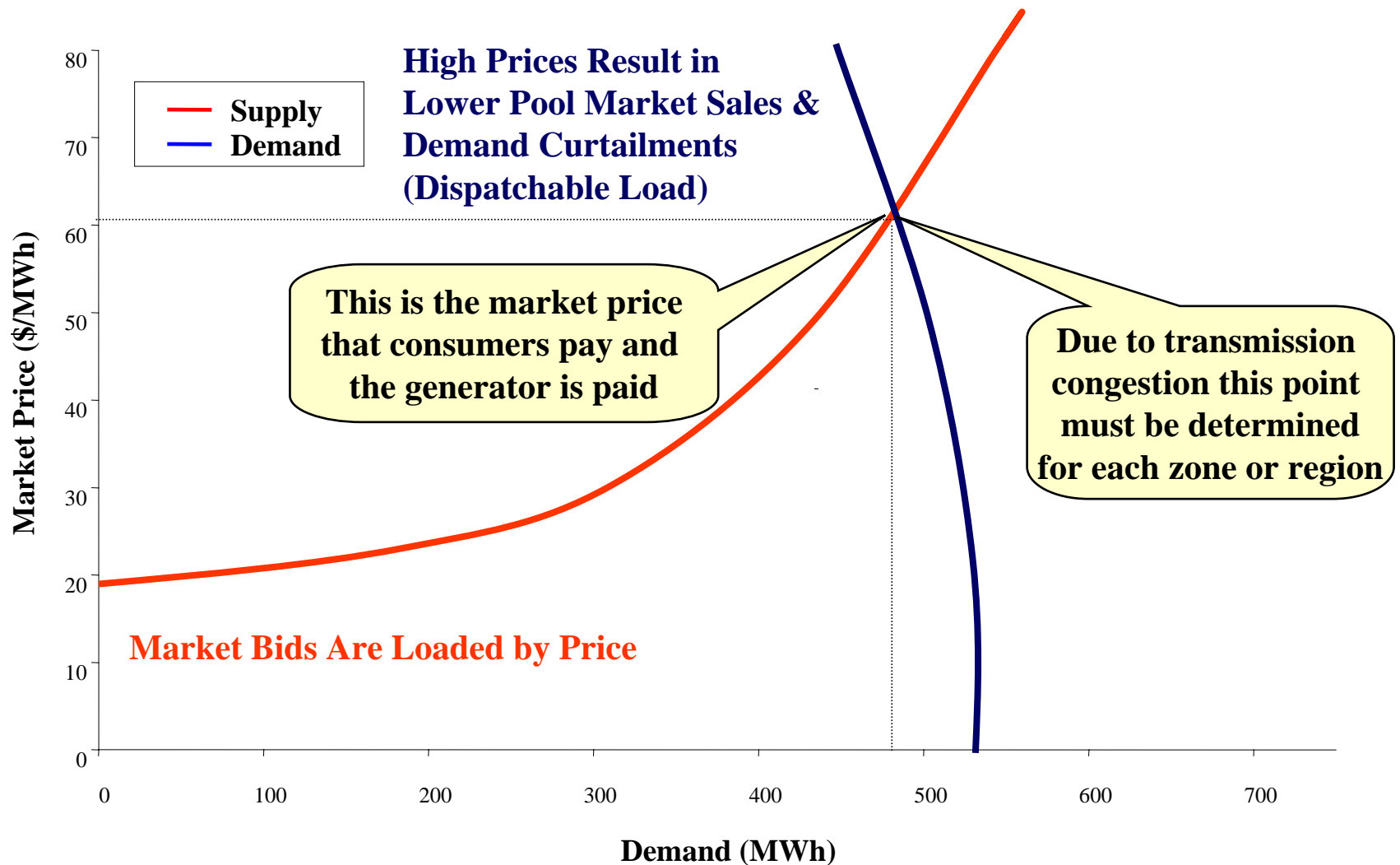
A Network of Nodes and Links Simulates Inter-Related Systems

- **Power flows**
 - From producers
 - To consumers
- **Water flows**
 - Among reservoirs
 - In river channels
 - Routed through diversions and pumps
- **Fuel Flows**
 - From producers and fuel storage
 - To points of consumption
 - Via pipelines
- **Flow of heat**
 - Produced by heat and CHP plants
 - To consumers
- **Flow of Money**

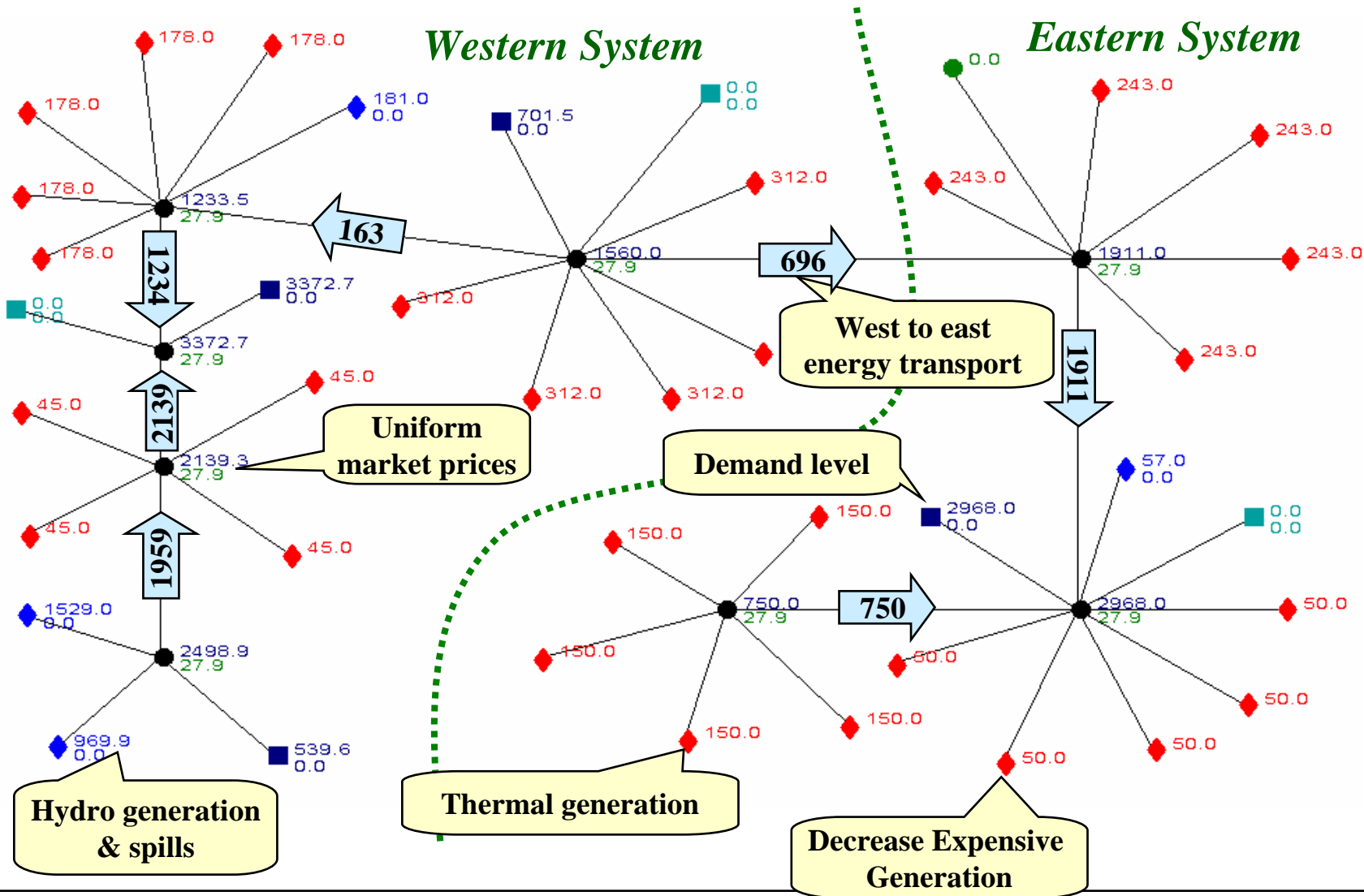
Using GTMax Building Blocks Customized Networks Are Created



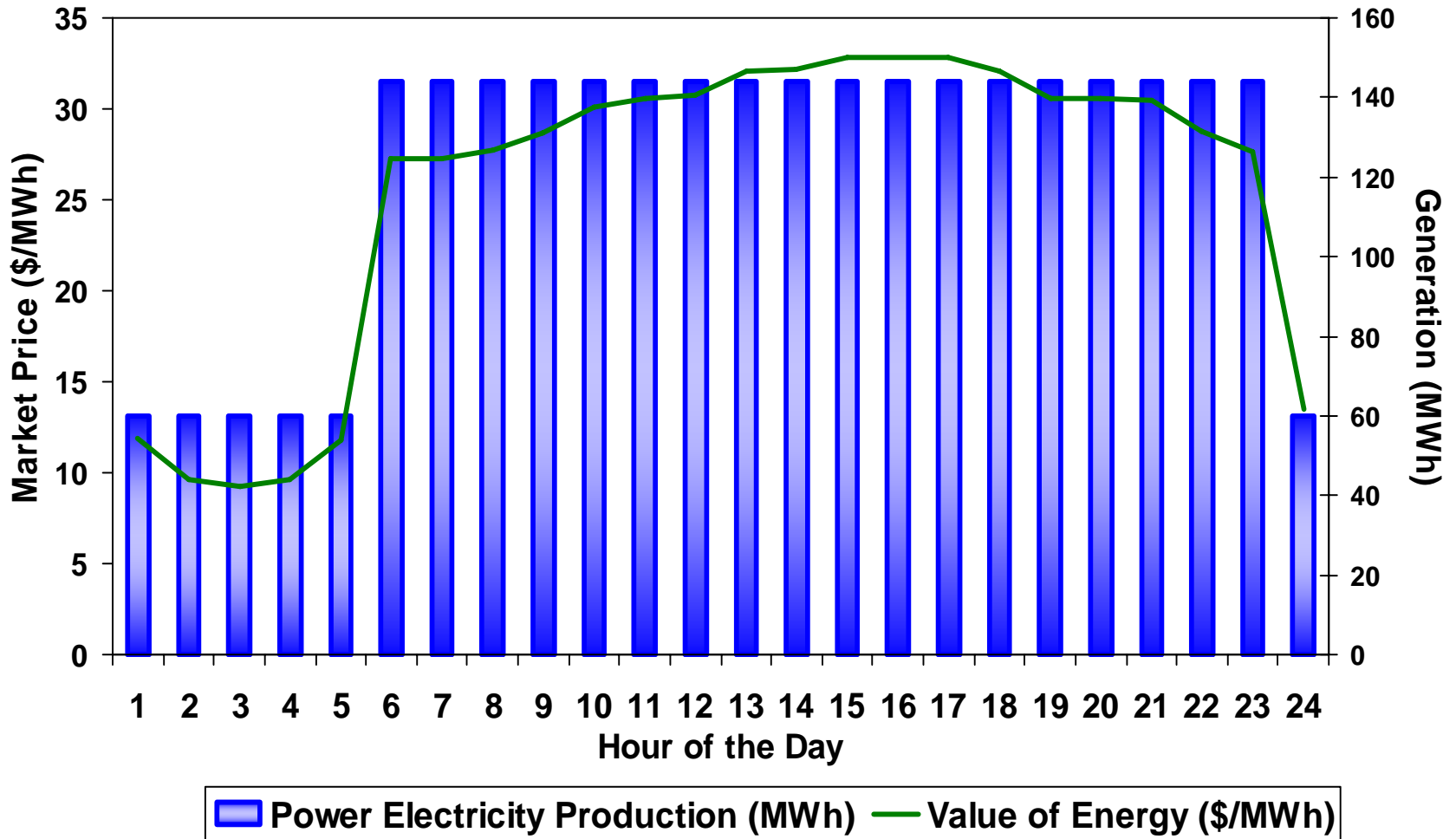
GTMax Balances Supply & Demand Bids from All Market Participants to Determine Market Clearing Prices



When the Systems Are Connected Market Prices Are Nearly Identical at All Locations

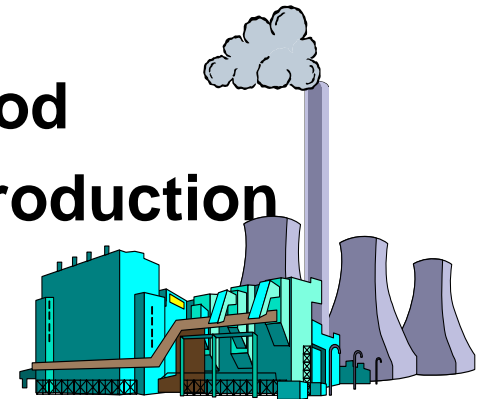


Hourly Power Operations in GTMax Respond to Market Forces Through Locational Price Signals

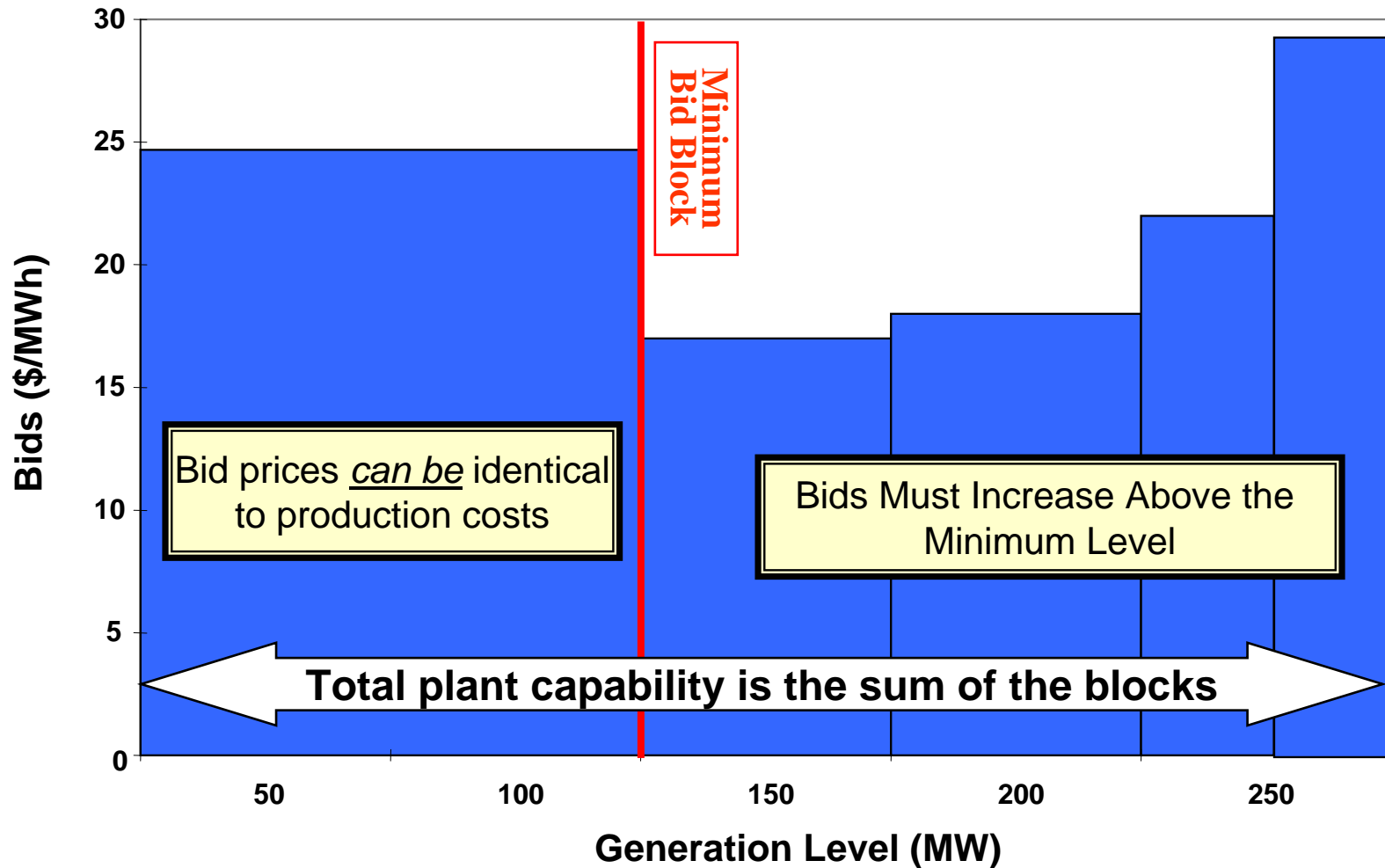


GTMax Has Detailed Thermal Power Plant Representations

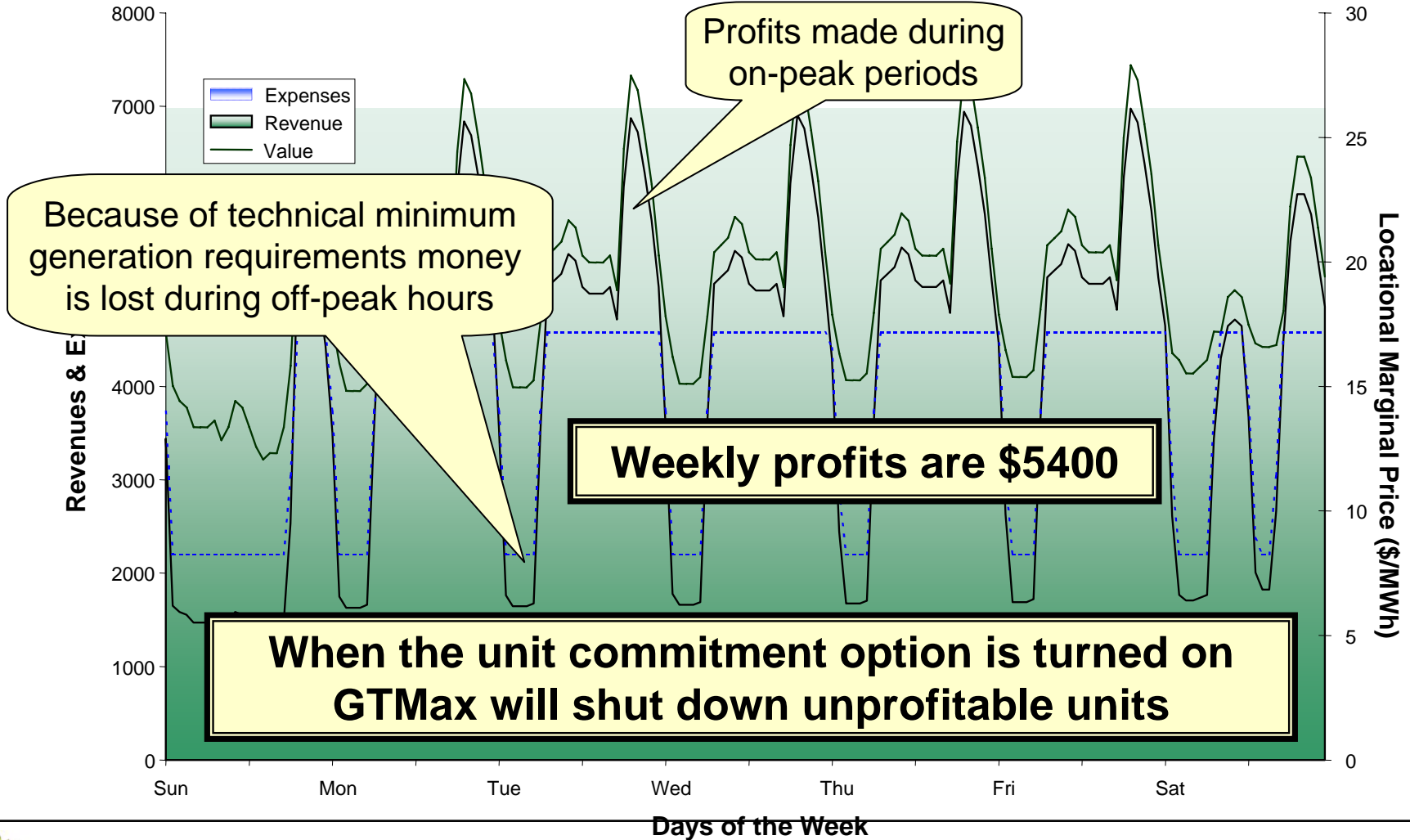
- Power plant or unit capacity
- Marginal production cost by block
- Total energy produced in a week period
- Daily minimum & maximum energy production
- Change in daily energy production
- Minimum hourly output
- Maximum hourly output
- Hourly up & down ramp rate restrictions
 - Change in generation from one hour to the next
- Daily up & down ramp rate restrictions
 - Change in generation over a 24 hour period



Market Bids for Each Thermal Node Are Specified as a Step Function on an Hourly Basis

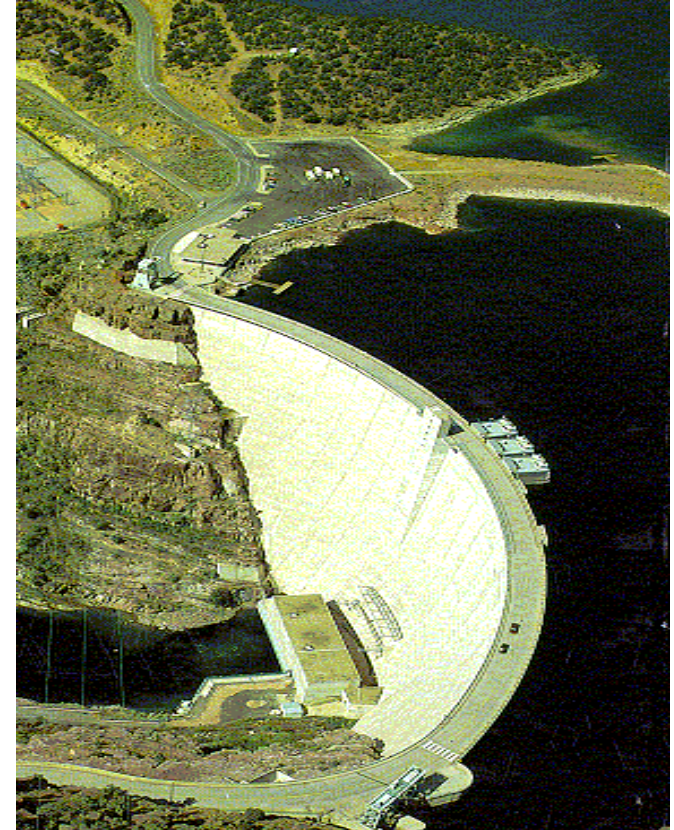


Thermal Units May Operate at a Loss During Low Demand Periods To Make a Profit During Peak Periods

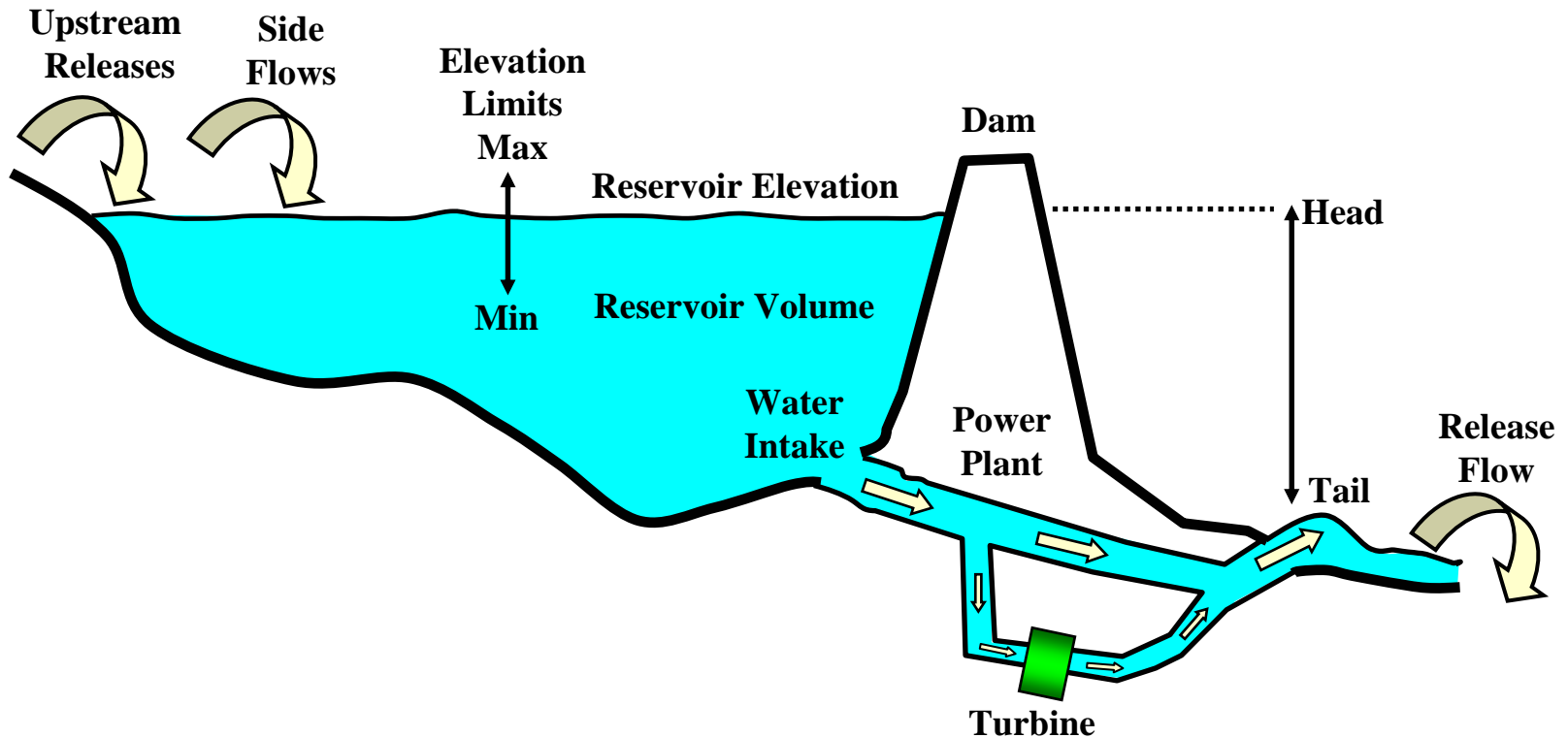
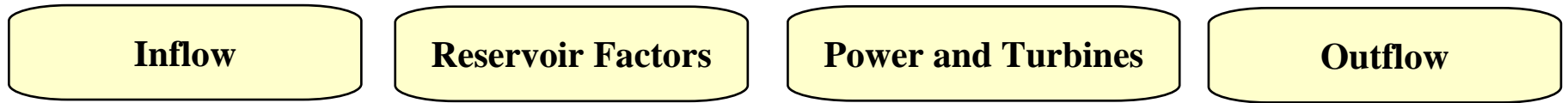


The GTMax Hydropower Dispatch Is Constrained by Reservoir Limitations

- **Maximum reservoir elevation level**
- **Minimum reservoir elevation level**
- **Daily reservoir elevation change**
- **Change over 2-day & 3-day periods**
- **Elevation levels are functions of:**
 - Initial reservoir conditions
 - Hourly up-stream reservoir releases
 - Side flows
 - Pumped water from a lower reservoir
 - Hourly reservoir releases
 - Water extracted for irrigation or other uses
 - Elevation volume function
- **GTMax computes the marginal value of water**



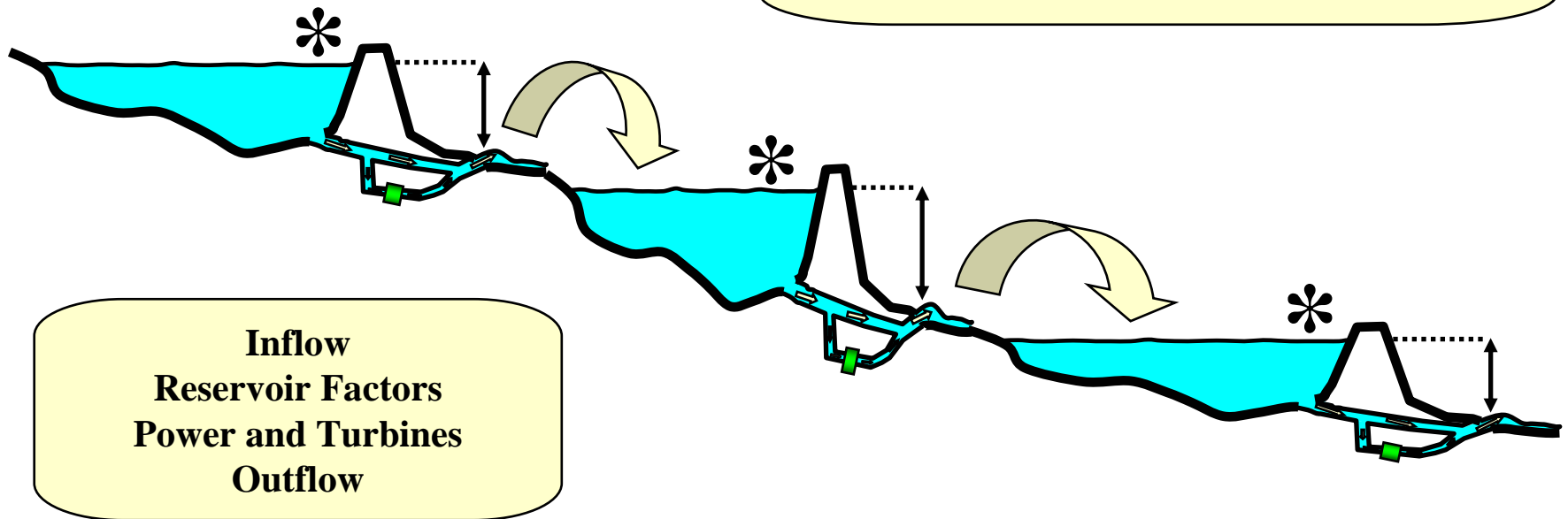
Hydro-Electric Dam Representation



Schematic of a Hydro-Electric Dam with Relevant Variables

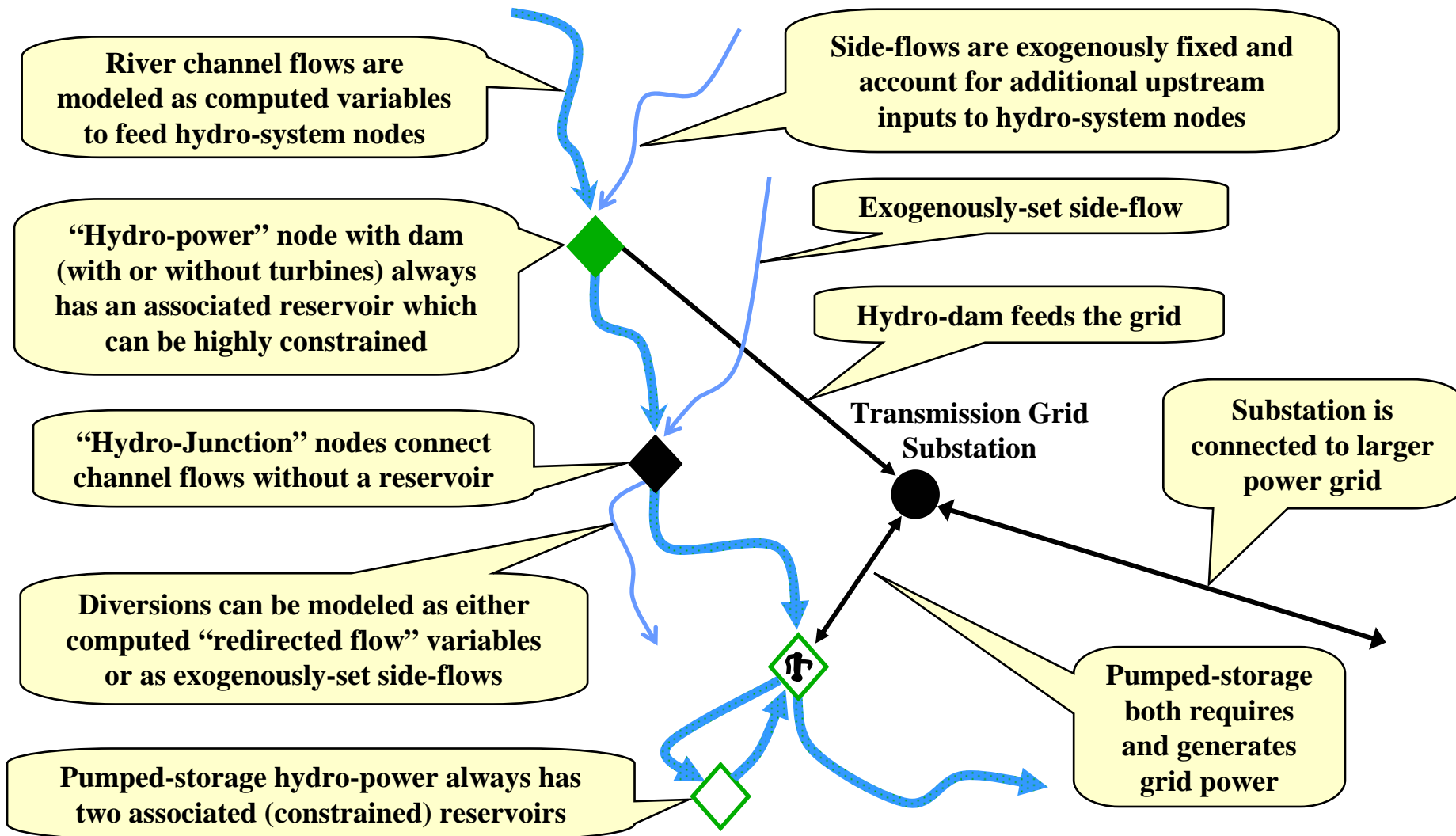
Power Plants Can Be Represented in a Cascade

Maintain Mass Balance as One Reservoir's
Outflow is Another's Inflow

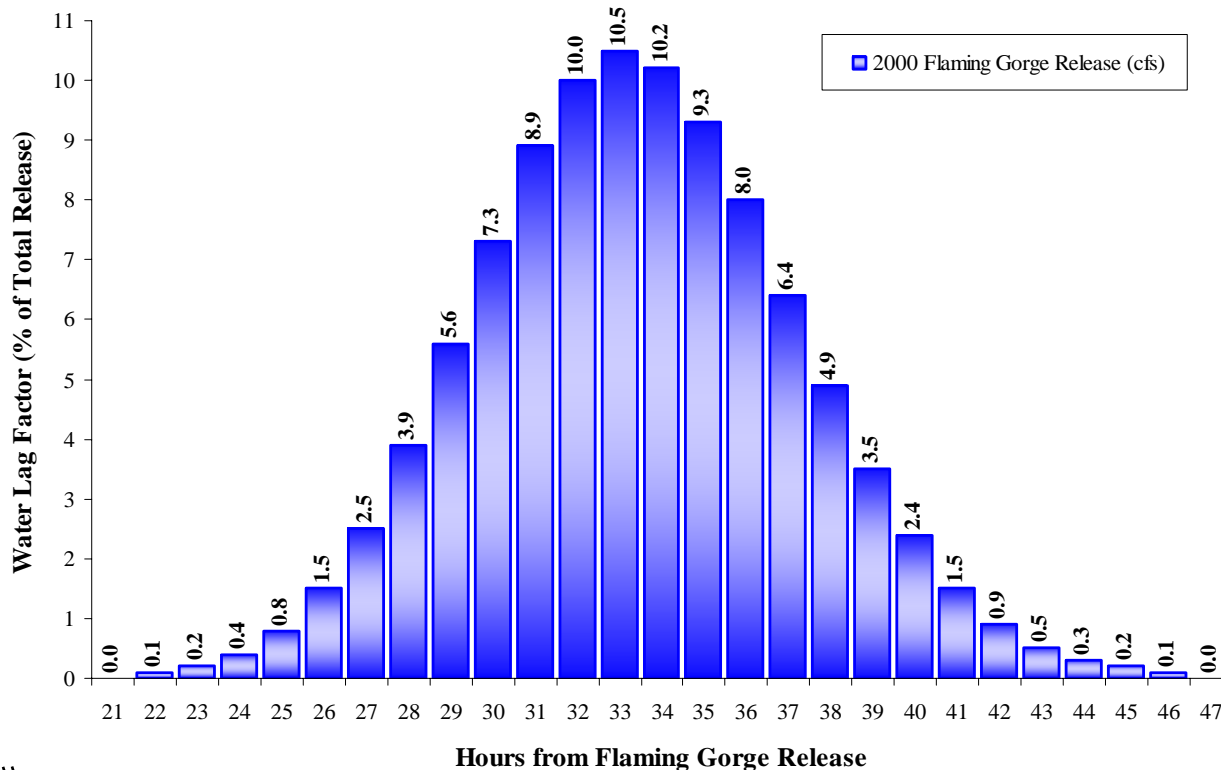


Inflow
Reservoir Factors
Power and Turbines
Outflow

The Hydrological System Can Be Comprised of Several Different Components

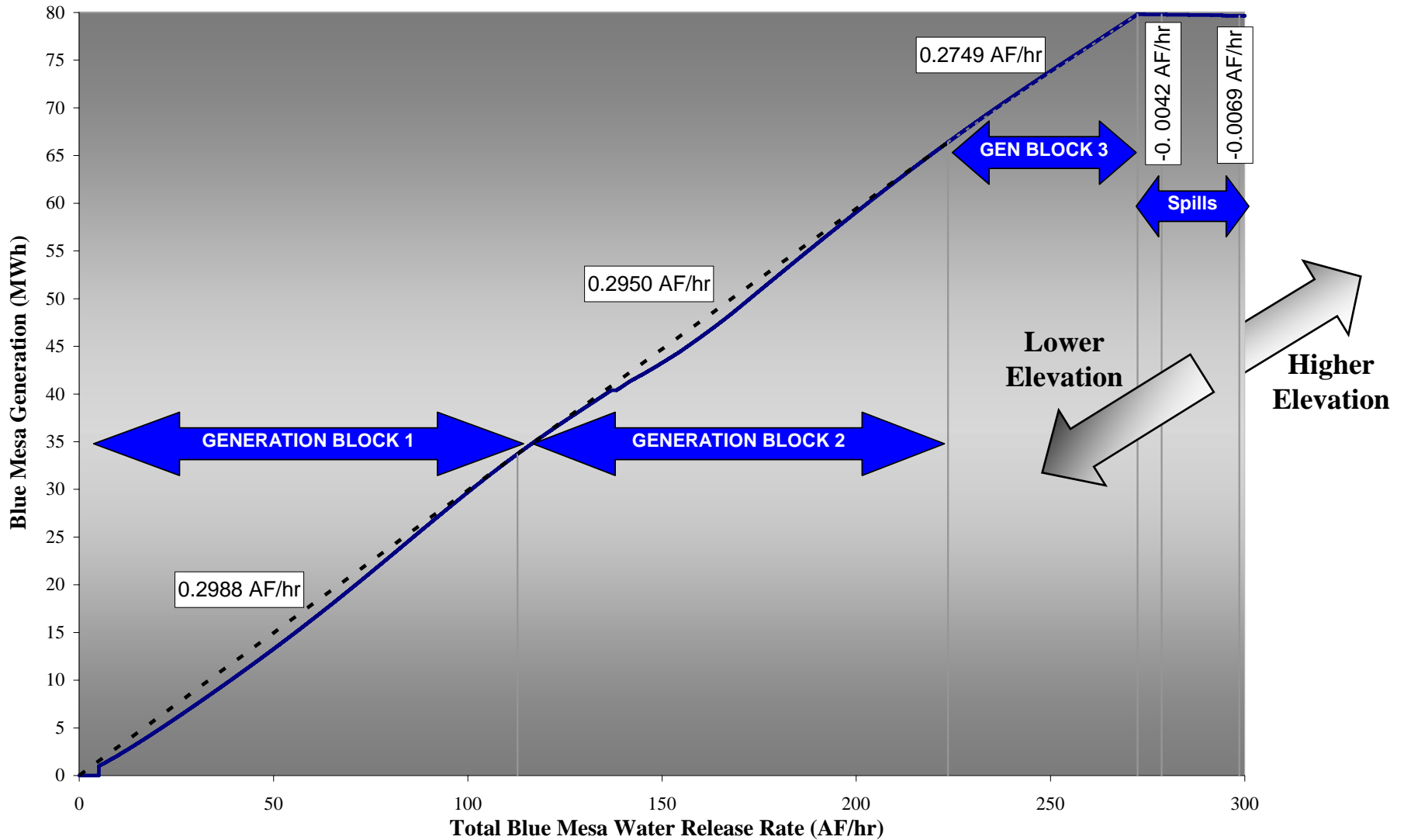


Water Travel-Time Distribution (WTTD)

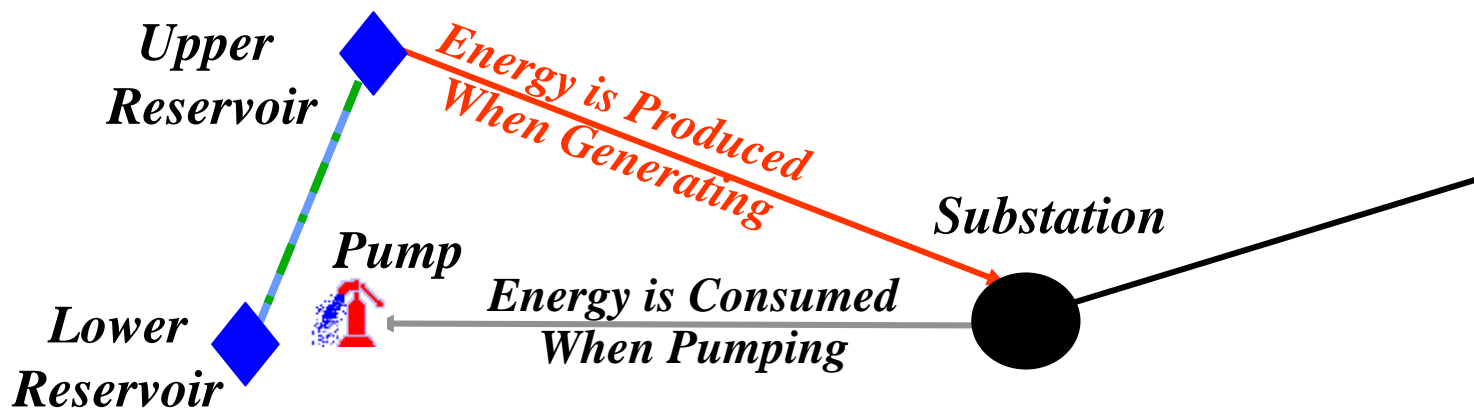


An single hour's upstream release will spread out over time and arrive at a downstream location L over multiple hours as depicted above. A (WTTD) function can accurately estimate channel flow many hours downstream from an initial release.

The Conversion of Falling Water to Power Is a Function of Reservoir Elevation & Turbine Flow Rate



GTMax Simulates Pumped Hydropower Plants



Reservoirs

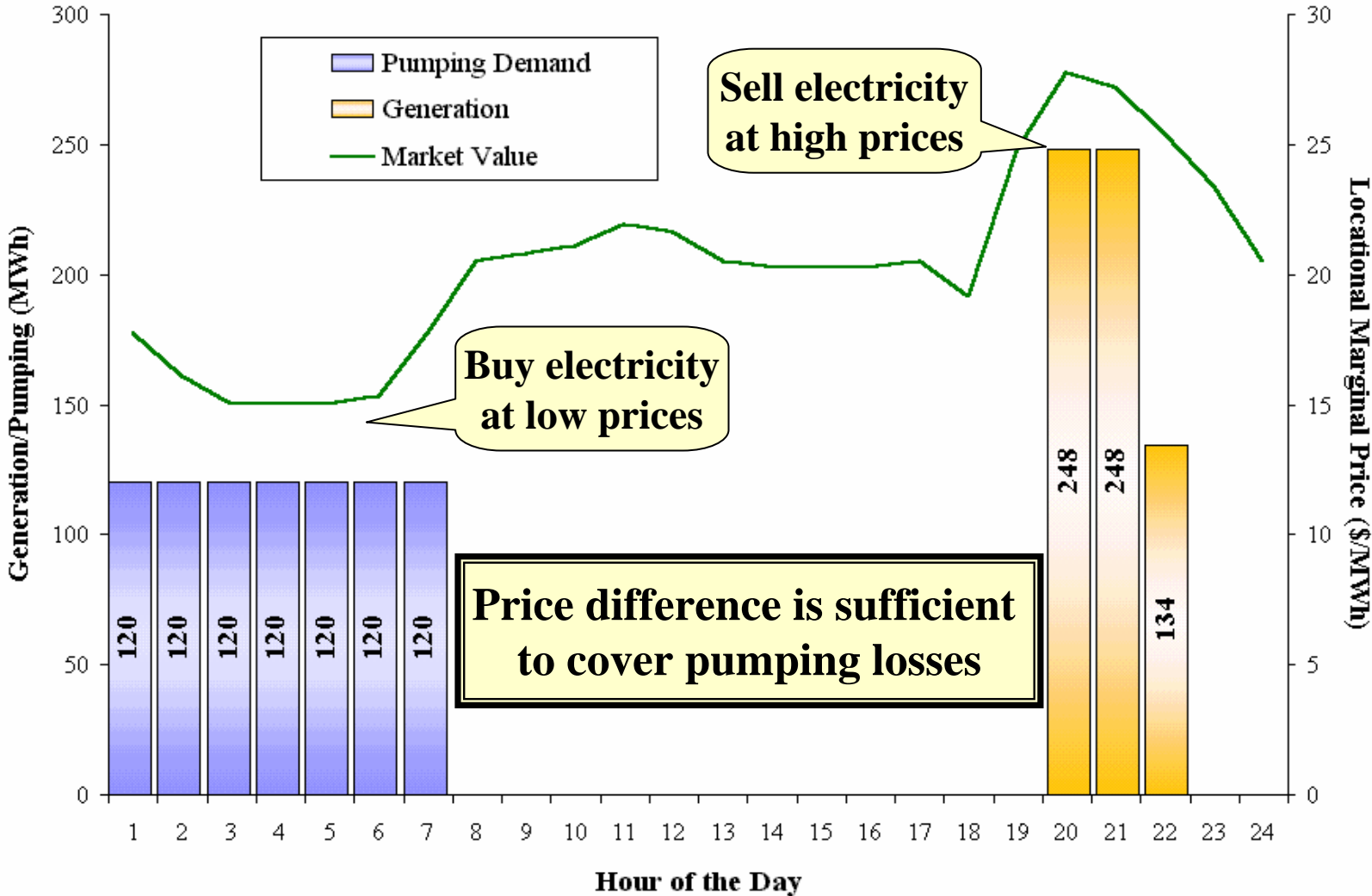
- Initial reservoir elevation
- Maximum reservoir elevation
- Minimum reservoir elevation
- Elevation change per water release
- Power conversion efficiency (upper)
- Generation capability (upper)

Pump



- Maximum pumping rate
- Pumping efficiency

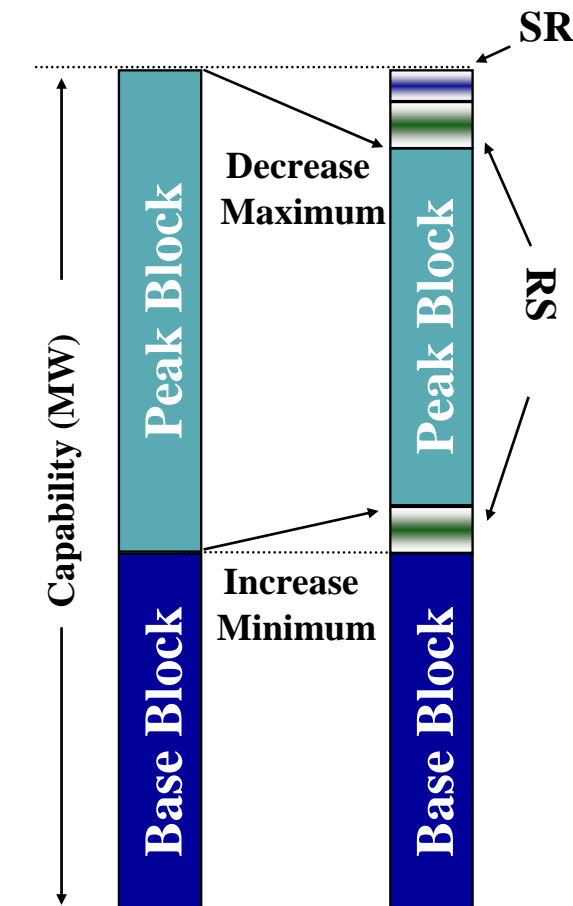
Pumped Storage Operations Are Based on Market Price Signals



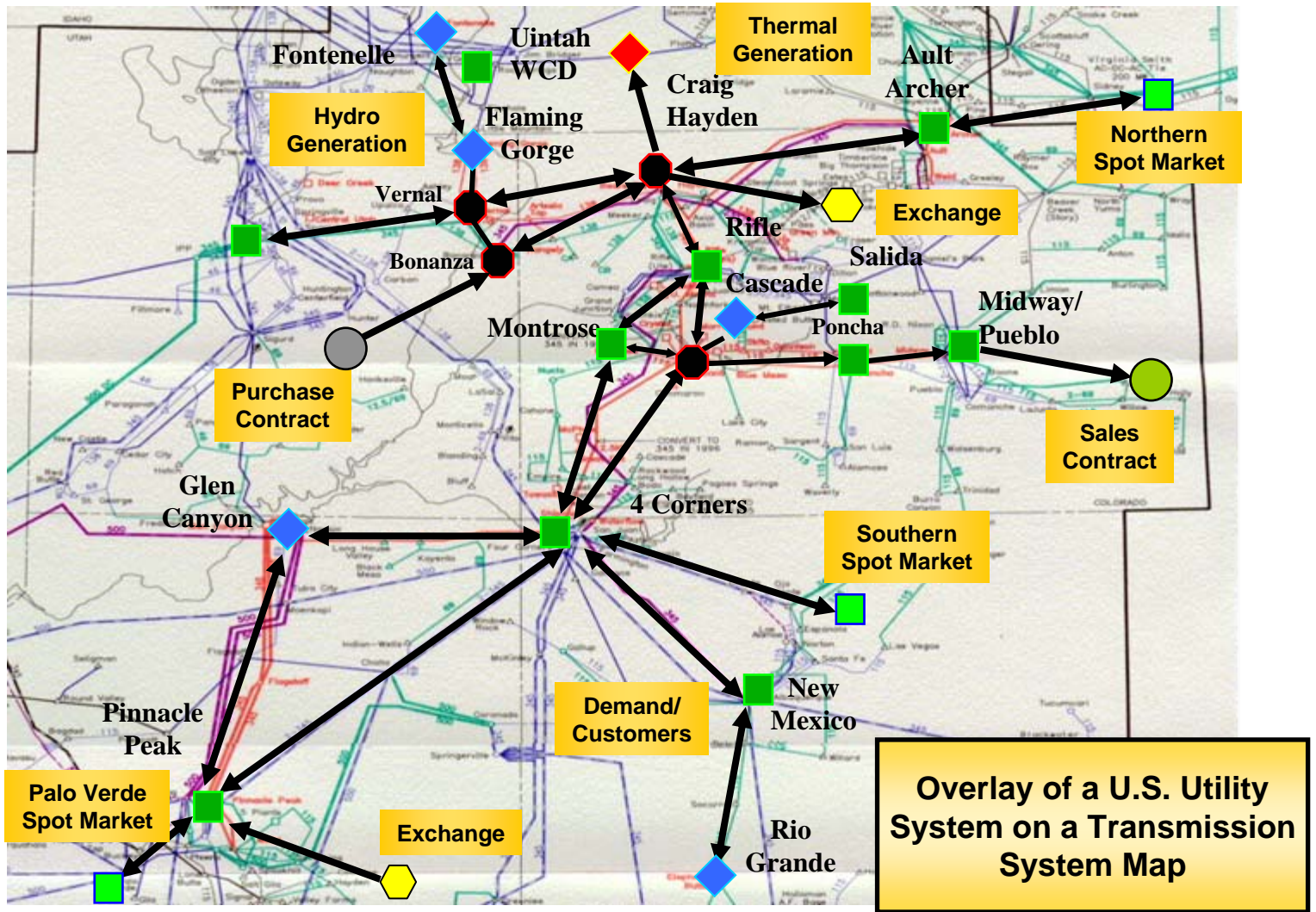
Power Operations Account for System Needs & Security/Reliability



- **Regulation services (RS)**
 - Affects minimum & maximum generation
- **Spinning reserves (SR)**
 - Affects maximum generation
- **Unit commitments**
 - Base block is expensive and its capacity is not needed by the system to meet the demand
- **RS and SR requirements are specified on a regional basis**

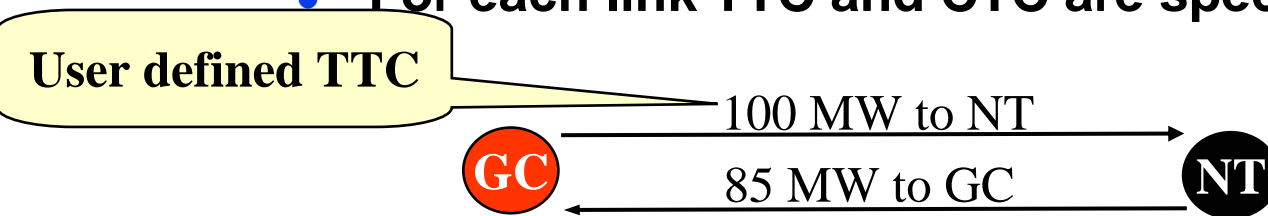


The Transmission System Links Different Types of Activities

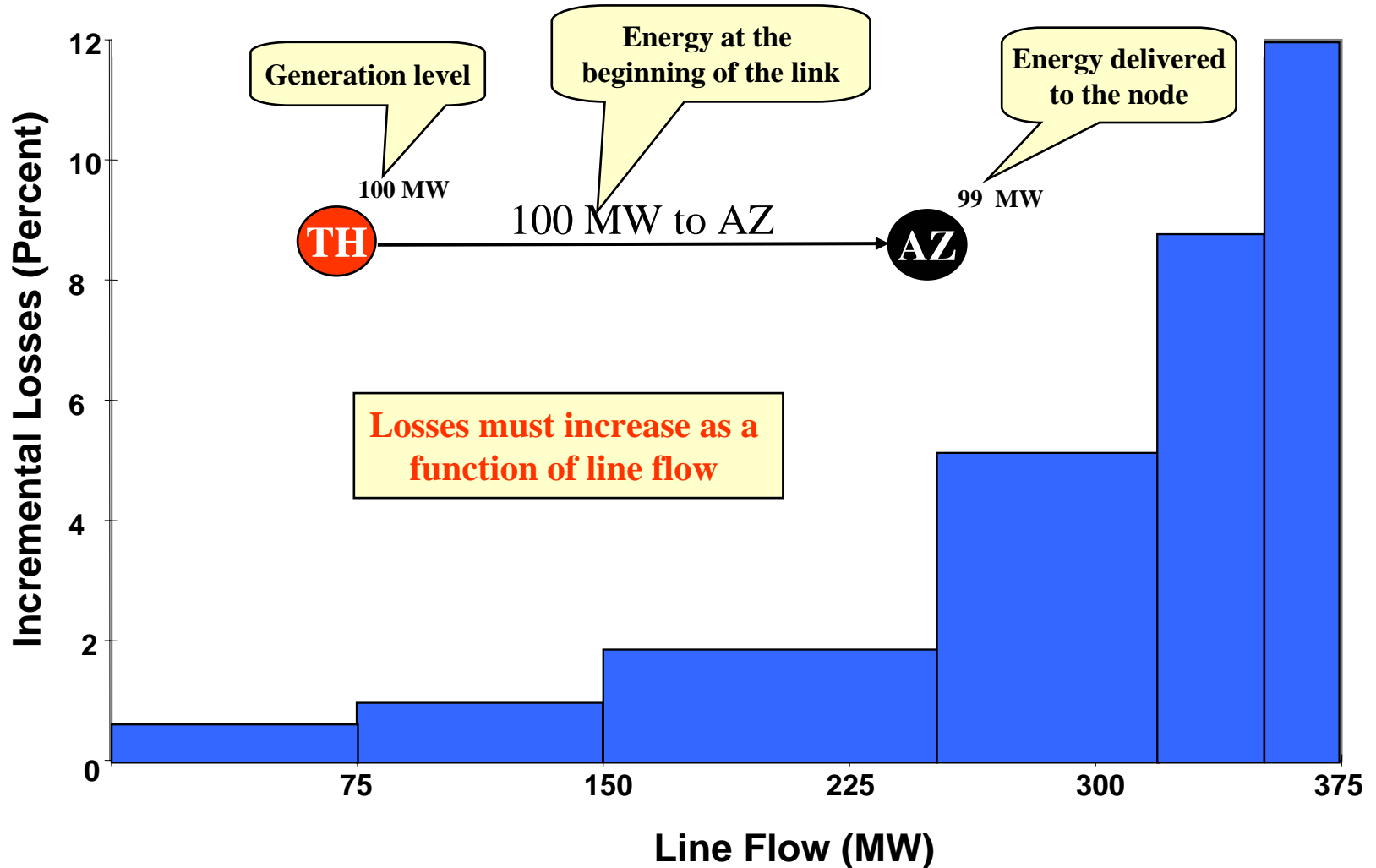


GTMax Transmission System Uses Contractual Power Flows

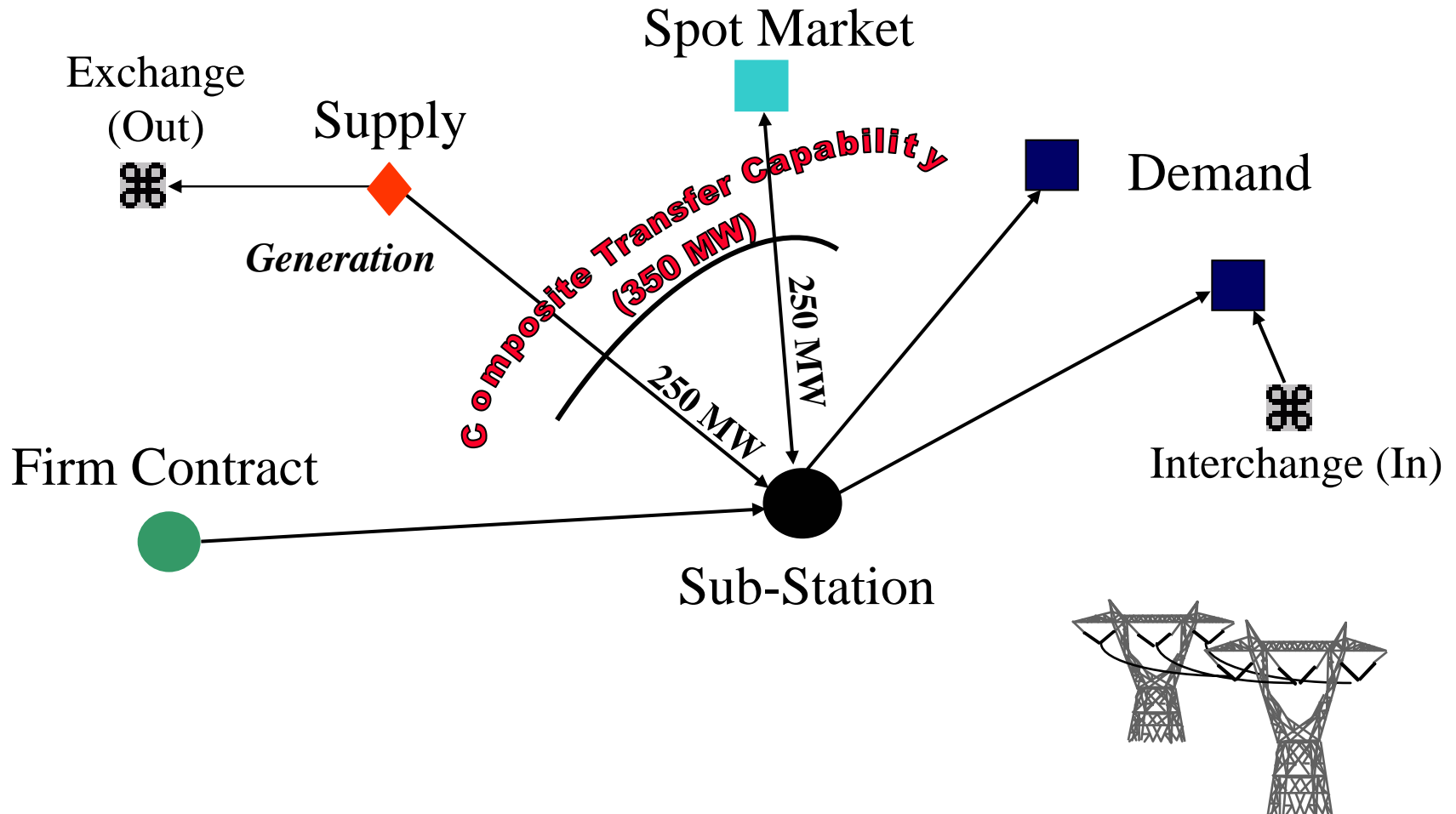
- **Transmission system representation**
 - Link nodes together (i.e., supply and demand)
 - Loss rates are specified as a step function
 - A link represents either single or multiple lines
 - A cost can be specified for line use
- **Link energy flows constraints**
 - Two-directional limits
 - Total Transfer Capability (TTC)
 - Composite Transfer Capabilities (CTC)
- **For each link TTC and CTC are specified hourly**



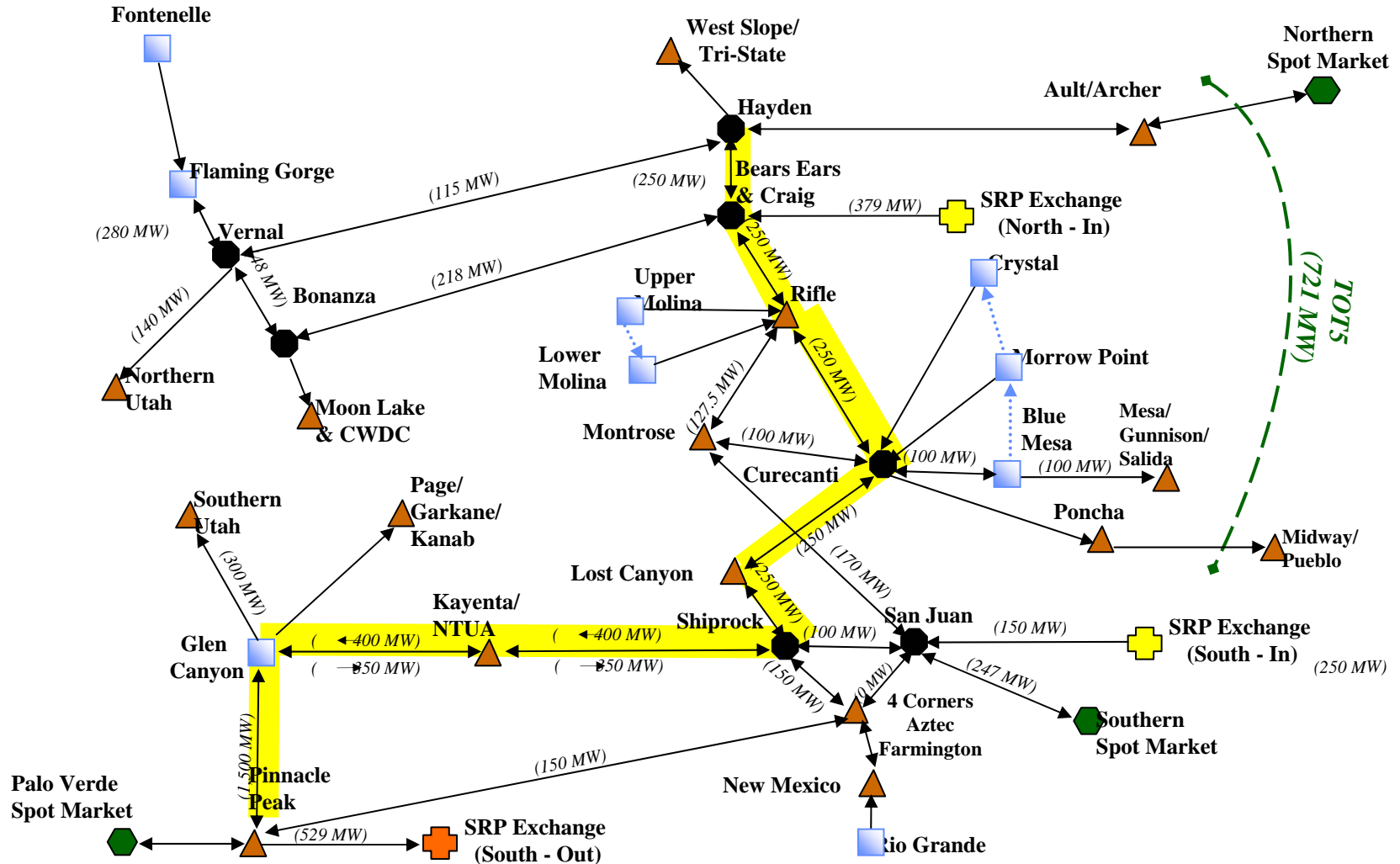
Line Losses Are Specified as a Step Function



Power Flows Are Subject to Composite Transfer Capability (CTC) Limits



GTMax Users Define Both the Path of Firm Transmission Contracts & Hourly Obligations



The DC Power Flow Computes Real Power Flows on Transmission Lines Connecting Two Busses

$$P_{i,j} = \frac{1.0}{x_{i,j}} \times (\theta_i - \theta_j)$$

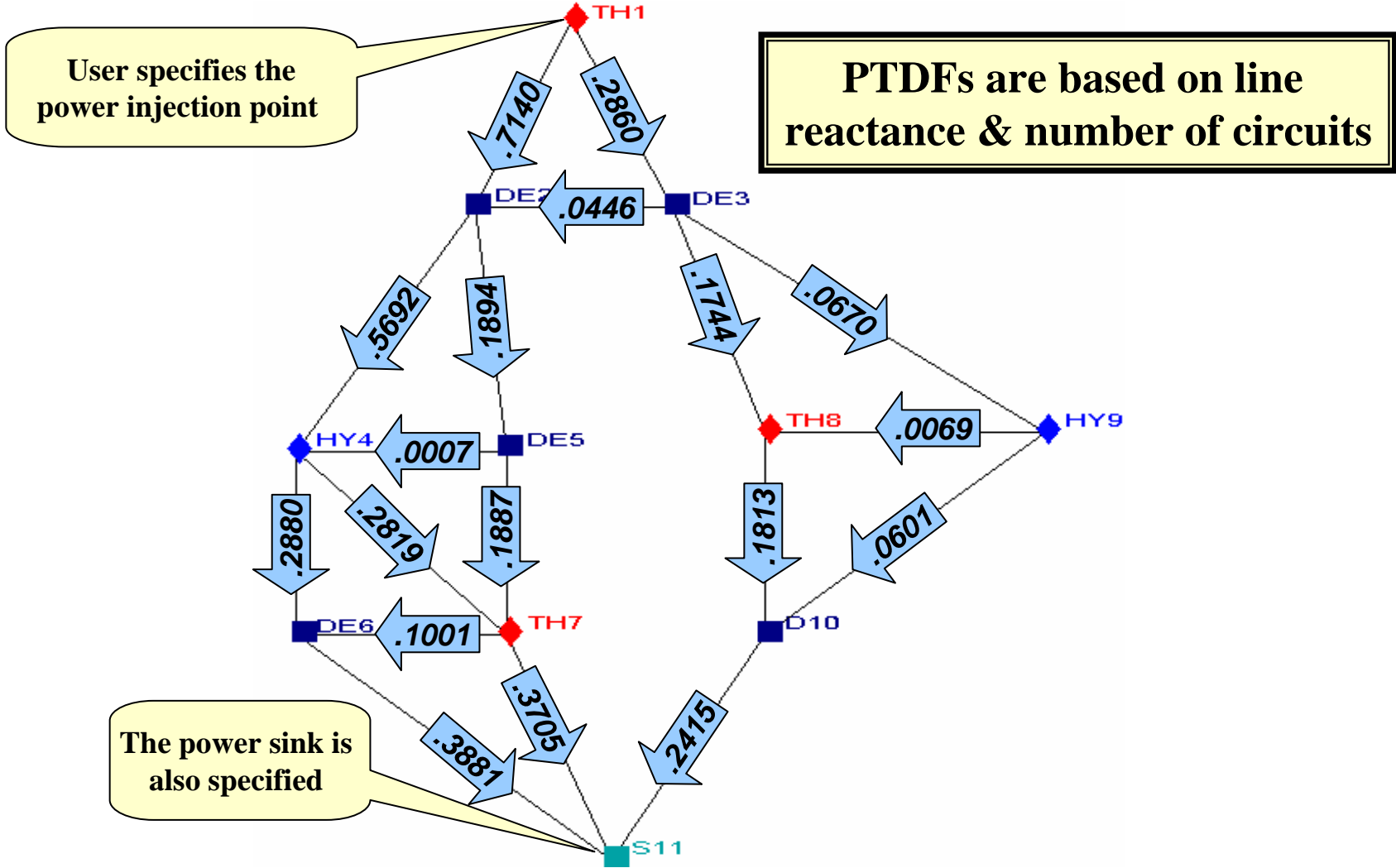
$P_{i,j}$ = Power flow (MW) on a transmission line connecting bus i to bus j

θ_i = Phase angle (radians) at bus i

θ_j = Phase angle (radians) at bus j

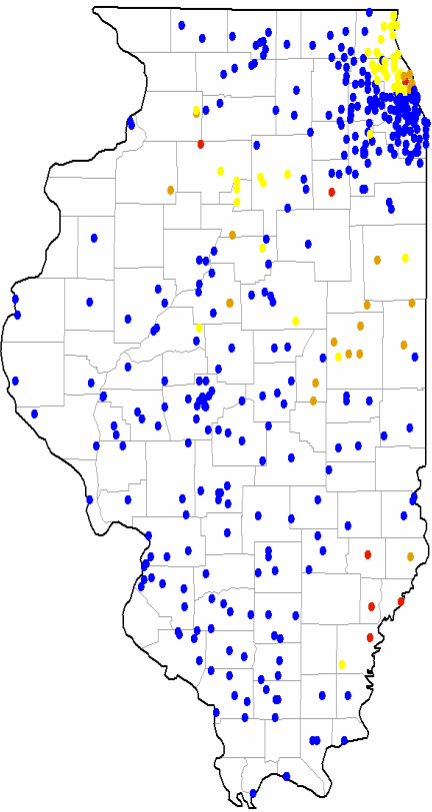
$x_{i,j}$ = Line inductive reactance (MVar) in per units

GTMax Computes and Displays Power Transfer Distribution Factors (PTDFs)

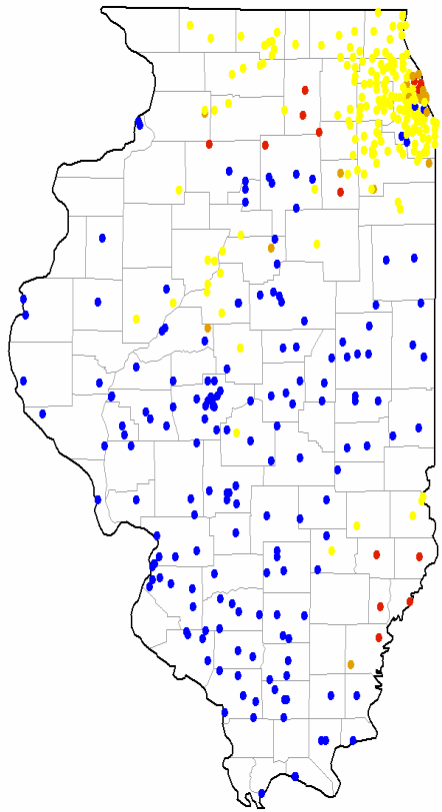


DC Load Flow Calculations Show How The Value of Energy Changes Across Time & Space

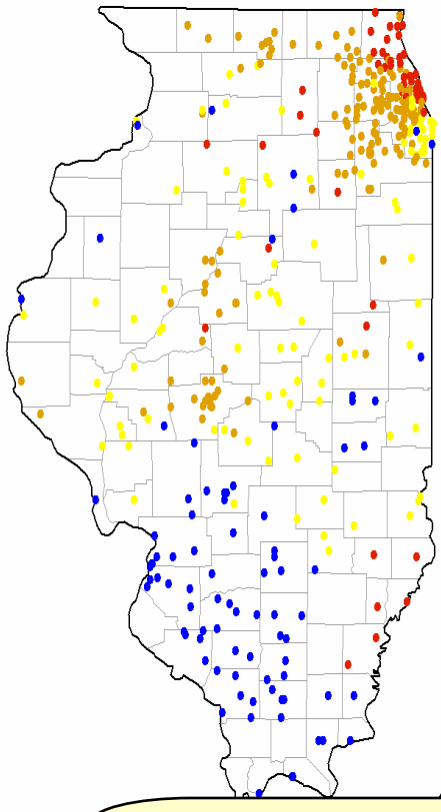
May



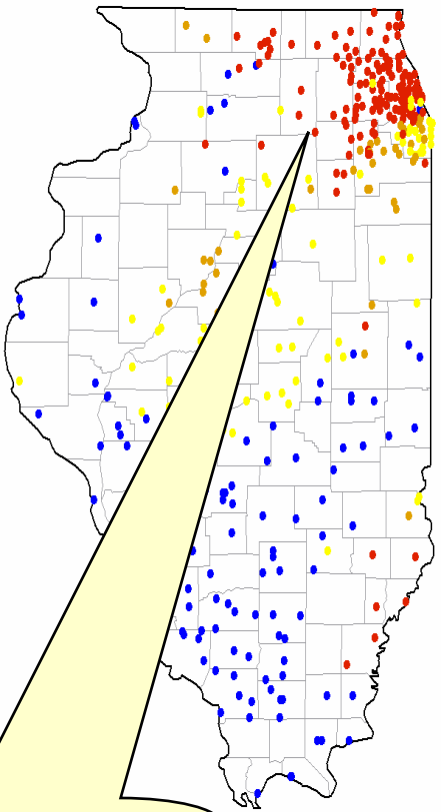
June



July

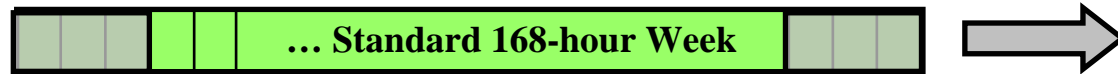


August

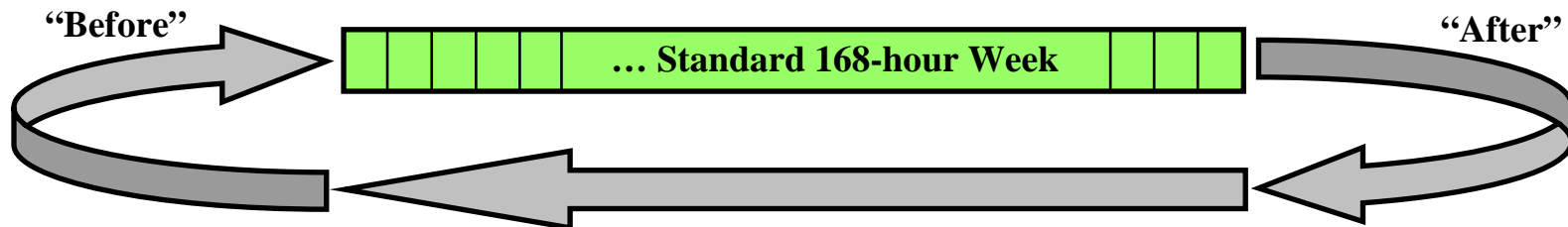


Price Differ Due to Transmission Congestion

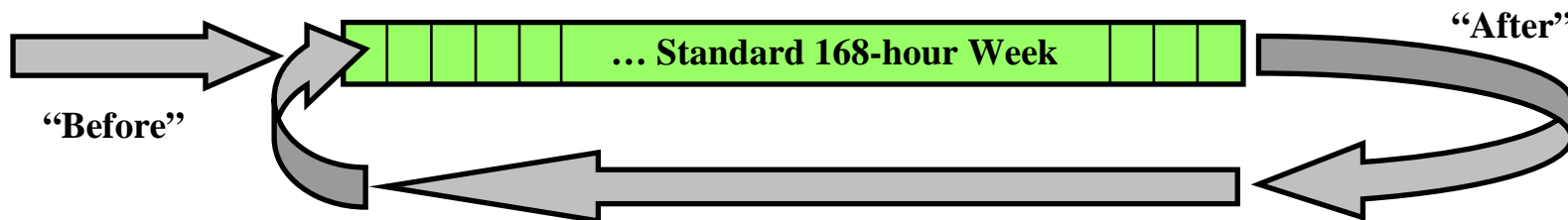
User-Specified Temporal Boundary Conditions



Without attention to temporal boundaries, calculations near the beginning or end of the simulation period (which are based on prior or subsequent time intervals) may be skewed. GTMax has several different options, or *wrap functions*, to automatically address temporal boundary conditions.

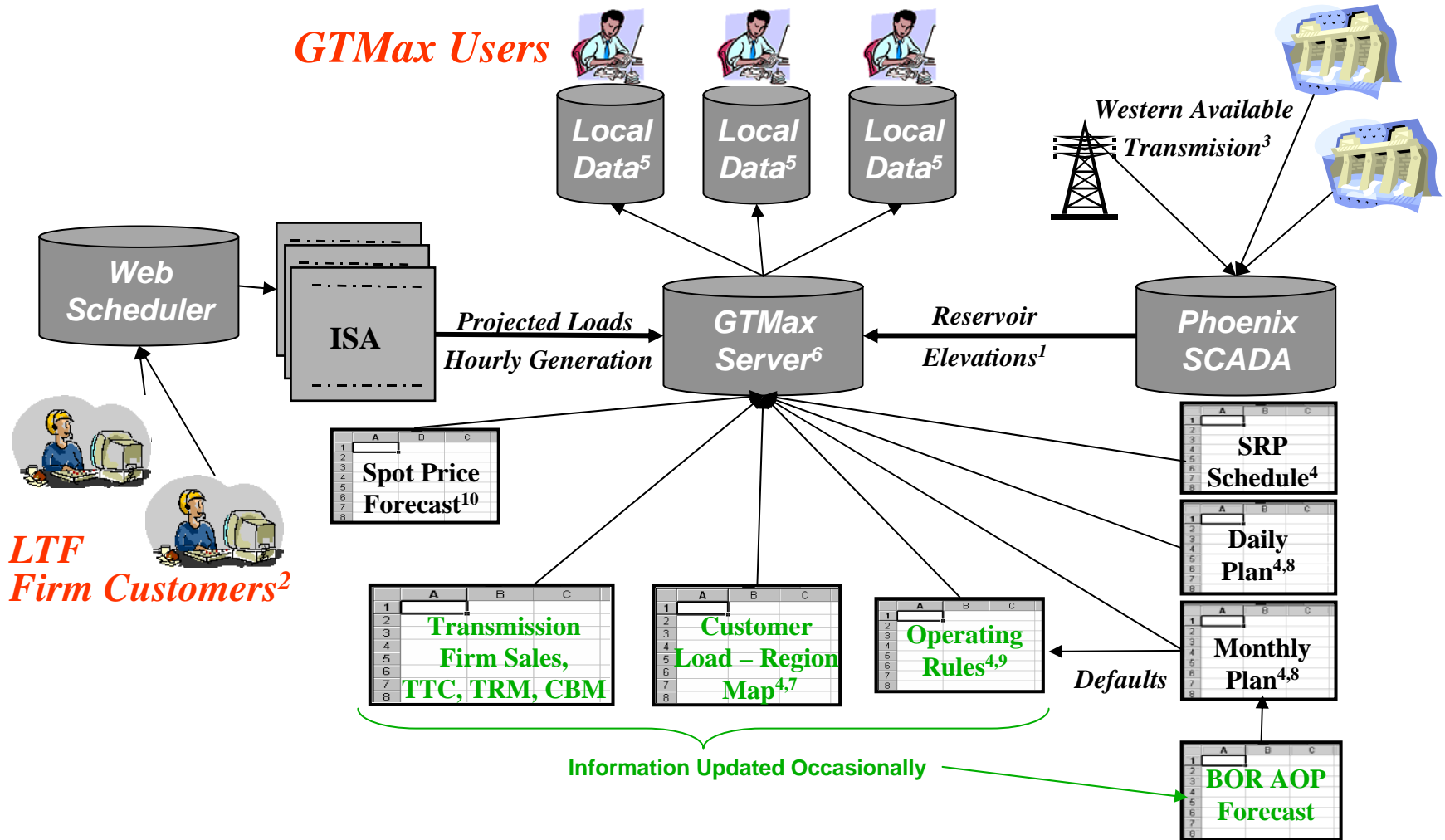


Before and after periods may be based upon extensions of current period's data.



Data for separate "before" and "after" periods may be supplied from external sources, including historical records, simulations, and real-time data feeds.

GTMax Is Currently Being Configured To Interact with Real-Time Data



Summary: GTMax Has Been Used to Analyze the Benefits of Interconnected Systems

- **Estimate the potential for future hourly bulk power transactions among isolated systems**
- **Compute the hourly market clearing price for each region before and after connecting isolated systems**
- **Compute the financial benefits to the buyers and sellers of power**
- **Estimate changes in the operations of power plants in response to regional market agreements**
- **Find best location for new generating resources**
- **Study new transmission lines to strengthen inter-ties**

GTMax Model Overview

Thank You

For additional information, please contact:

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