Development of a health risk assessment Bayesian Network for the management of recycled wastewater: A case study

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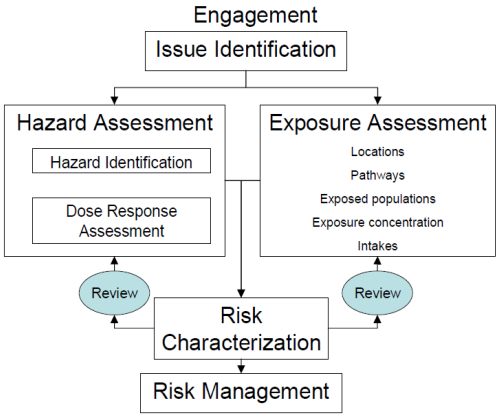
Background: Risk Assessment

- Quantitative risk management strategies have been successfully applied to drinking water systems around the world
- Also promoted in the Australian guidelines for Water Recycling to develop a better understanding of the risk posed by water recycling schemes

Background

- Framework
  - provides an objective, scientific evaluation of the likelihood of unacceptable impacts to human health arising from exposure to a given hazardous substance (e.g. pathogens and chemicals).
  - This information is used to inform and guide the development of risk management protocols.



Heads of consideration for Quantitative Risk Assessment (QRA)

Data needs

1.Source concentration
- Initial concentration
- Pathogens
- Chemicals

2.Barrier effects
Identify & quantify barrier performance
- Log reduction values of treatment processes
- Natural barriers / fate and transport

3.Exposure pathways
Exposure routes
- Quantify exposure / dose
- Consumption rates
- Frequency and duration

4.Dose response
DR models to estimate Prob. of illness
- Probability of infection
- HQ and cancer risk
- DALYs

5.Hazardous events and scenarios
e.g. failure of treatment barriers
- Type
- Frequency
- Consequence

The challenge!

- The process of quantifying model inputs and choosing numerical values for the multiple heads of consideration is critical to the QRA process, yet daunting for the risk analyst
- Integrating all this information (which often come from disparate datasets) makes QRA a difficult challenge
- QRA also requires
  - scenario testing and revision of inputs based on new information
  - consideration of parameter variability and uncertainty
  - transparency for auditing by regulatory authorities

Aim

To develop a practical and interactive quantitative BN model that integrates QRA modeling approaches for the management of water recycling schemes

Objective

The QRA BN approach was trialed on a water recycling case study: “the replacement flows scheme” in western Sydney, where highly treated municipal effluent is used for the supplementation of environmental flows in the Hawkesbury-Nepean River

Replacement flow scheme

- Western Sydney Recycled Water Initiative:
- To maintain environmental flows within Hawkesbury-Nepean River, water is released from potable sources (Warragamba Dam)
- Conservation of potable water from Warragamba Dam & other supplies
- Direct tertiary-treated effluent into the Hawkesbury-Nepean River, from Penrith, St. Marys, Quakers Hill STPs to maintain environmental flows.
- Advance tertiary treatment works (Microfiltration & Reverse Osmosis)
- Sydney Water commissioned WRC to undertake a desk-top chemical and microbial Risk Assessment
  - Model inputs were based on literature values

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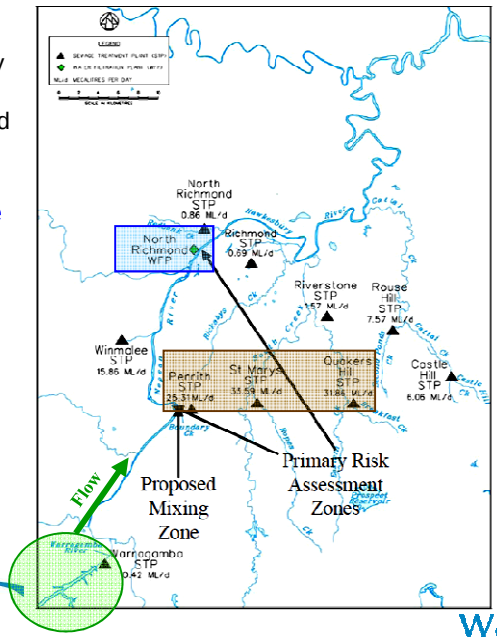
Exposure scenarios:

- ingestion during primary contact (recreation)
- Consumption of irrigated vegetables
- Consumption of fish
- Consumption of potable water supply



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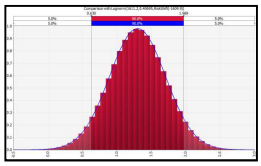
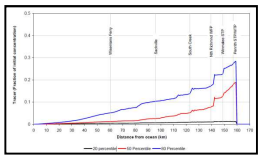
Integration and management of data

- Large amount of information (which come from disparate datasets)
  - Quantitative
    - PDFs or Point estimates
    - Sophisticated model outputs
  - Qualitative
    - Expert opinion (e.g. Hazardous Events)
- Employed BN to…
  - Conceptualise the 'system'
    - Identify data needs and gaps
  - Integration of data
  - Scenario testing e.g. hazardous events





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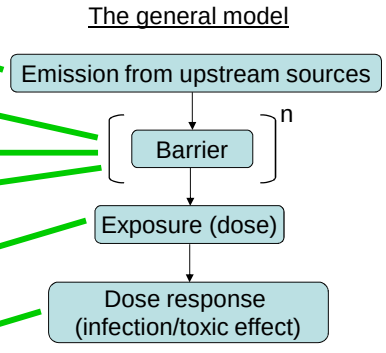
Replacement flows Risk Assessment: the ideal BN case study !

- Evaluation nodes
  - Source contaminant levels (STP)
    - Focused on *Cryptosporidium* & Benzene
  - Tertiary/advanced treatment barriers
    - MF/RO
  - Post treatment storage / treatment
    - River (considered different flow regimes)
  - Reprocessing barriers
    - WTP
  - Estimating dose (from planned use)
    - Only focused on potable consumption
    - Richmond WTP
  - Acute & chronic health effects (Risk)
    - Many, which are specific to hazard and exposure route
  - Integrate data
    - A system to manage information



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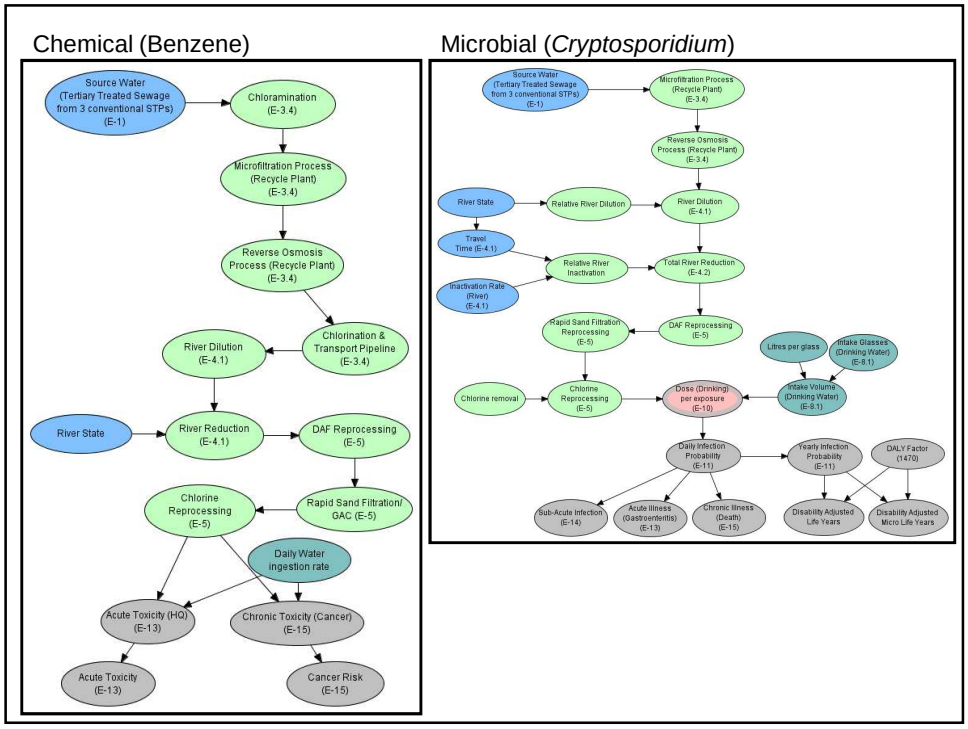
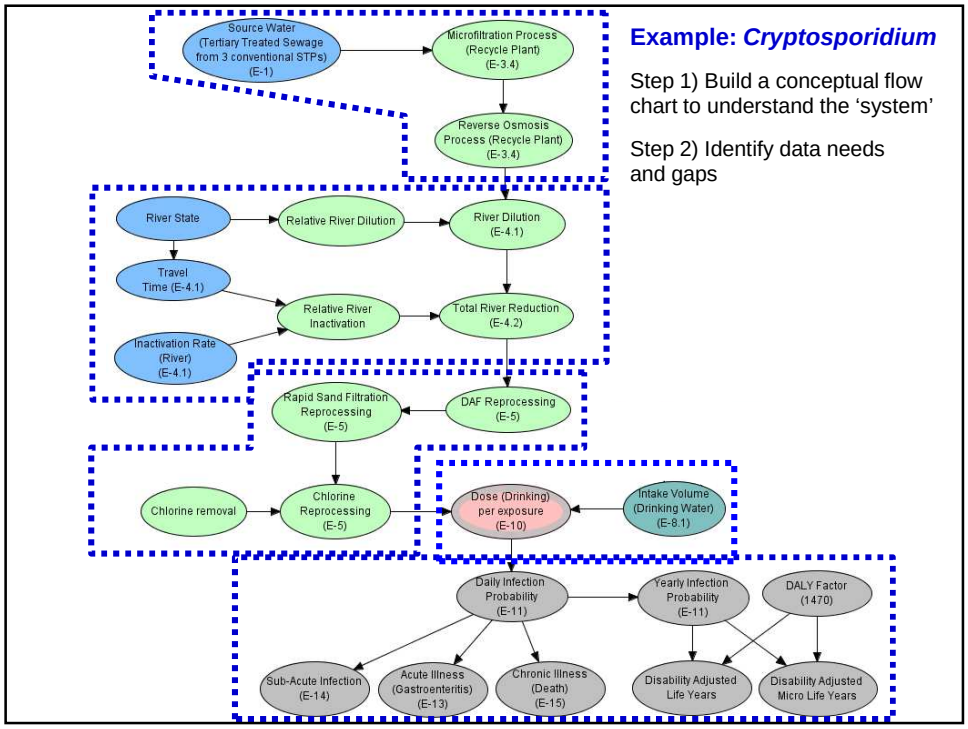
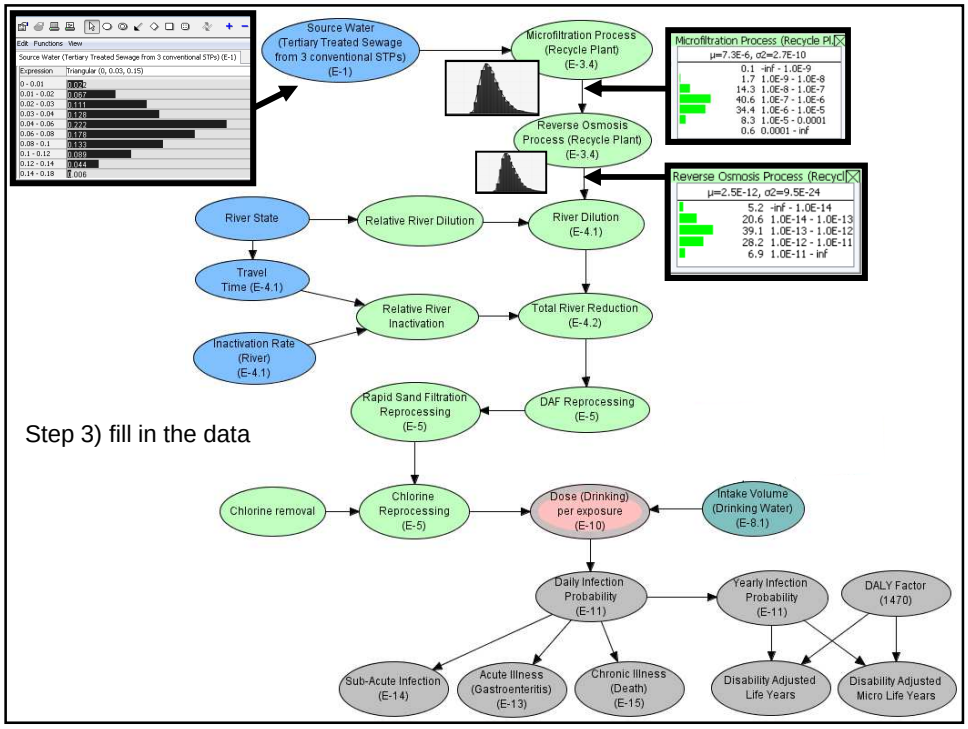


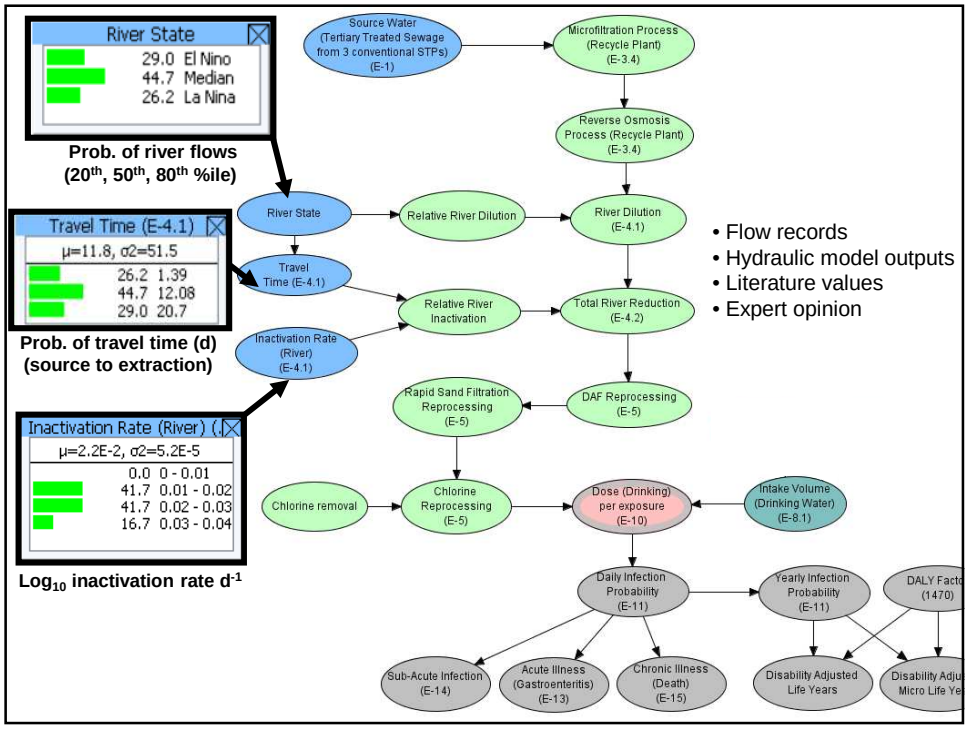


Example: *Cryptosporidium*

Step 1) Build a conceptual flow chart to understand the 'system'

Step 2) Identify data needs and gaps


Source Water (Tertiary Treated Sewage from 3 conventional STPs) (E-1)
Microfiltration Process (Recycle Plant) (E-3.4)
Reverse Osmosis Process (Recycle Plant) (E-3.4)
River State
Relative River Dilution
River Dilution (E-4.1)
Travel Time (E-4.1)
Relative River Inactivation
Total River Reduction (E-4.2)
Inactivation Rate (River) (E-4.1)
Rapid Sand Filtration Reprocessing (E-5)
DAF Reprocessing (E-5)
Chlorine removal
Chlorine Reprocessing (E-5)
Dose (Drinking) per exposure (E-10)
Intake Volume (Drinking Water) (E-8.1)
Daily Infection Probability (E-11)
Yearly Infection Probability (E-11)
DALY Factor (1470)
Sub-Acute Infection (E-14)
Acute Illness (Gastroenteritis) (E-13)
Chronic Illness (Death) (E-15)
Disability Adjusted Life Years
Disability Adjusted Micro Life Years
Step 3) fill in the data


River State
29.0 El Nino
44.7 Median
26.2 La Nina
Prob. of river flows (20th, 50th, 80th %ile)
Travel Time (E-4.1)
μ=11.8, σ2=51.5
26.2 1.39
44.7 12.08
29.0 20.7
Prob. of travel time (d) (source to extraction)
Inactivation Rate (River) (
μ=2.2E-2, σ2=5.2E-5
0.0 0 - 0.01
41.7 0.01 - 0.02
41.7 0.02 - 0.03
16.7 0.03 - 0.04
Log10 inactivation rate d-1
Source Water (Tertiary Treated Sewage from 3 conventional STPs) (E-1)
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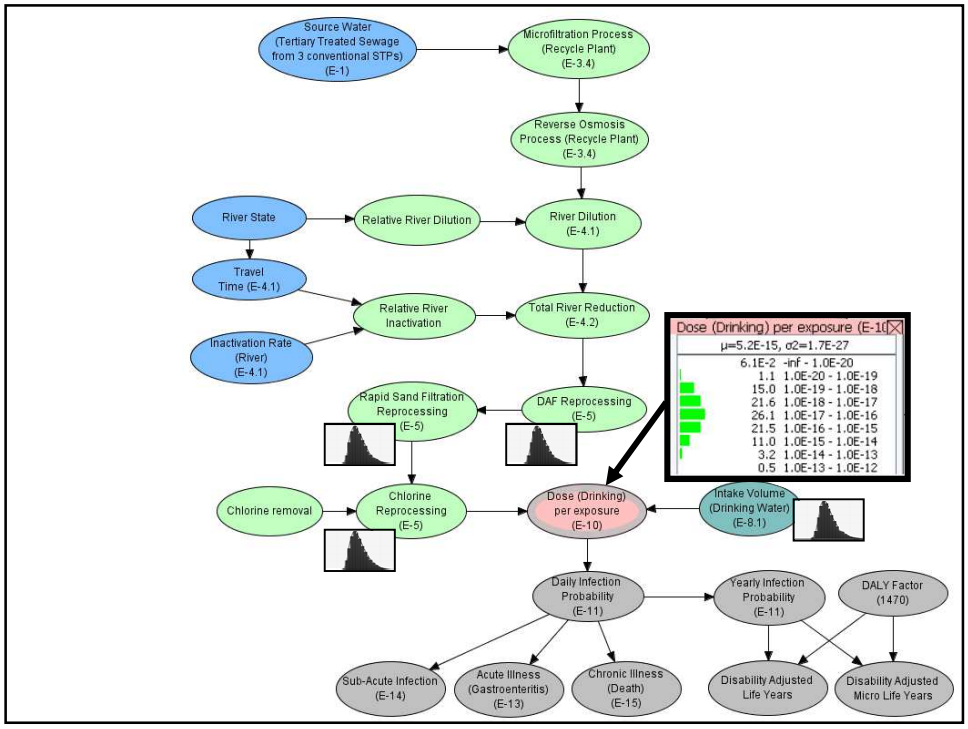
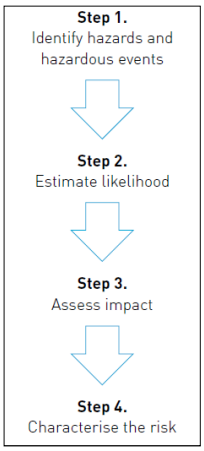
Acute Illness (Gastroenteritis) (E-13)
Chronic Illness (Death) (E-15)
Disability Adjusted Life Years
• Flow records
• Hydraulic model outputs
• Literature values
• Expert opinion

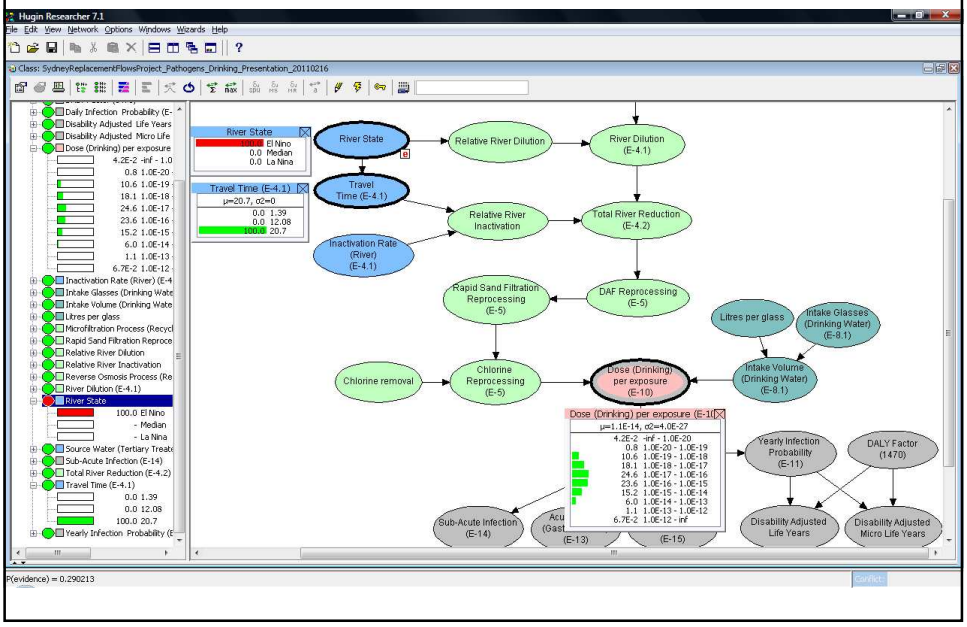


BN and scenario testing

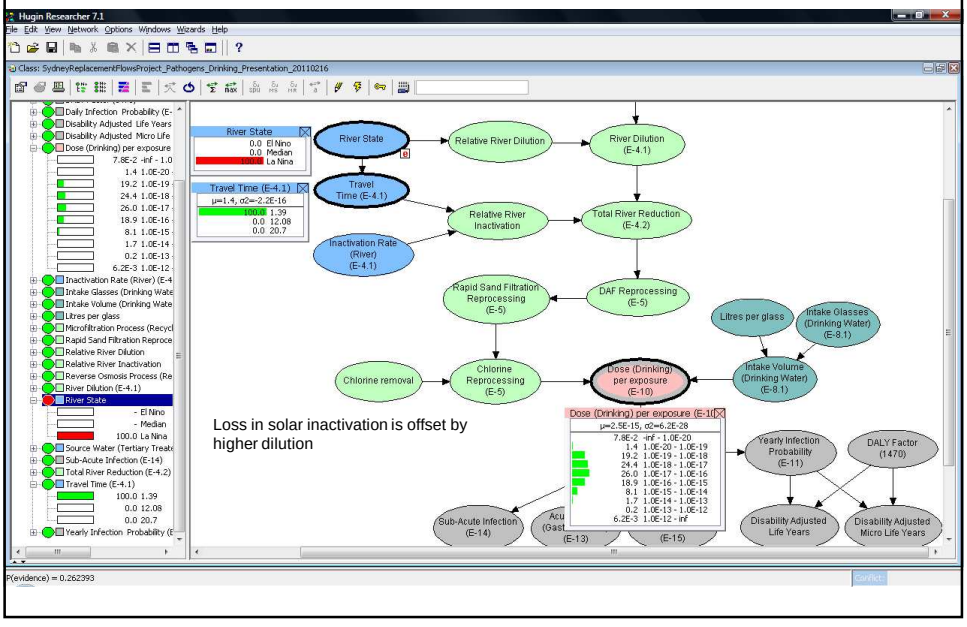
- AGWR recommend consideration of Hazardous Events
- Explore combinations
- BN is flexible
- For example...



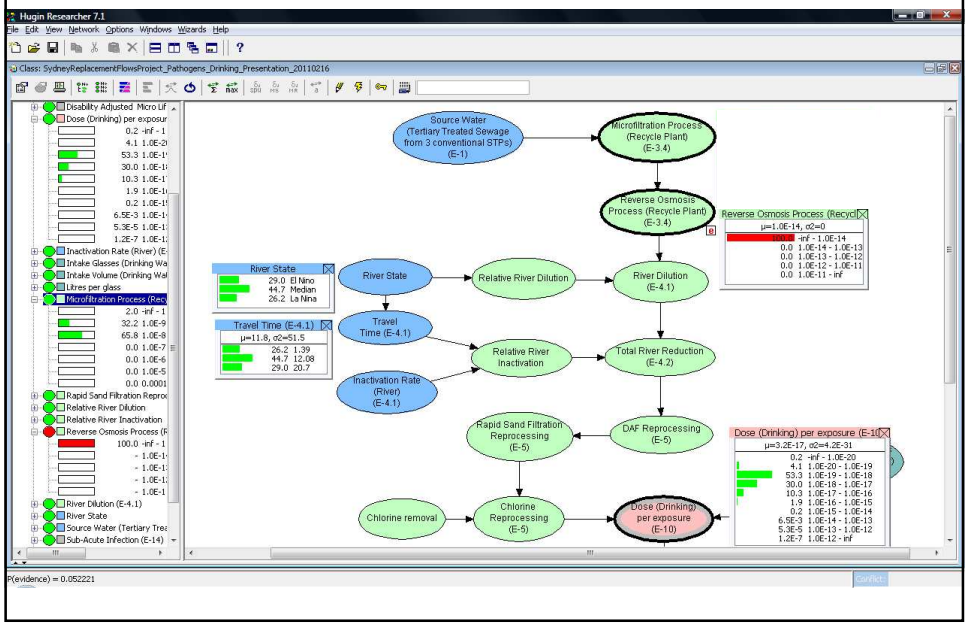
Scenario testing: Low river flows



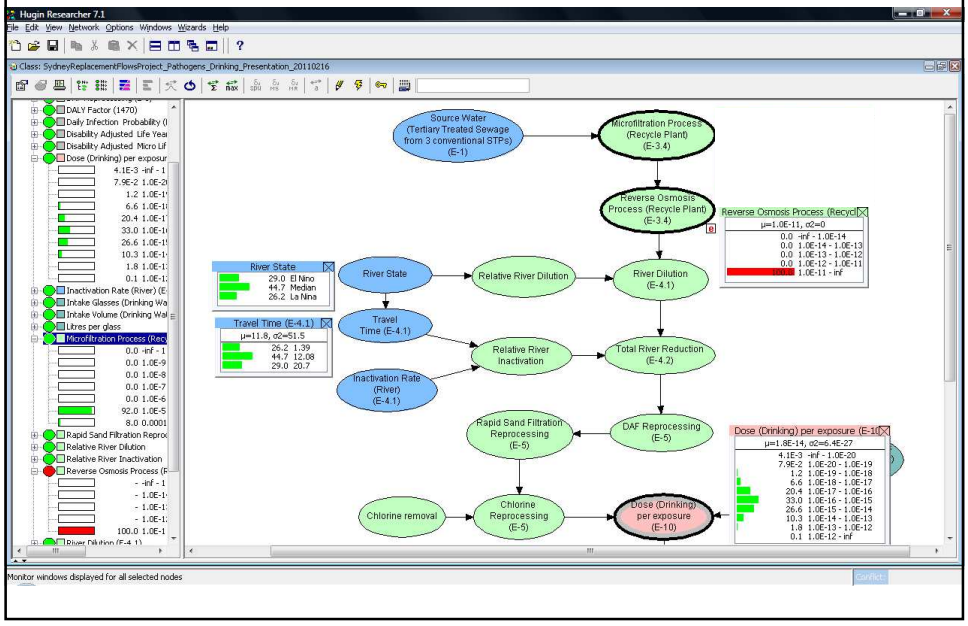
Scenario testing: High river flows



Scenario testing: Good RO

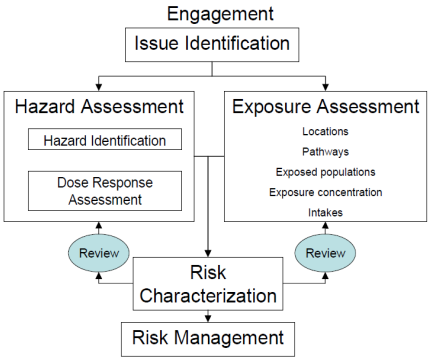


Scenario testing: Poor RO



Bayesian Network: A 'living' model

- RA is a continuous process
  - Review and reality check
  - Bayesian is flexible
  - Refine inputs based on new information
  - New scenarios (e.g. process upgrades)
  - Other hazardous events / combinations
- Open to both revision and auditing



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Conclusions

- Results showed that the BN was useful at integrating the diverse sources of data needed for QMRA
  - e.g. expert opinion, monitoring and observation records, outputs from transport models
- Accommodated uncertainty and variability
- BN's can offer a scientifically credible and adaptive approach for assessing the risks of complex water recycling schemes.