SUSTAINABLE, JUST & PRODUCTIVE
WATER RESOURCES DEVELOPMENT IN WESTERN NEPAL
UNDER CURRENT & FUTURE CONDITIONS
(DIGO JAL BIKAS – DJB)

Hydro-economic modeling for more efficient water resources management

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Overview

1. Brief overview of hydro-economic modeling
   - What is it and why is it useful?
   - Traditional approach
   - Brief overview of more recent conceptual advances

2. Examples

3. Basic overview of model structure for Western Nepal

What is hydro-economic modeling?

"Hydroeconomic models represent regional scale hydrologic, engineering, environmental and economic aspects of water resources systems within a coherent framework" (Harou et al., 2009)

- Solution-oriented tools for discovering strategies to advance efficiency in water use
- Shift away from quantity-based, or physical, "targets"
- Reliance on a single metric to guide decisions – economic value (rather than multiple objectives)

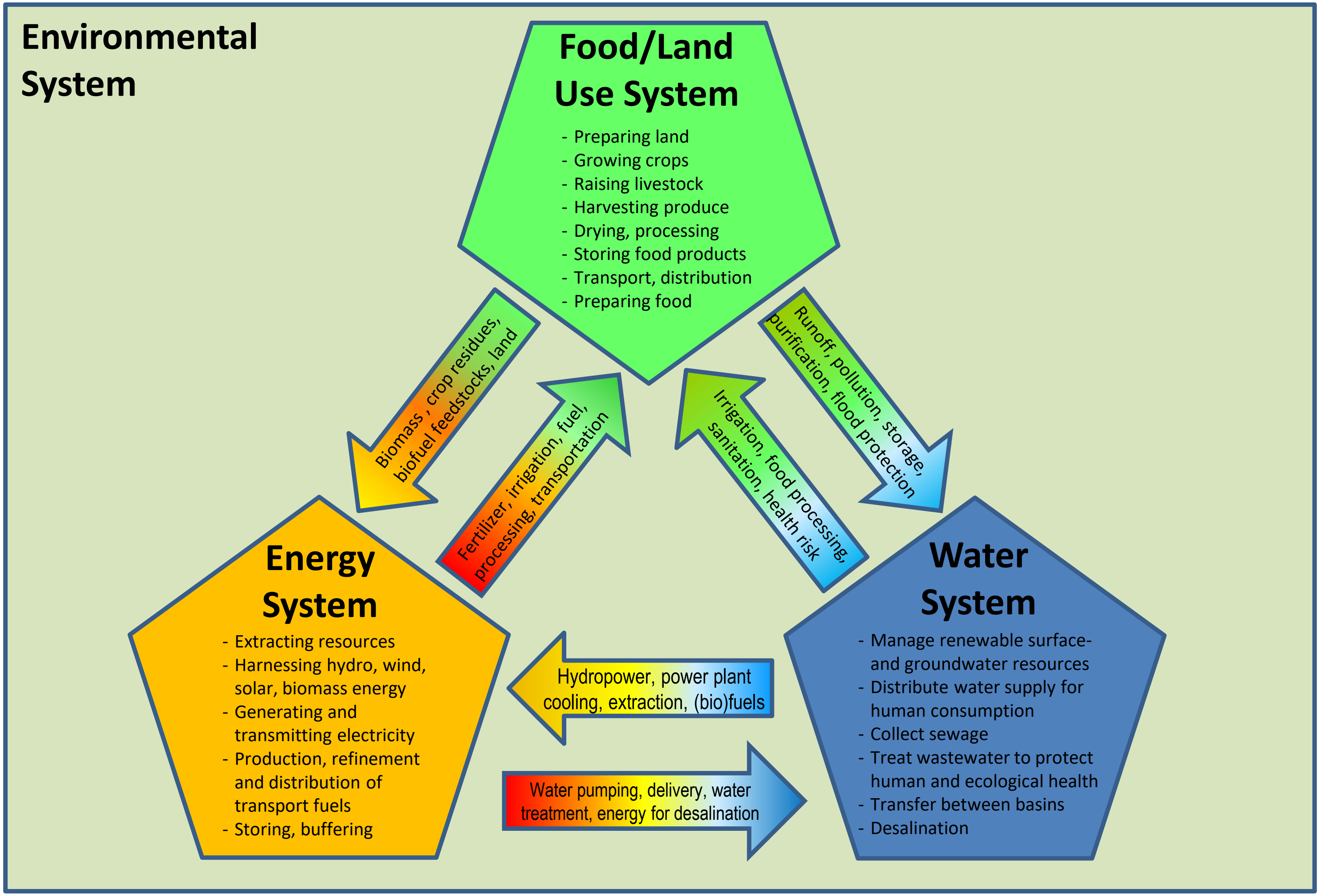
Why is hydro-economic modeling useful?

- Can answer questions about the value of new development (which hydropower, irrigation projects generate highest value, relative to costs?)
- Can be used to improve basin coordination (should dam storage be increased during some periods to better allow dry season irrigation?)
- Can help identify tradeoffs between uses (do we lose irrigation potential if we increase hydropower production?)
- Can help expand solution set (can changes in water management solve shortages?)
- Can help quantify economic losses or gains due to changes in other factors (how does climate or land use change affect economic outcomes?)

Common applications of these models

- From a recent review (Bekchanov et al. 2017), much work on:
    - Economic sensitivities (to climate change, value of energy, etc.)
    - Tradeoffs between uses, especially irrigation vs. hydropower
    - Water efficiency investments (drip irrigation, lining of canals, etc.)
    - Water pricing (which makes water use more efficient)
    - Water trade (where users can trade water rights to those willing to pay)
- Relatively less on:
    - Ecosystem values
    - Complex feedbacks (water-energy-food nexus)

Our ambition: Better capturing this complexity



Traditional hydro-economic approach

- **Optimization** model that helps planner choose "best" infrastructure (e.g. where, how big)
  - Economics enter the objective function, which is in $
  - Typical objectives include maximizing the value of market outputs and/or minimizing penalty functions for undesirable impacts (like floods)
- Reliance on historical flows (stationarity)
- Exploration of future changes by:
  - Specifying changes as decision variables controlled by planner; **or**
  - Creating scenarios of development for factors outside planner's control (e.g., assumed changes in hydrology, or population)
- Typical misconception: Hydro-economic modeling is <u>usually</u> for planning purposes, not for operations

Problems with the traditional apprach

- Planners do not have **perfect foresight**
  - Models that solve for "optimal" allocation are perhaps unconvincing
  - Operations may be quite different
- Water planners are **risk averse**
  - They may not care much about average results, but want to reduce risk
  - They tend to think in terms of 'satisficing', not maximizing $
- Water planning challenges **optimization**
  - Many-dimensional uncertainty, 'deep' uncertainty
  - Near optimality (flatness of objective), or non-dominance of solutions
  - Political economy of water
  - Valuation difficulties
- But various methodological advances allow improvements over the traditional approach (stochastic, robust optimization, fuzzy mathematical programming)

Basic design choices in hydro-economic models

Options	Description	Comments
Model type: Optimization Simulation	-What strategy is best? -How does strategy perform if…?	-Flexible solution space, but may be unconvincing or challenge solvers -Computational advantages, realistic rule representation, but may underperform
Flows: Historic Stochastic	-Measured series -Sampling from stochastic series’	-Intuitive comparisons for managers / decision makers, but future may not be like the past -More thorough incorporation of variability, but less intuitive, may still misrepresent future
Uncertainty: Scenarios Risk-based Other	-Best-worst / ranges -Well-specified prob. distributions -No or partial prob. distributions	-Deterministic and simple, but limited -Amenable to standard methods in decision analysis, assume away “deep” uncertainty -Perhaps most relevant, but challenge for decision-making
Integration: Modular Holistic	-Linked models run separately -Single integrated platform	-Well adapted to limited expertise, but can be clunky to use -Allow modeling of feedbacks; but may be difficult to run

Choosing a particular architecture

- Need to know objective: Inform policy, promote uptake, or work at the cutting edge of methods?
- Tension between promoting uptake and maintaining objectivity:
  - Users often impose assumptions to improve realism
  - These assumptions may reduce transparency

II. Brief overview and discussion of examples from the Nile (Why the Nile?)

Hydro-economic examples from the Nile

Author(s)	Year	Model type	Flows	Uncertainty	Integration
Wu et al. (NEOM)	2005; 2006; 2016; 2017	Optimization	Deterministic	Flow, dams, energy value	Holistic (Full basin)
Strzepek et al.	2007	Optimization (CGE)	Deterministic	Capital shocks	Holistic (Egypt)
Block (IMPEND)	2010	Optimization	Deterministic	Climate scenarios	Holistic (Eastern Nile)
Jeuland (3 linked models)	2010a, b; 2014	Simulation	Stochastic	Flow; development	Modular (Full basin)
Halleux; Goor; Arjoon et al. (Nile SDDP)	2009; 2010; 2014	Optimization	Stochastic	Infrastructure	Holistic (East. Nile)
Dinar	2013; 2015	Optimization	Deterministic	Initial rights	Holistic (East. Nile)
Geressu et al.	2015	Optimization	Deterministic	Weights for decision vars.	Holistic (East. Nile)
Satti et al. (SHOM)	2015	Optimization	Deterministic	Flow; prices; development	Holistic (Nile in Sudan)

Irrigation; Hydropower

Economy-wide

Irrigation; Hydropower; Flood control

Irrigation; Hydropower; Siltation

III. Interdependence and tradeoffs: Example from the Ganges

Standard narrative in water resources development

- To achieve optimal outcomes, one needs to consider the complete water resource system
- Several reasons: dependencies across…
  - Space; e.g. spillovers/externalities not considered by agents located upstream
  - Time; e.g. depleting water storage (in soils, surface or groundwater) could lead to permanent changes in land cover and hydrology
  - Outcomes; e.g. markets for goods and services, nonmarket values, environmental quality
- The need to consider the system resonates with ecologists / engineers / economists

Where do we see these ideas reflected?

Two examples (among others):

- Wide inclusion in national policy of **Integrated Water Resource Management (IWRM)** : “A process which promotes the coordinated development and management of water, land & related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”
- **Hydro-economic optimization models**: How should one choose where to build infrastructure, how to allocate water, etc., to maximize economic benefit?

Ganges Basin: One of very first international case studies for hydro-economic optimization

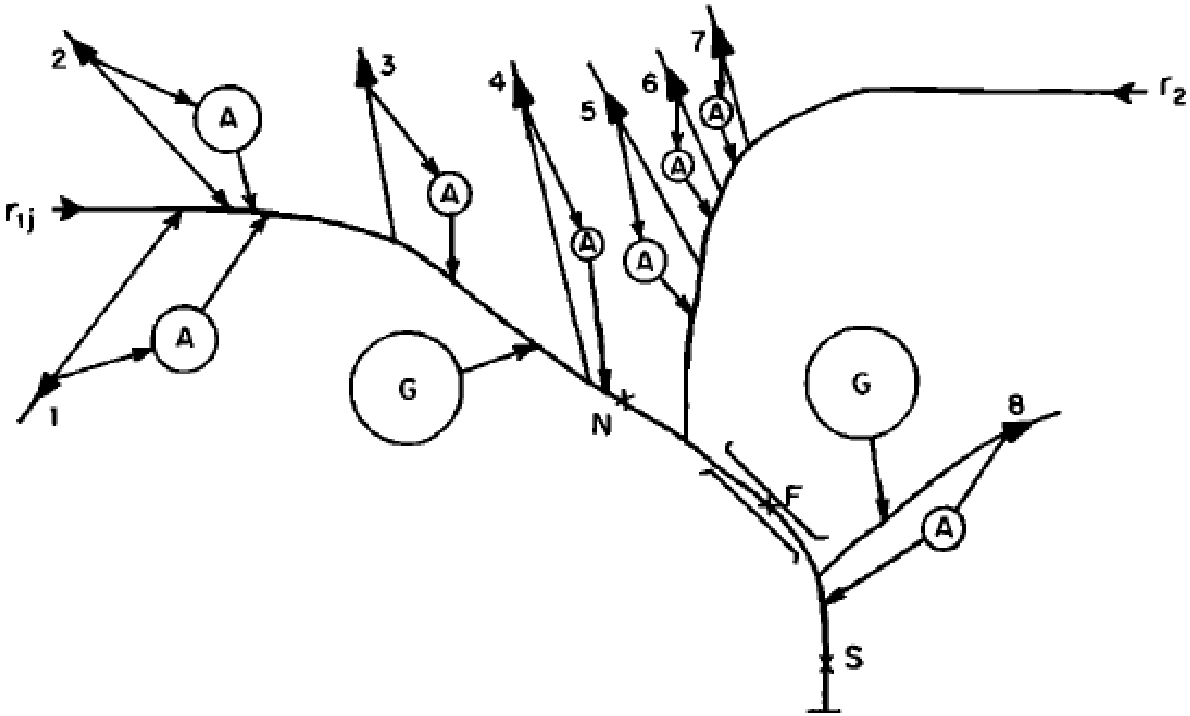
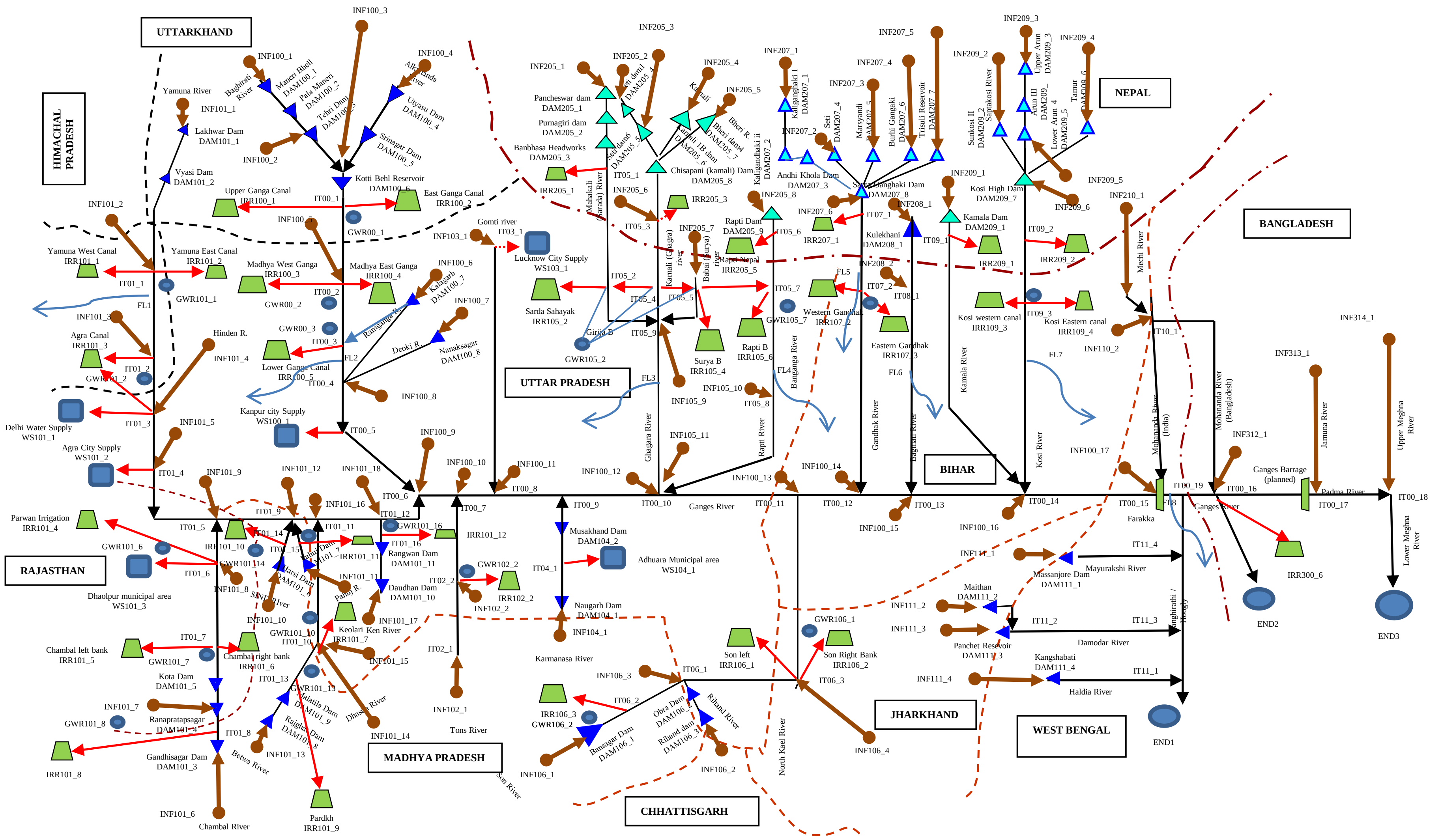


Fig. 2. Schematic representation of lower Ganges-Brahmaputra basin, where G, ground-water fields; A, surface water irrigation; F, flood control; N, navigation control; and S, salinity control.

Objective: Maximize economic benefits (Hydropower + irrigation – flood damages)

<u>Source</u>: Rogers (1969). “A game theory approach to the problems of international river basins.” *Water Resources Research* 5(4): 749-760.

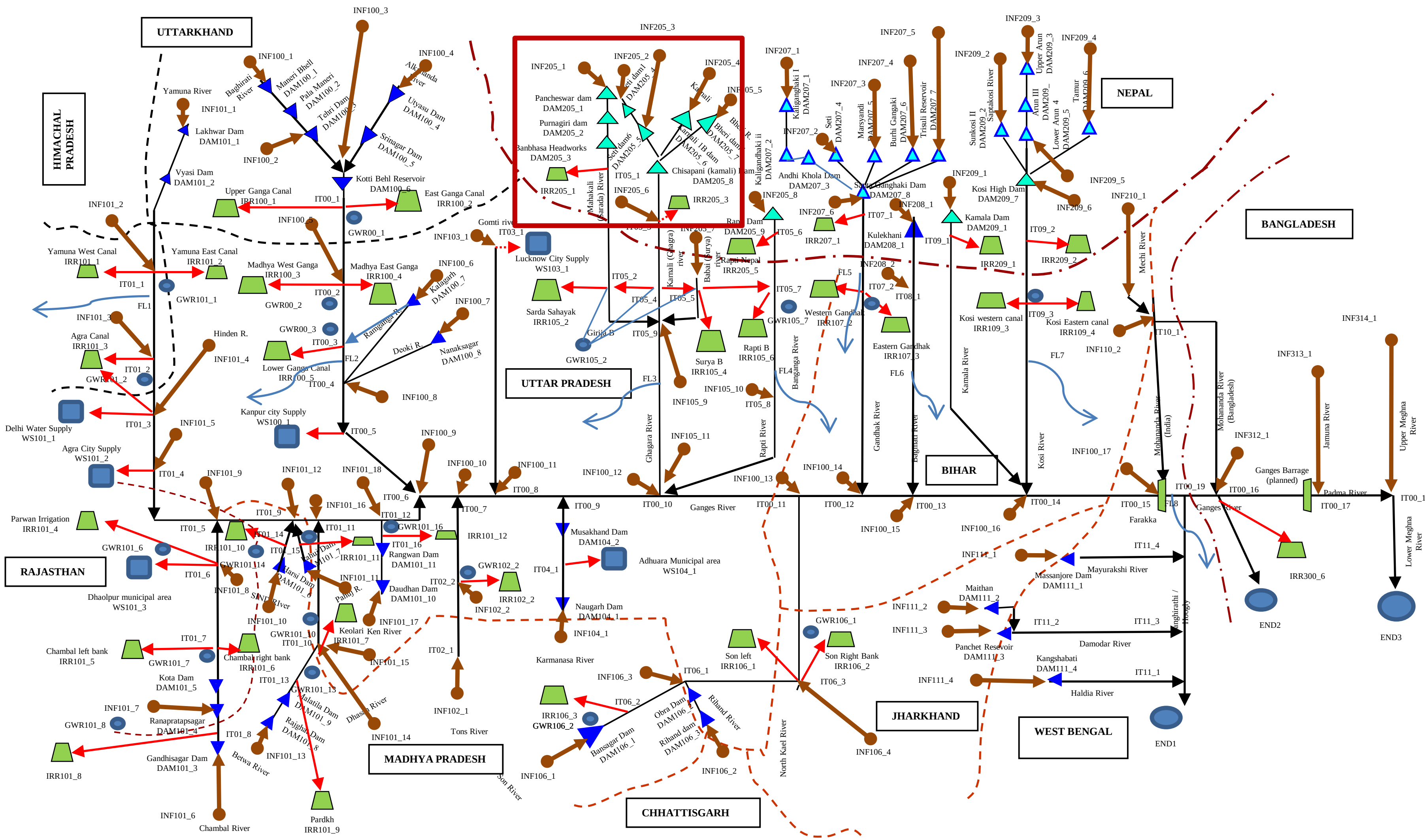
More recent Ganges model



Insights from these models

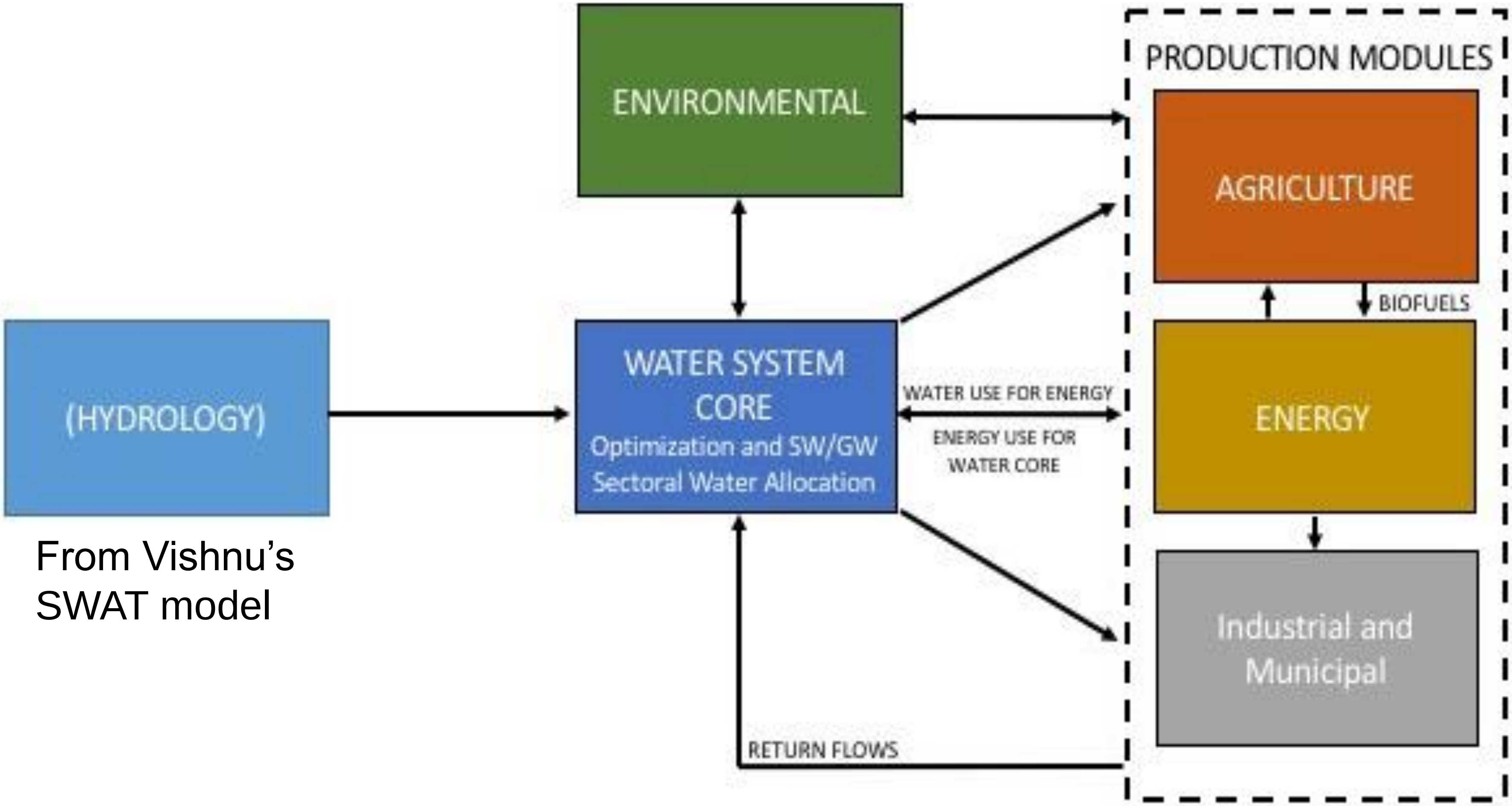
- The largest dams in the Himalaya do not provide much storage compared to annual flow of Ganges
- Tributary flows can be reduced somewhat with storage, but ability to control floods is limited
- Dams would provide low flow augmentation, but these **induce** tradeoffs between:
  - Irrigation (mostly in India) and
  - Ecosystem and water quality benefits (mostly in Bangladesh)
- Few other tradeoffs, at least at large scale
- What about at smaller scale (in Western Nepal?)

More recent Ganges model



IV. Western Nepal model: Basic structure

Modular structure



From Vishnu's SWAT model

Figure 8. Module interconnections for HEM model

More details on connections

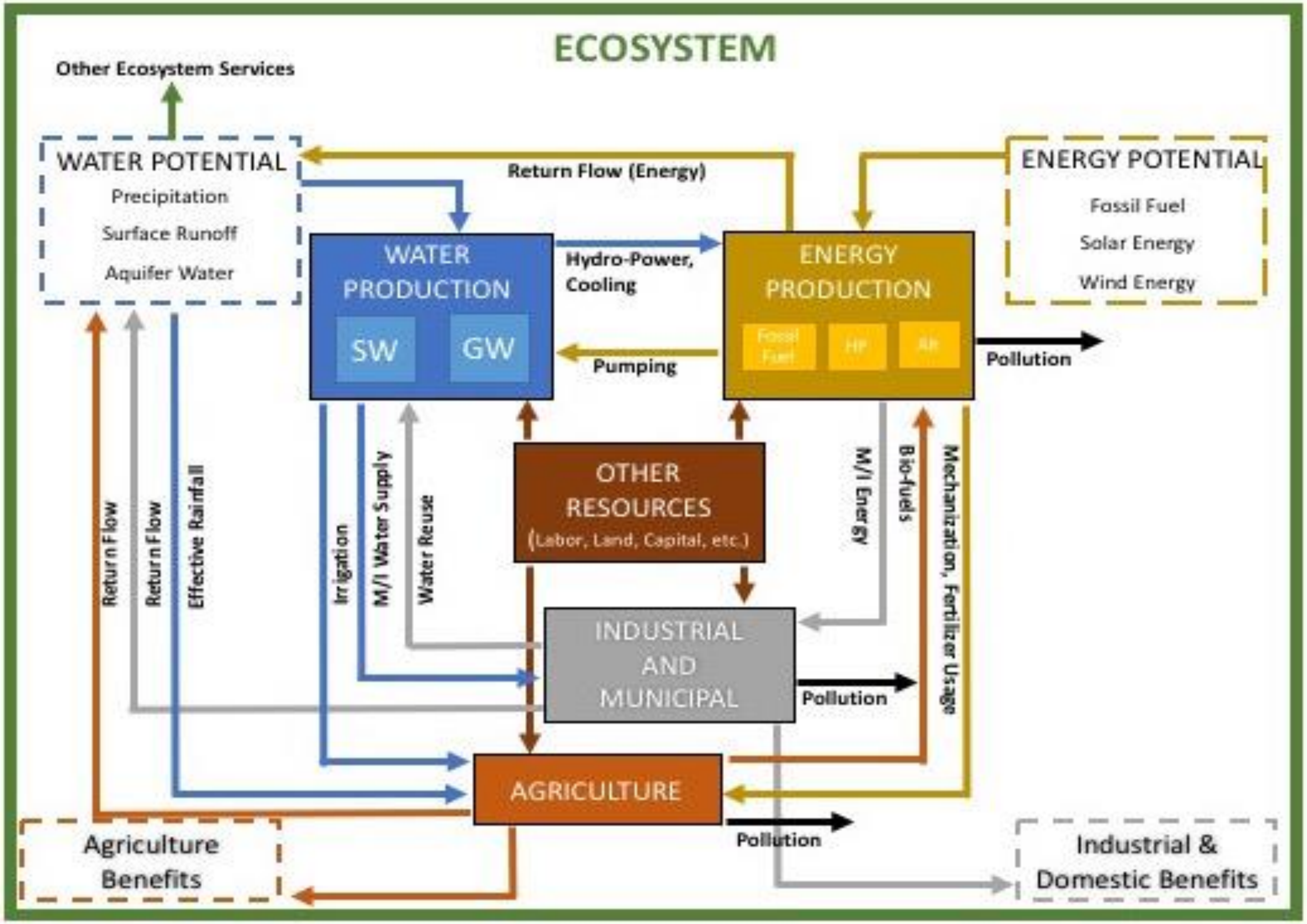


Figure 2. Interactions between production domains included in the WEEF framework

Nodes and links

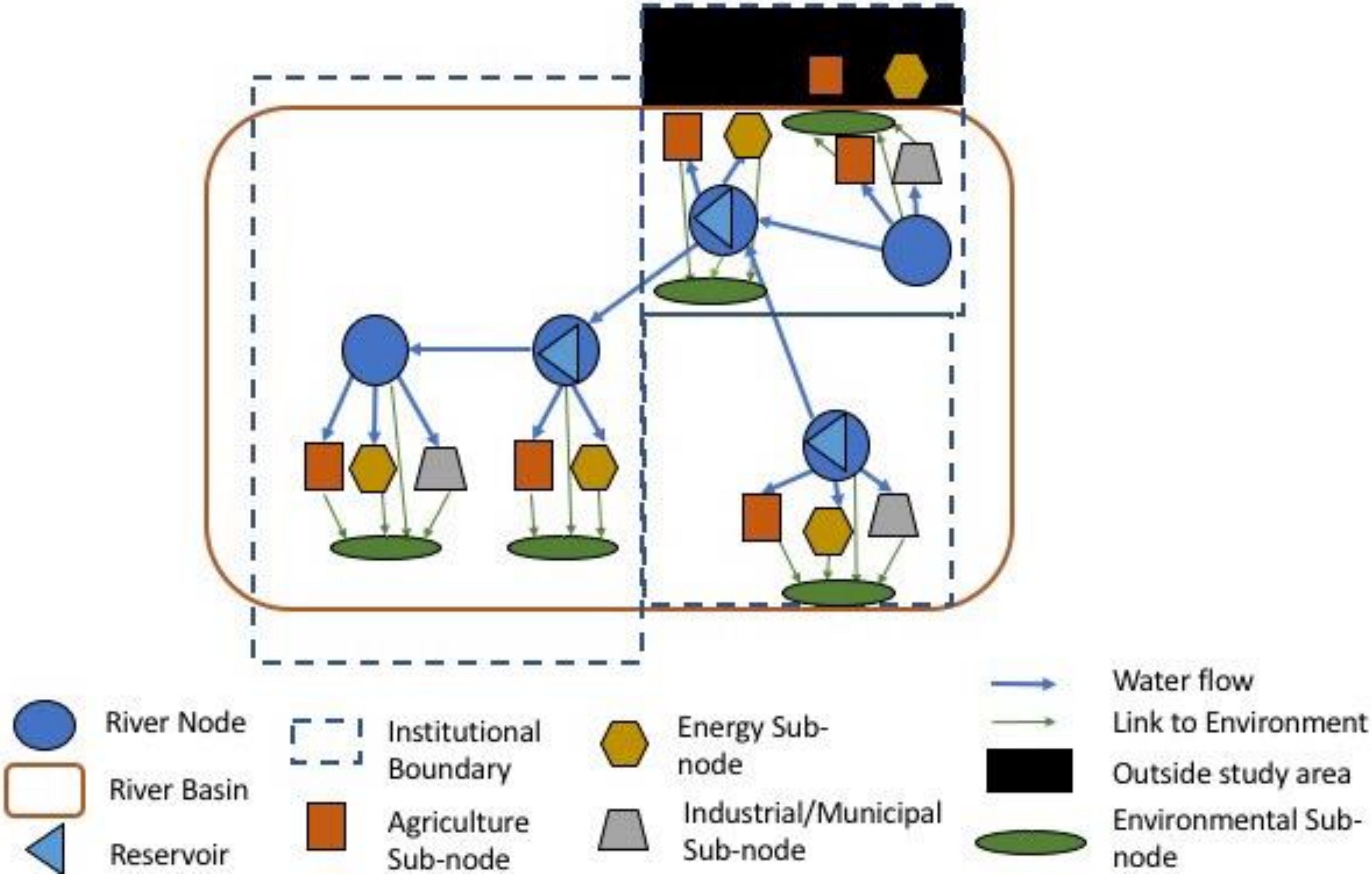
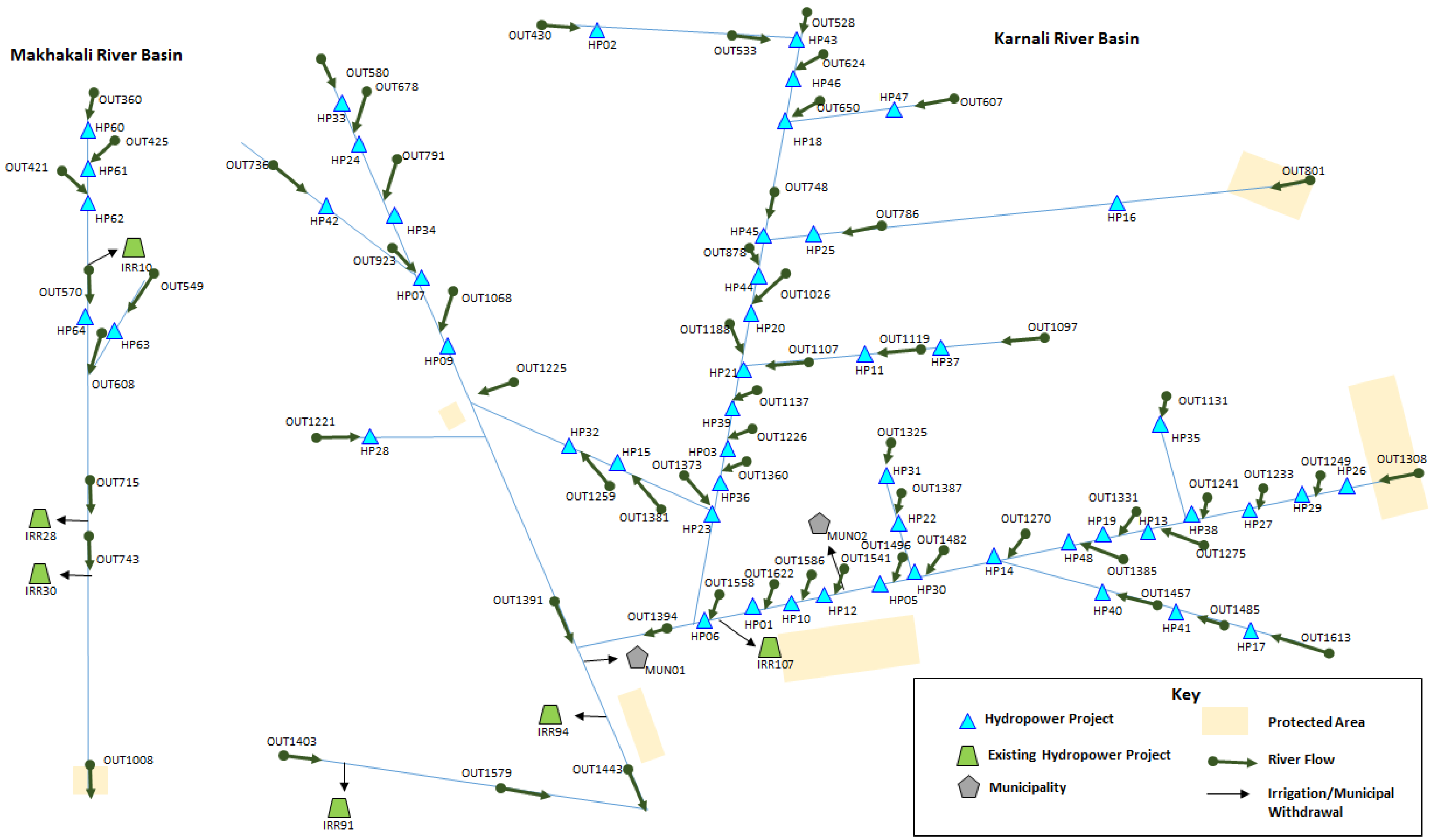


Figure 9. River Node network scheme

Model schematic



Mathematical equations

- Objective is to maximize economic value (from hydropower, irrigation, what else?)
- Nodal water balance (inflow, storage, diversion, outflow)
- Production using water: Energy, food crops, industry, other services (including environmental)
- Consumption by end users (households)
- Use of energy by water sector (nexus!)
- Institutional & other constraints (minimum flows, specific allocation rules)

Questions we hope to ask…

- What is the value of new water infrastructure? (storage/hydropower dams, expanded irrigation canals)
- Are there tradeoffs between uses? (e.g., irrigation vs. hydropower, ecosystem services vs. hydropower)
- Are there tradeoffs across space and time? (groundwater irrigation now vs. later; micro-irrigation in hills vs. irrigation in Terai)
- What is the effect of institutional constraints? (guaranteed flow to Terai irrigation, or power supply to India)

Thank you!