Accounting for Human Intervention in Streamflow Forecasting

Presentation to HICs Workshop

Silver Spring, MD

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Agenda

- Who are we?
- What do we do?
- What's the issue?
- What's the problem?
- What's the solution?
- What are the next steps?
- Questions – as if these are not enough!

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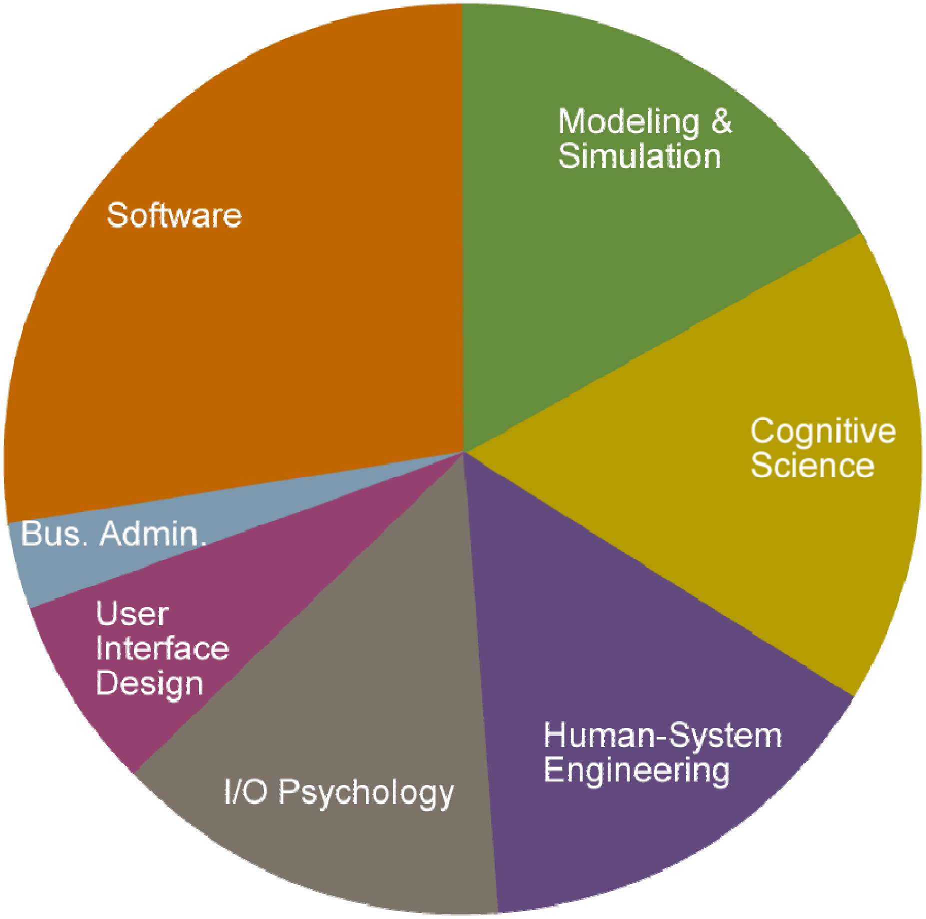
Who are we? Aptima, Inc.

Interdisciplinary Small Business

- 100+ staff (80% graduate degrees)



- Founded in 1995; consistent annual growth (43% CAGR)
- Serving government and commercial clients
- 300+ contracts with the DoD
- Offices
  - Woburn, MA, (HQ)
  - Washington, DC
  - Dayton, OH
  - Ft Walton Beach, FL

What's the issue? Streamflow Forecasting

- NWS is responsible for providing weather, hydrologic, and climate forecasts and warnings
  - provides web-based Advanced Hydrologic Prediction Services (AHPS) through 13 regionally-based River Forecast Centers
  - AHPS uses computer models that simulate river flow, rainfall, etc. to generate predictions and these are conveyed to users
- Predictions are filled with uncertainty, which is difficult to convey
  - **Human behavior**, which directly impacts the water levels and flood conditions, remains one of the chief sources of uncertainty in hydrology forecasts
- Current models do not explicitly account for behavior of the humans in the loop (forecasters, WRMs)
  - River regulation complicates streamflow forecasting due to lack of human influences

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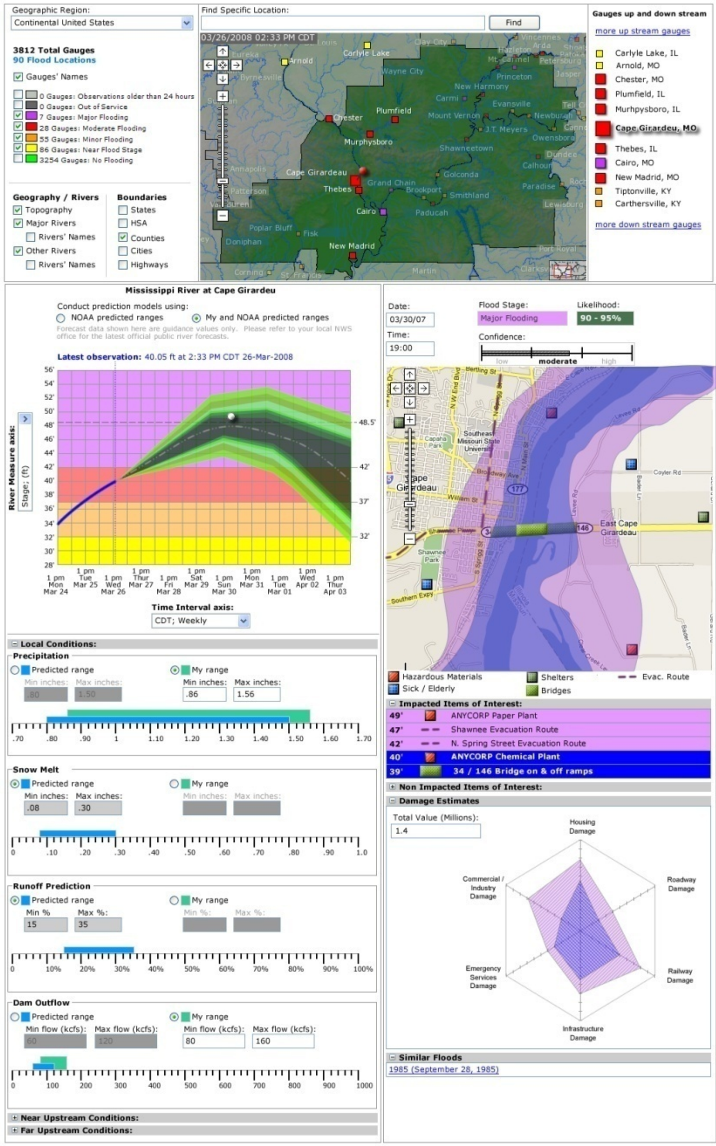
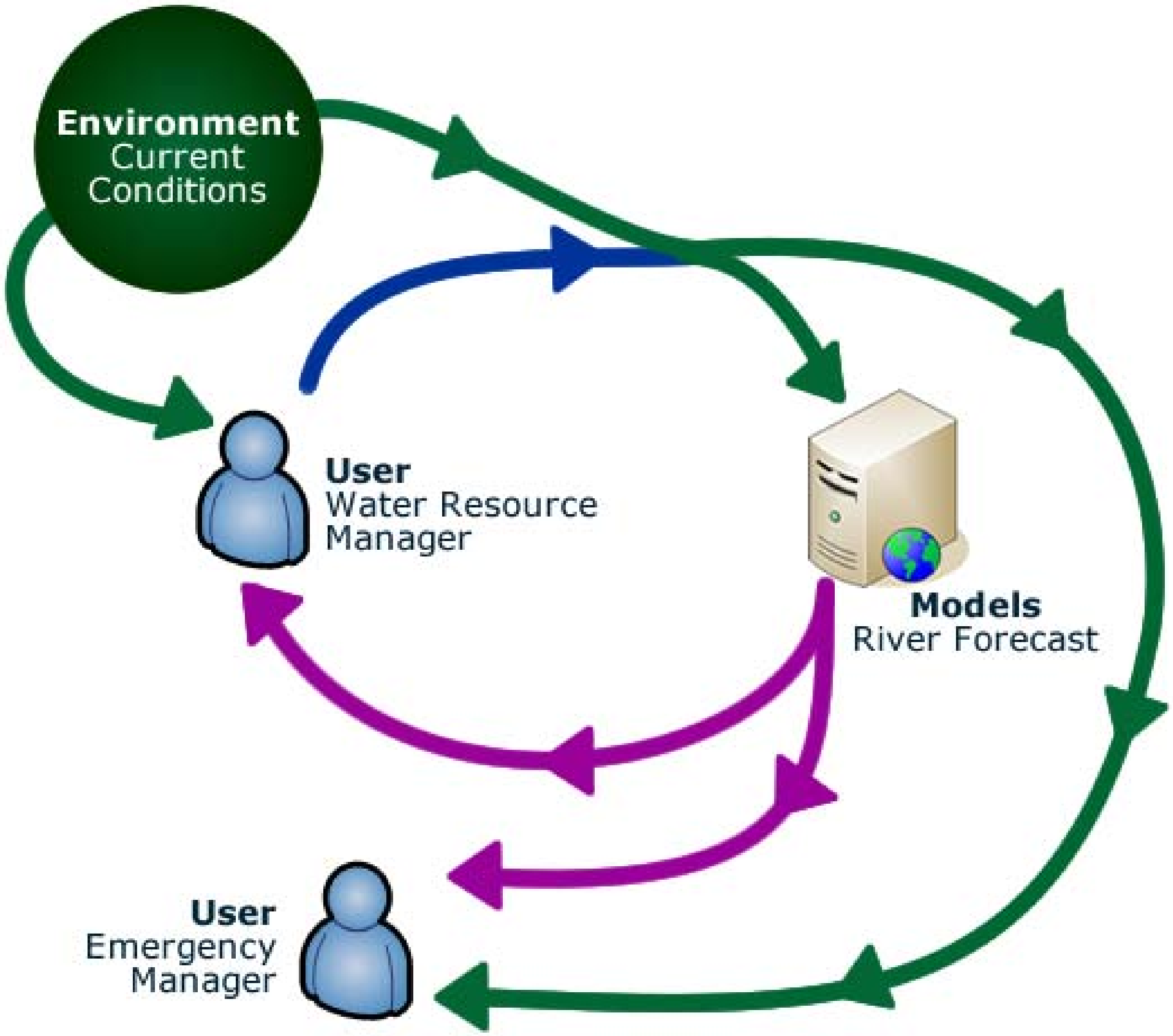
Visual Display Design

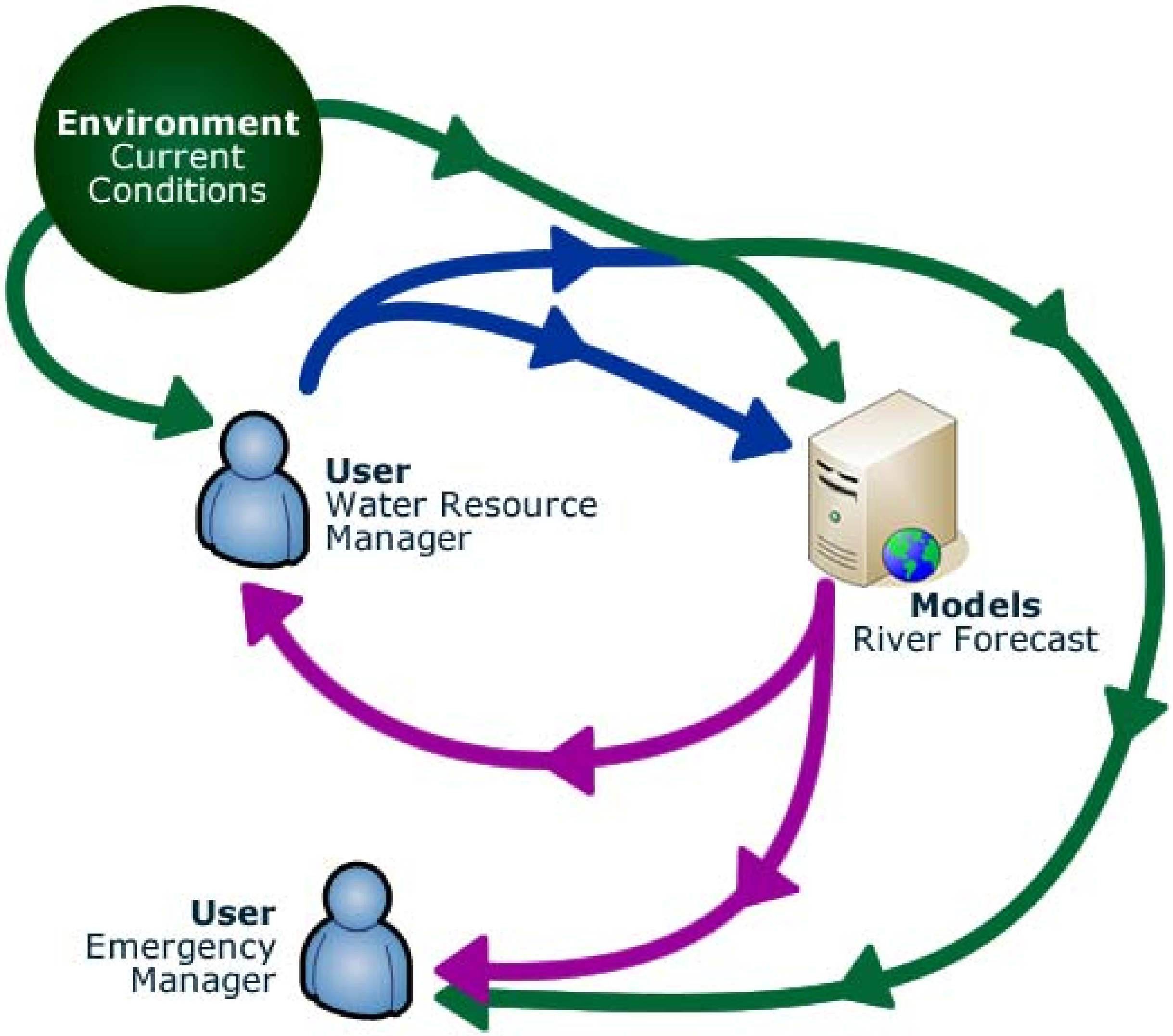


- Support EMs' decision making regarding courses of action.
  - Visualizations of river forecasts with *uncertainty*
  - Visualizations of "impact" of various flooding scenarios
- Visualization of *uncertainty model* inputs for clear understanding of "why" predictions are what they are.
- Allow for local knowledge to be incorporated into predictions
- Fusion / organization of information for clear understanding of relationship to one another and enhanced orientation.

What's the problem?



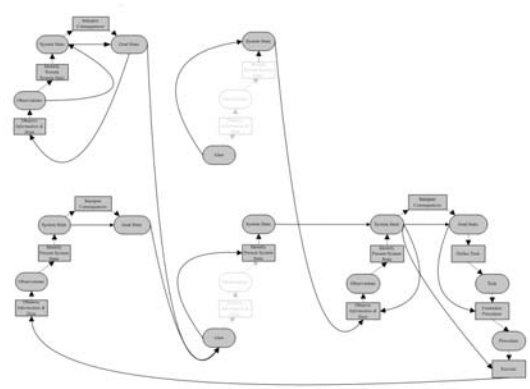
What's the solution?



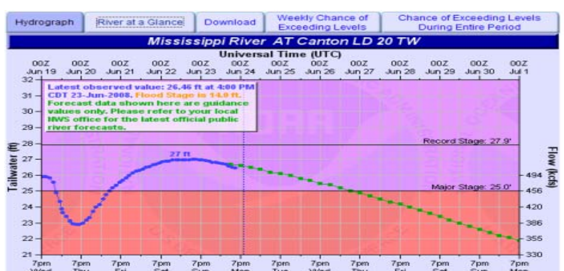
Objectives

Understand Influences and Actions of Water Resource Managers

Develop Models which Account for Human Behavior



Link Hydrology Forecasts To Human Models



Incorporate Human Behavior Forecasts Into Hydrology Predictions

What do we do?
Human–Centered Engineering

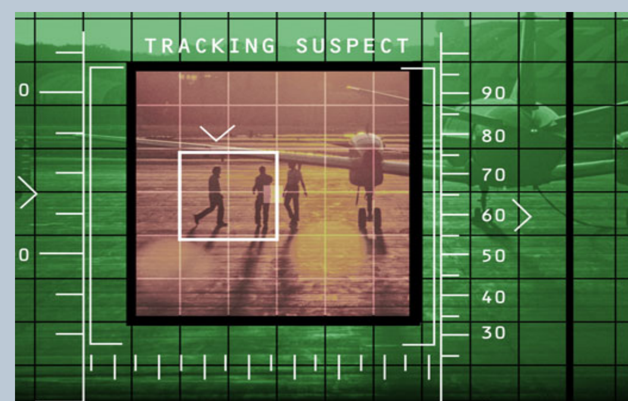
Social & Organizational Structures

Technology Capabilities

Congruence
or ...
Disruption

Human Agents

Mission, Tasks & Work Processes

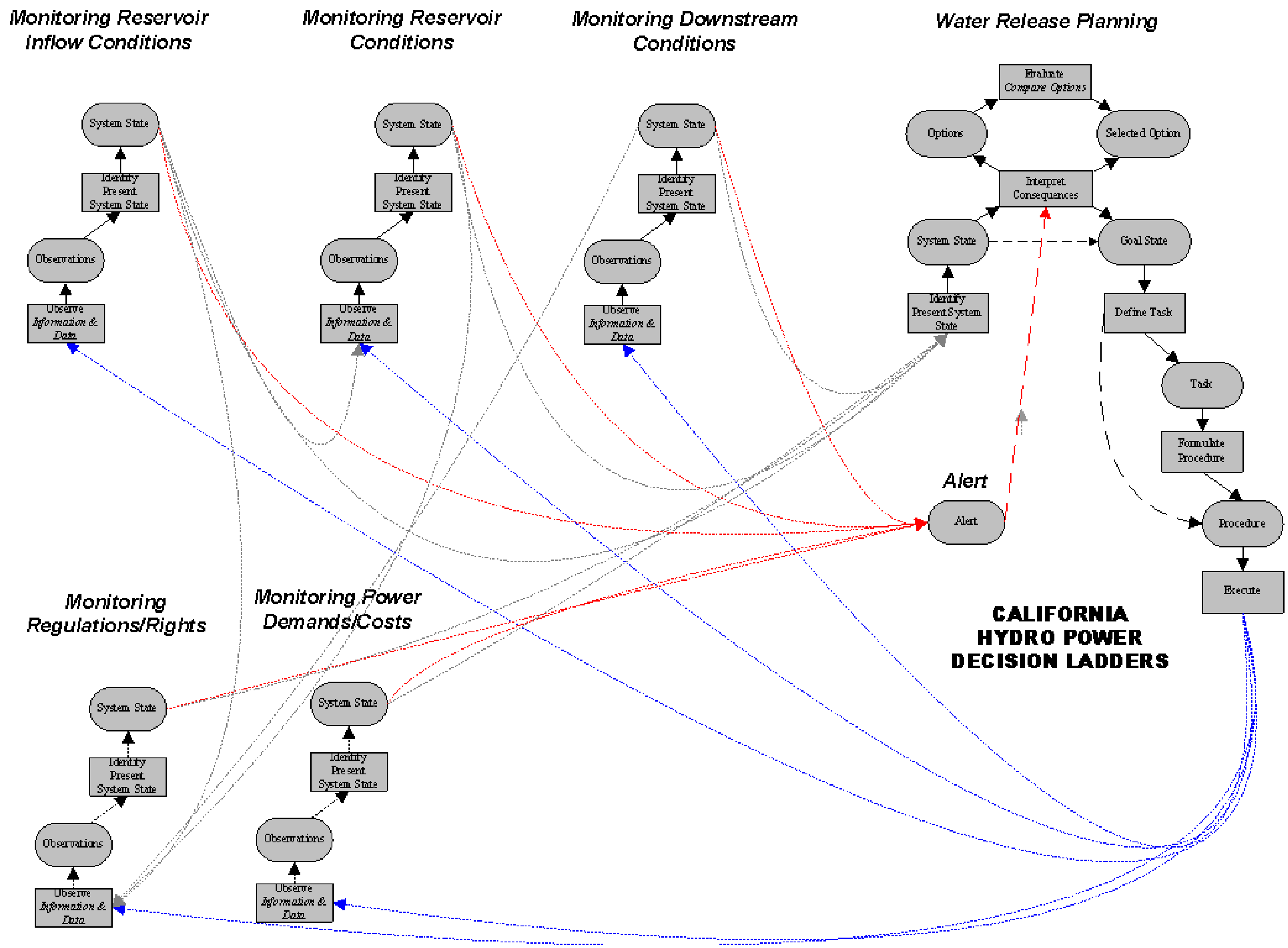


SME Interviews

- Northeast RFC – Taunton, MA
- Development and Operations Hydrologists (DOH Workshop in SS)
- US Army Corps of Engineers – Reservoir Control
- First Light Power Resources – New Milford, CT
- California-Nevada RFC – Sacramento, CA
  - NWS, USACE, SMUD, PG&E, SFWATER, USBR, CA Water

[Decision Ladders]

Decision Ladder Structure



Decision Ladder Details

Monitoring Regulations/Rights

Task Description	Ladder Code	Role	Combination of Information
Observe dam conditions and inputs	3 Observe information and data	Hydropower Water Resource Manager	**REGULATION** Amounts can divert and hold for storage over time, Seasonal restrictions on reservoir levels (e.g. level for docks/recreation, weed control, etc), Seasonal restrictions on reservoir releases (e.g. white water rafting, weed control, etc), Seasonal quality regulations (salinity, turbidity, temperature), current season, downstream water rights (amounts/quality), downstream water contracts (amounts/quality), requests made from downstream right owners, types of downstream water rights (i.e. junior, senior, right to historic conditions, etc.), types of downstream water right users (i.e. agriculture, ranchers, fisheries, etc), water right holders needs (known/predicted), water pumping contracts (ability to pump, amounts that can pump from downstream), "complaints" from water right owners downstream, life (years) of water rights, last time water right exercised (can be lost if not used in 5 years), stringency of regulation ("shale" vs. "try"), regulations on pollutant levels, **CONDITIONS TOWARDS REGULATIONS** Amount diverted and held for storage over time, Time held for storage, Amounts "pumped" from downstream over time, Current reservoir levels, Predicted reservoir levels, Current quality (salinity, turbidity, temperature) conditions downstream, Predicted quality (salinity, turbidity, temperature) conditions downstream, Current quality (salinity, turbidity, temperature) conditions at reservoir, Predicted quality (salinity, turbidity, temperature) conditions at reservoir releases (amounts/timeframe) downstream, planned releases (amounts/timeframe) downstream, Additional predicted stream inputs downstream (amounts/timeframe), water right holders impacted by "pumping", water right holders impacted by "diversions", water right holders impacted by "storage", last time water right exercised (can be lost if not used in 5 years), pollutant levels in reservoir/releases,
Perception dam conditions and inputs	4 Observations	Hydropower Water Resource Manager	**REGULATION** Amounts can divert and hold for storage over time, Seasonal restrictions on reservoir levels (e.g. level for docks/recreation, weed control, etc), Seasonal restrictions on reservoir releases (e.g. white water rafting, weed control, etc), Seasonal quality regulations (salinity, turbidity, temperature), current season, downstream water rights (amounts/quality), downstream water contracts (amounts/quality), requests made from downstream right owners, types of downstream water rights (i.e. junior, senior, right to historic conditions, etc.), types of downstream water right users (i.e. agriculture, ranchers, fisheries, etc), water right holders needs (known/predicted), water pumping contracts (ability to pump, amounts that can pump from downstream), "complaints" from water right owners downstream, life (years) of water rights, last time water right exercised (can be lost if not used in 5 years), stringency of regulation ("shale" vs. "try"), **CONDITIONS TOWARDS REGULATIONS**

Decision Ladder Details

Planning			
Task Description	**Ladder Code**	**Role**	**Combination of Information**
Integrate system states from monitoring activities to obtain "patters"	5 Indentify System State *(System here is the full river system)*	Hydropower Water Resource Manager	**SUBSYSTEMS** System state of *Reservoir Inflow Conditions* System state of *Reservoir Conditions* System state of *Operational Conditions* System state of *Downstream Conditions* System state of *Regulations and Rights* System state of *Power Demands/Costs*
Comprehend **current state of *river/power* system** (inclusive of	6	Hydropower Water Resource	Trends of power demands over time, Trends in power prices over time, Optimal times in 24 hour period for generating power, Optimal times "long term" for generating power
Evaluate and compare options	9 Evaluate and compare options	Hydropower Water Resource Manager	**Release** (e.g. ability to make immediate profit, ability to come in lines with downstream regulation/rights, ability to come in lines with downstream recreational regulations/rights, ability to bring reservoir in lines with goal levels when over goal height, ability to bring dam in lines with integrity limits when above limits, ability to accept anticipated inputs, ability to reduce height of river upstream and have associated impacts on quality variables upstream, ability to change quality levels at reservoir by reducing water, ability to generate power that is in lines with power demands) vs. **Storing water** (e.g. ability to provide long term power generation during peak seasons, ability to come in lines with regulations at reservoir when under regulation heights or storing will impact quality in appropriate manner, ability to bring reservoir in lines with goal levels when under goal height, ability to continue to provide power/profit if anticipated inputs do not come to fruition, reduce flooding downstream that may already be occurring, ability to increase height of river upstream and have associated impacts on quality variables upstream, ability to change quality levels at reservoir by reducing water, operate within "ancillary" market, maintain minimum levels needed for generating power, wait to produce power when profit out ways cost) **Spill** (schedule maintenance to optimize power generation capability long term, working within "ancillary" market, movement of water to downstream power generation houses while in "ancillary" market, minimize impact to downstream area that is already high) vs. **Release** (produce power at reduced efficiency to reduce spill, produce power when no other power houses can use water if spilled, work outside "ancillary" market, push more water downstream when able to take it). **Achieve Regulation** (meet stringent regulation that has large fine associated to it) vs. **Breach Regulation** (go against a regulation that is not stringent, does not have a heavy penalty, can easily be rectified later). **Produce Power** (generate profit when cost effective) vs. **Purchase Power/Produce**

[Model]

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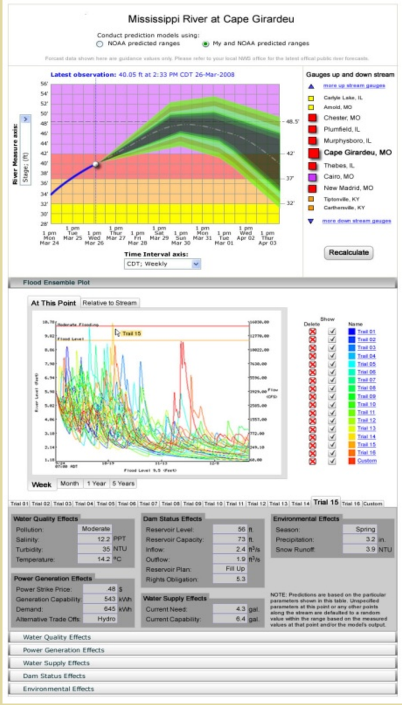
Model Approach

Data
- Environmental
- Human

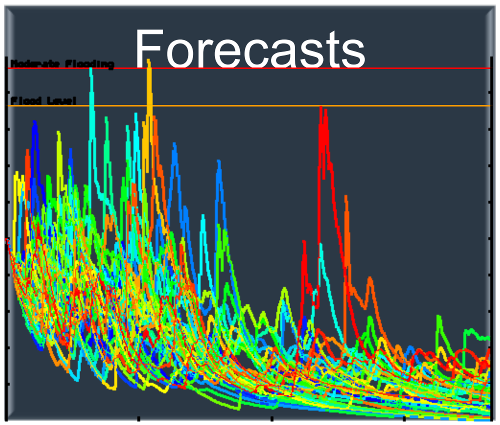
Human Model
- Finite State Automata
- Bayesian Inference

Visualization

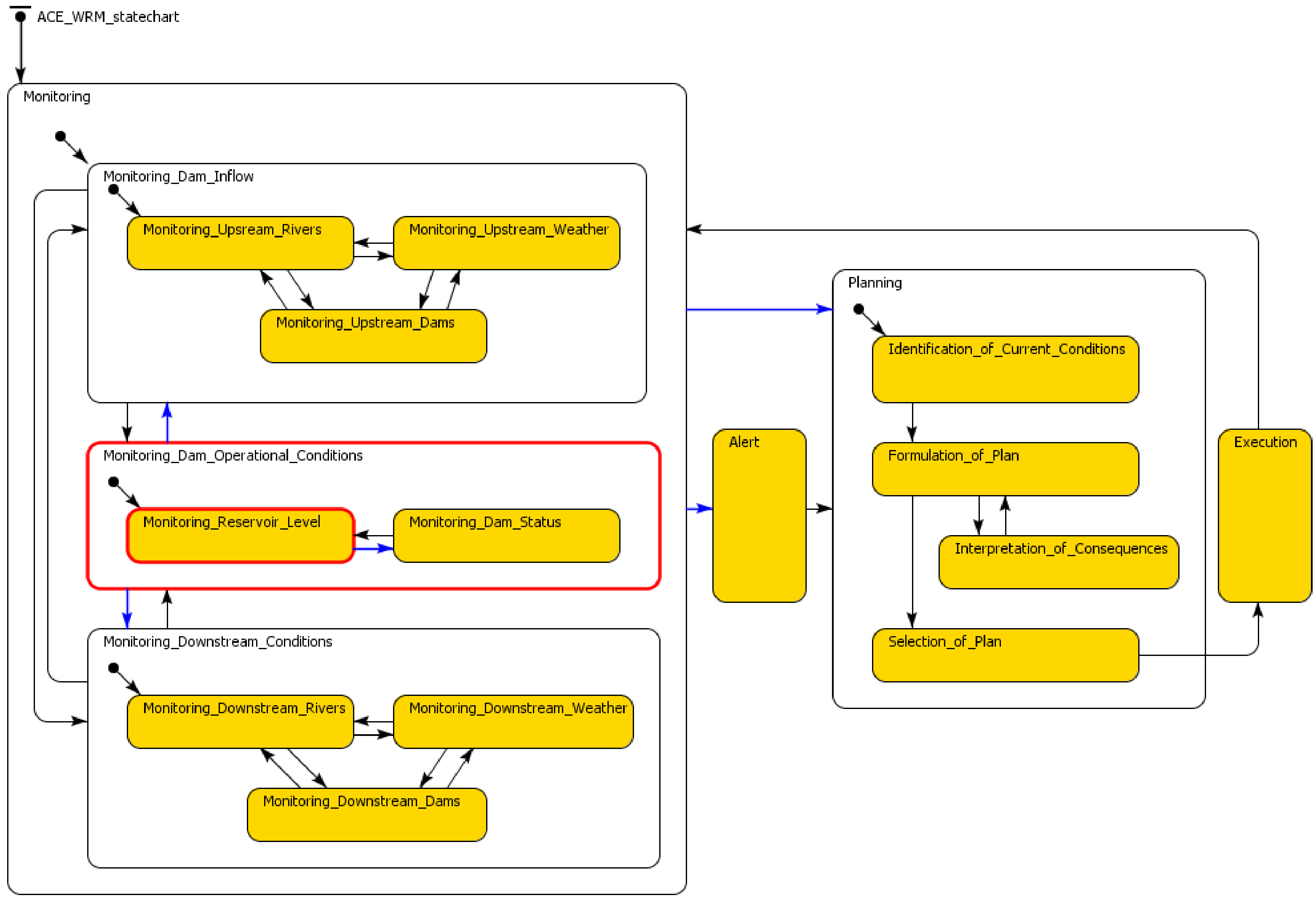


Hydro Models

Forecasts



Initial Model: Finite State Automata



Bayesian Model

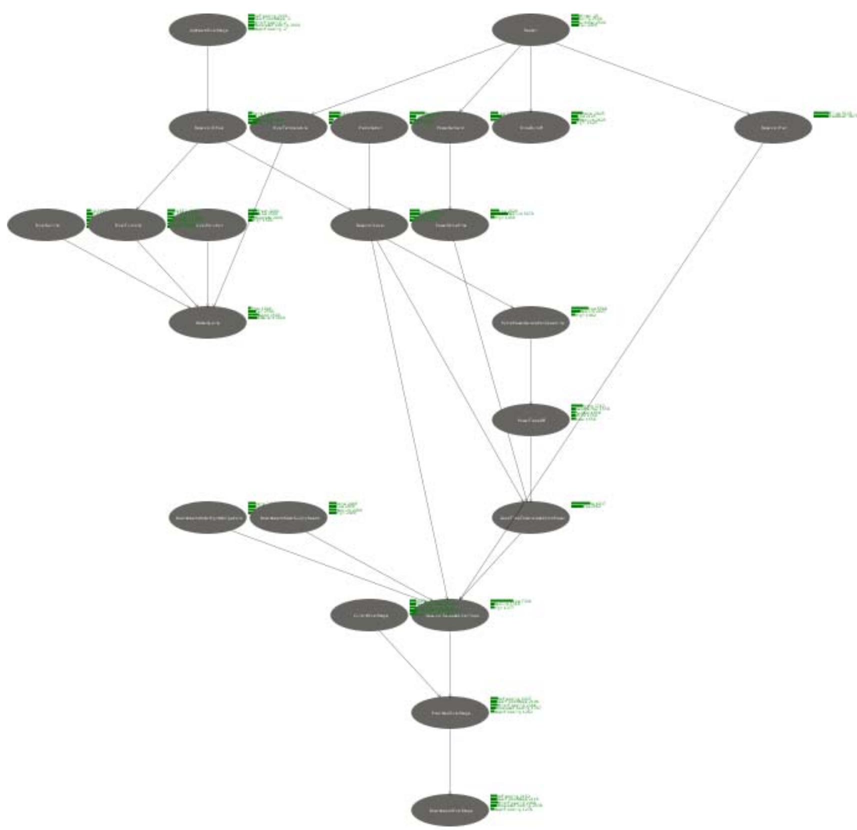
- Representation of information and influences
- A Bayesian Network is a directed acyclic graph with an associated set of random variables

$$B = (V, E) \qquad \{X_v\}_{v \in V}$$

- Joint probability distribution

$$P(X_1 = x_1, \ldots, X_n = x_n) = \prod P(X_i = x_i \mid X_j = x_j, j \in \mathrm{pa}(i))$$

- We use the Bayesian Network to calculate the likely actions based on the observed information



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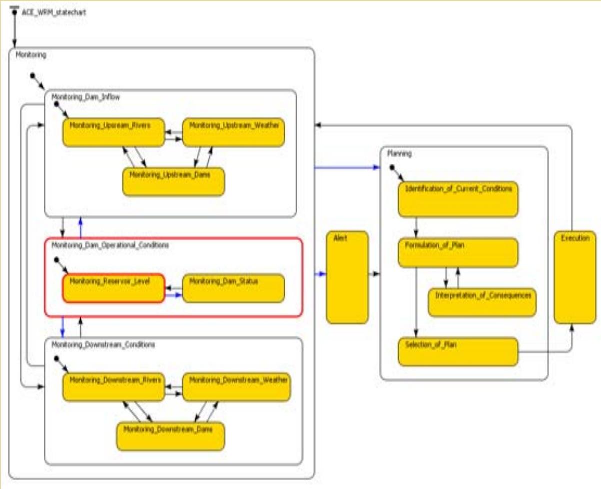
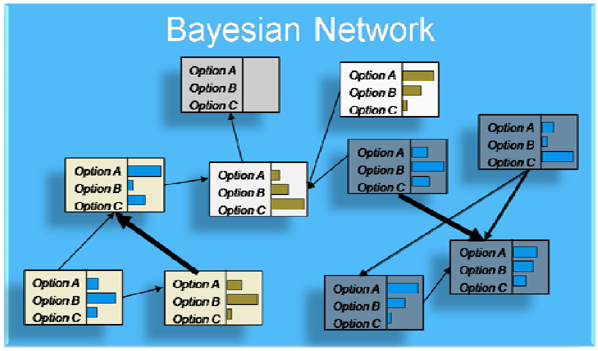
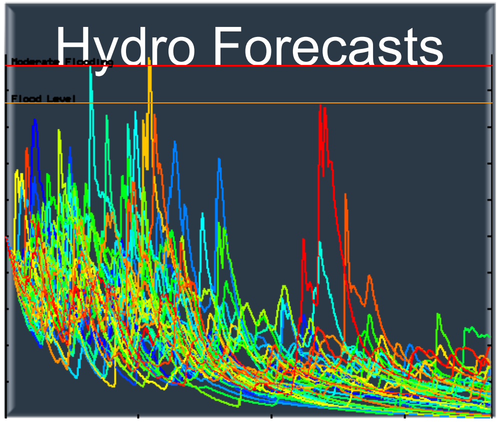
Integrated Model

Finite State Automata based on Decision Ladders



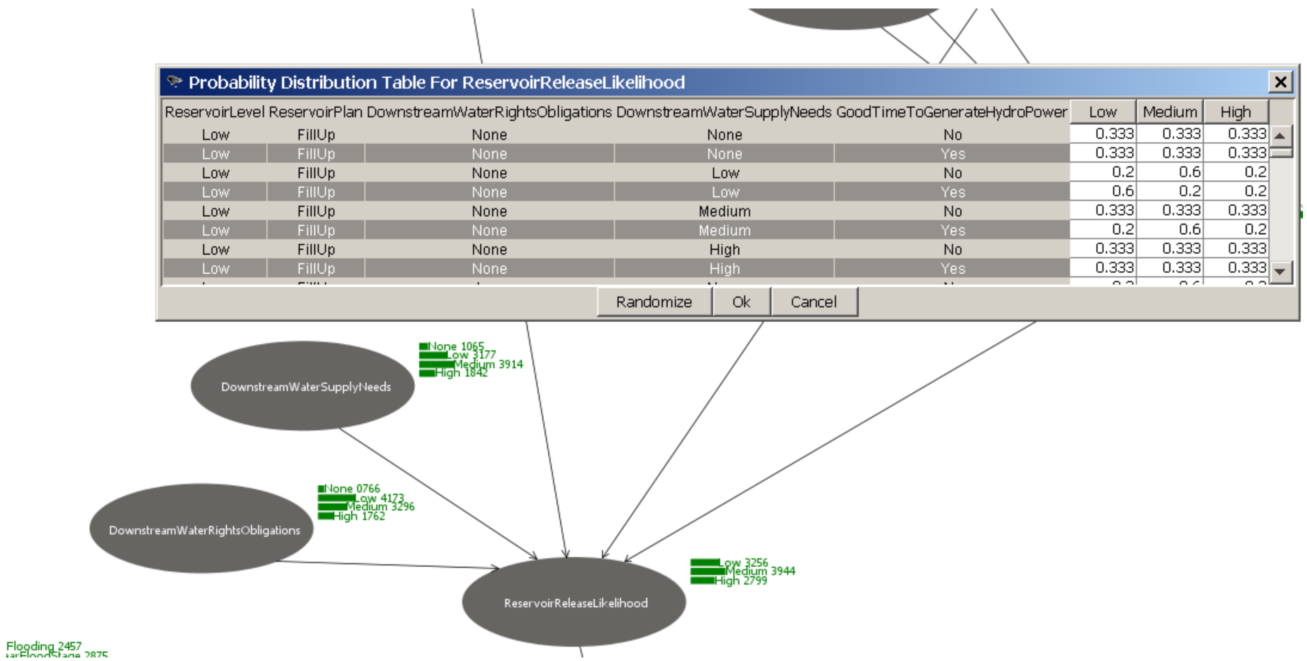
- Prune Nodes
- Adjust Conditional Probabilities
- Insert Known Prior Distributions





“Adversarial” Modeling

- How do we model the actions of “non-cooperative” water resource managers, i.e., those individuals who don’t share their operational plans, schedules, etc.?
- The Bayesian model can learn the conditional probability distributions based on observed data.



ReservoirLevel	ReservoirPlan	DownstreamWaterRightsObligations	DownstreamWaterSupplyNeeds	GoodTimeToGenerateHydroPower	Low	Medium	High
Low	FillUp	None	None	No	0.333	0.333	0.333
Low	FillUp	None	None	Yes	0.333	0.333	0.333
Low	FillUp	None	Low	No	0.2	0.6	0.2
Low	FillUp	None	Low	Yes	0.6	0.2	0.2
Low	FillUp	None	Medium	No	0.333	0.333	0.333
Low	FillUp	None	Medium	Yes	0.2	0.6	0.2
Low	FillUp	None	High	No	0.333	0.333	0.333
Low	FillUp	None	High	Yes	0.333	0.333	0.333

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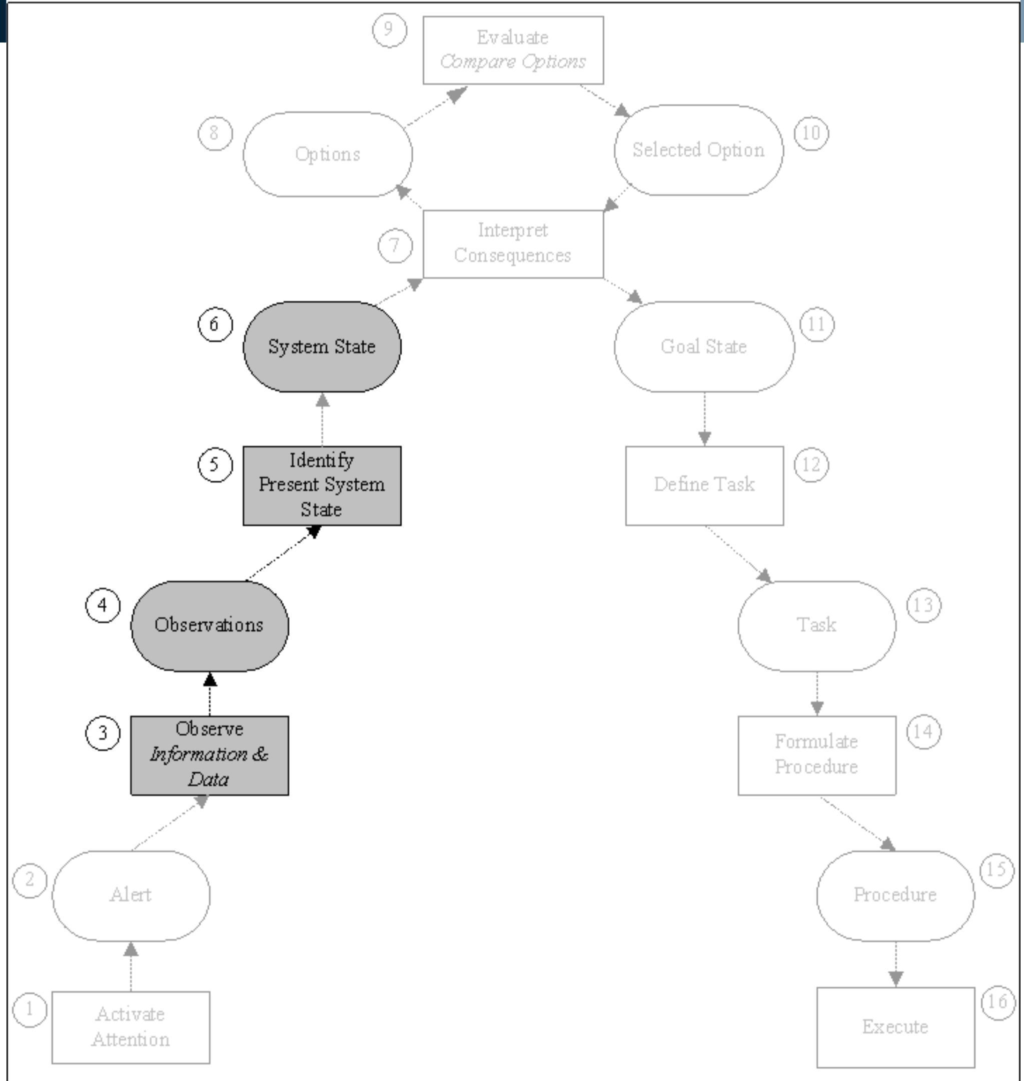
[ACE]

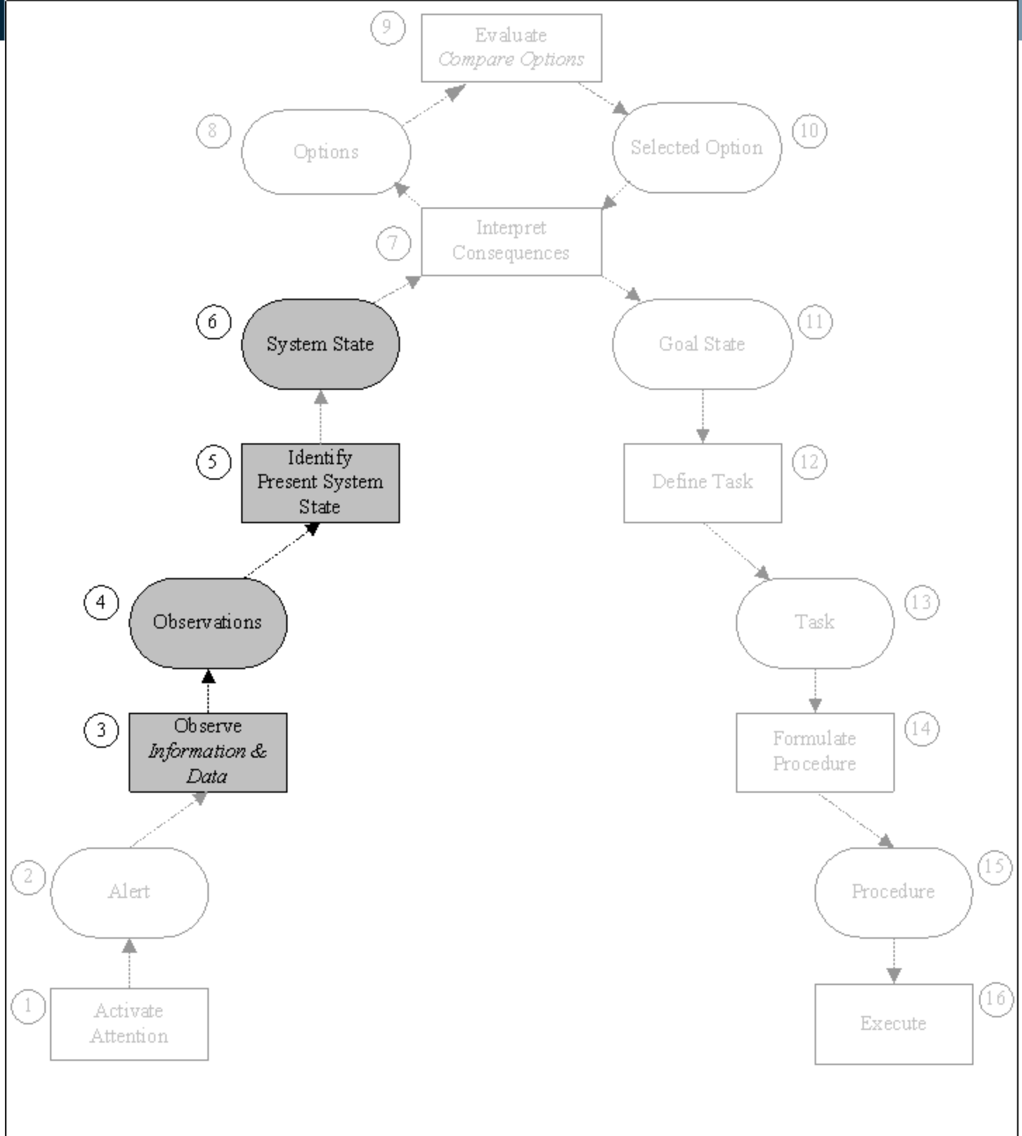
USER POPULATION: Army Corps of Engineers Water Resource Manager	
TITLE: Monitoring Dam Inflow	
Scenario	Identification of the current inflow and impact of reservoir height, as well as the evaluation of predicted weather and river forecasts for identification of future inflow levels and impact on future reservoir heights.



USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Monitoring Dam Operational Conditions

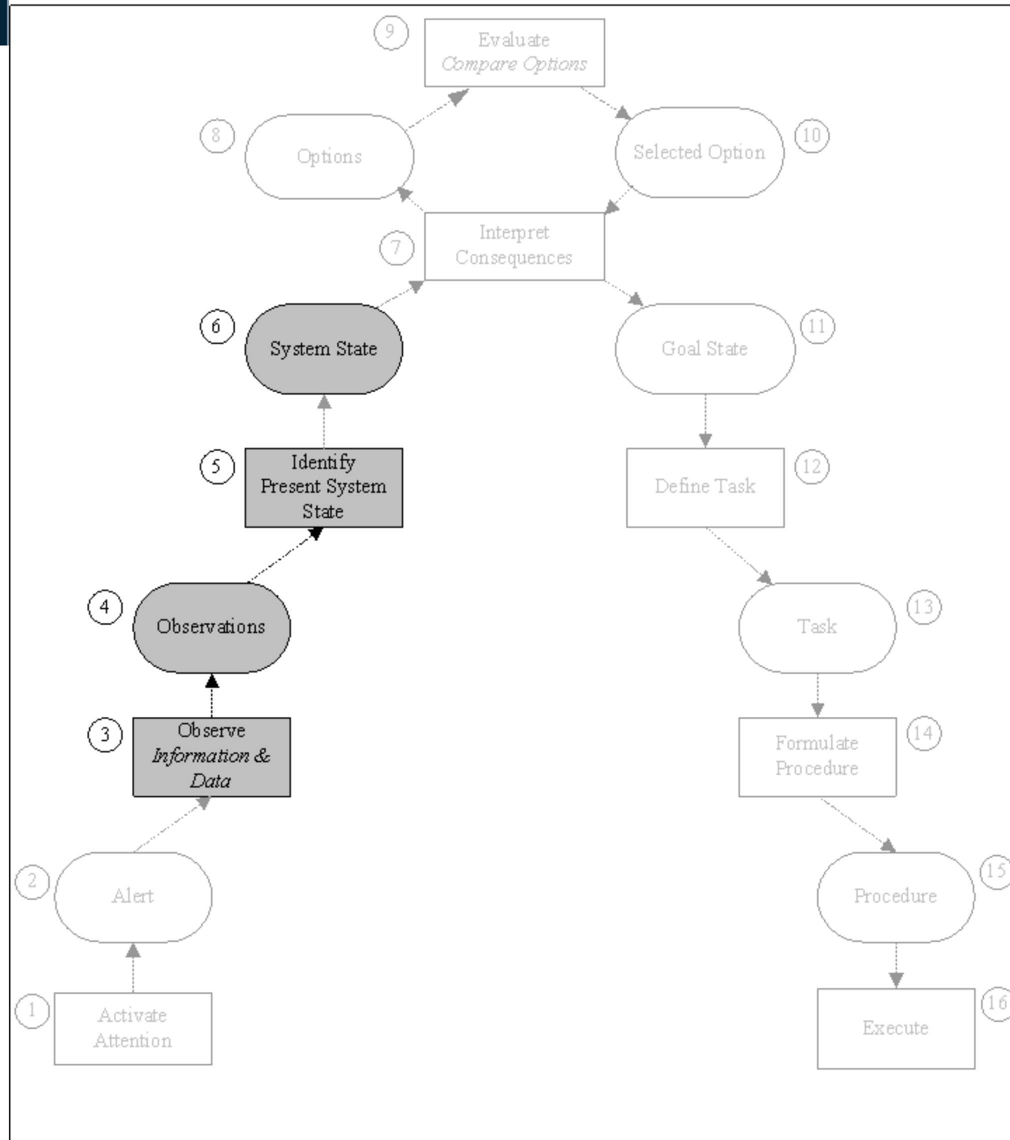
Scenario	With input from the "Monitoring Dam Inflow", the WRM monitors current and expected reservoir heights in relation to the gates conditions for release rates and the dam's operational capacity (if reservoir is going to, or does, exceed safety conditions, "Alert" is triggered).



USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Monitoring Downstream Conditions

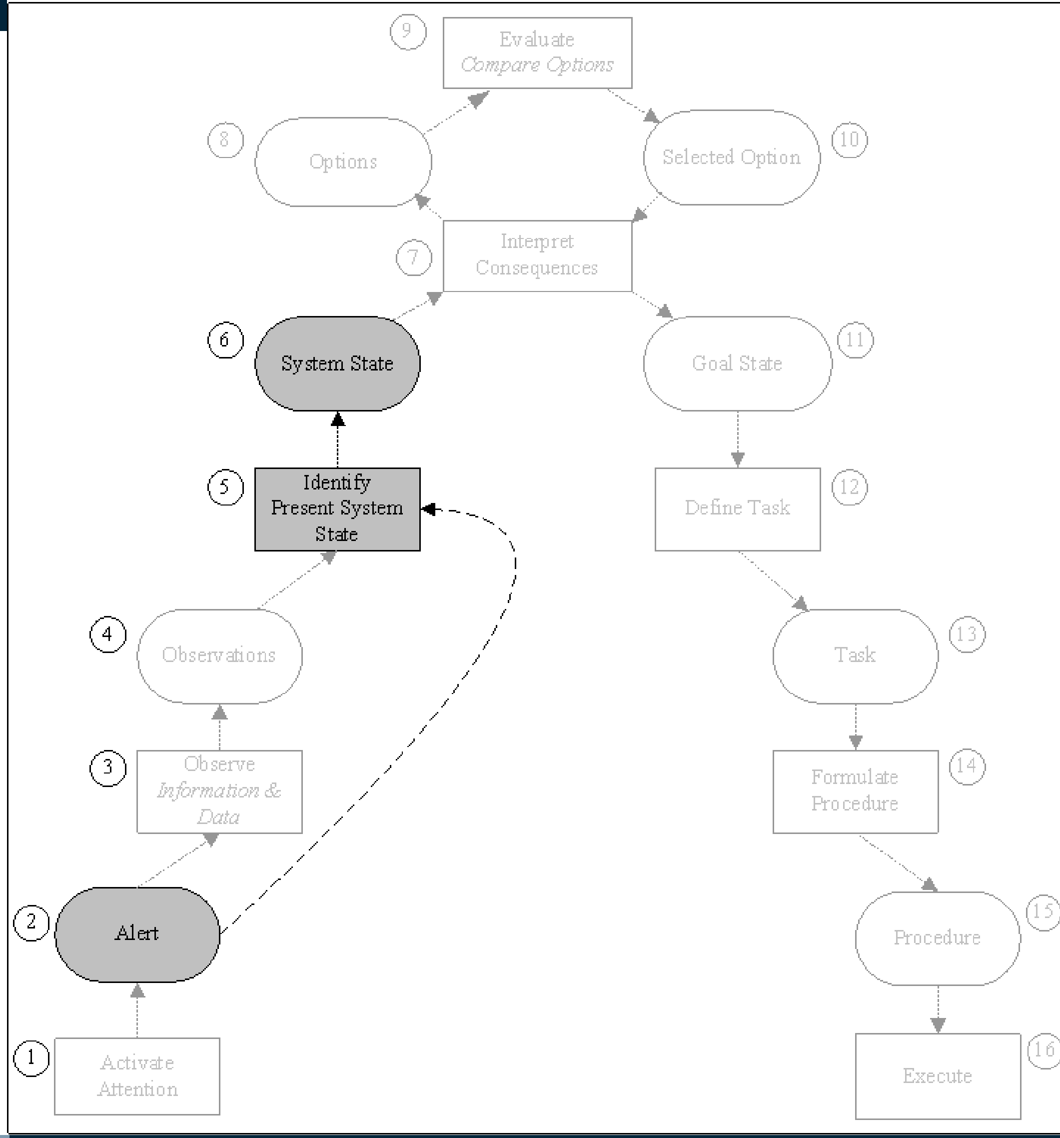
Scenario	Water resource managers monitor downstream conditions in terms of current conditions (from gauges) and expected conditions (from river forecasts and expected releases) to identify the state of the system downstream. If downstream conditions are changing below a hydropower dam that are not in lines with expected patterns from their release schedules, an Alert may be triggered.



USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Alert

Scenario	See that the water gauge under a Hydropower Dam is raising while ACE was releasing water to a stream they had not anticipated rising. See that the height of a reservoir at a Dam is approaching or exceeding the limits set for it to be operating at a safe level.



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USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Water Release Planning

Scenario	Upon understanding the entire system, planning is conducted on when to release water (long term, and short term) where options are evaluated and a selected goal defines the courses of action to take. Alerts can trigger re-planning activities.