Bayesian Networks: A tool for making good decisions in river catchment management

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- What is the best "minimum river flow" level to set for maximising regional economic growth, trout fishing and suitability of the river for swimming?
- What combination of water allocations for irrigation, farming best practices and urban stormwater management can ensure reliability of water supply, protect food gathering and river aesthetics for minimal cost to rate payers and land owners?
- Are the management options for protecting drinking water supply and minimising flood risk at odds or aligned with each other?

These are some possible questions that might arise when developing a catchment-scale freshwater management plan. As you can see, the questions involve many simultaneous decisions and affect a number of different values (some competing, some aligned). On top of that, they relate to the behaviour of a large and complex river system with many interacting components. This makes them hard to answer. To make things harder still, in most situations we don't know exactly how much one component changes when we change another. So, we need a tool that allows us to show all of the different values the community holds about the river system, the main components of the river system that those values depend on, and the effects of one component on another. And we want to use all the knowledge we have about those effects, while recognising that our knowledge is not 100% accurate.

Bayesian Networks, or BNs (also known as Bayesian Belief Networks), are a tool designed to achieve exactly that. They show in a diagram the important components of a system and the relationships between them, i.e. which components depend on which others. The components, called "nodes" in BNs, may be things we can control (practices, management options), the effects of what we do, our targets (e.g. aspirations or statutory guidelines) or indicators that show whether something we value is in a healthy or unhealthy state. Other nodes can be added to show more clearly how the system works (e.g. how one component indirectly affects another via an intermediate node). Cause-effect relationships between the nodes are shown by arrows linking the "causing" nodes to the "affected" nodes.

A BN can be left at this stage, just showing the important components and how they are linked together – as shown in Figure 1 below (note this is just to show what BNs look like – it is not meant to be realistic!). Or it can be developed to a second stage to show *how much* one component affects another. Then it can be used to help find solutions for resolving competing demands on water. If the BN is developed to the second stage, then each node is given two or more possible states, e.g. in Figure 2 "Trout fishing OK" can be "true" or "false". The probability of the node being in each state is shown by "belief bars" – how likely we think is it that the node will be in each of the states shown. To show how much the state of one node depends on the state of another, we need to put numbers on the relationships between the nodes. Because we often don't know these cause-effect relationships precisely, we use probabilities to represent how strong the relationships are. For example, we may say that if we set a minimum flow in a river to x m^3/s then there is only a 10% chance that bacteria levels will always be safe for swimming (Figure 2) – so if the node "Minimum flow limit" is set to x m^3/s, then the node "Bacteria levels safe for swimming" is "always: 10%".

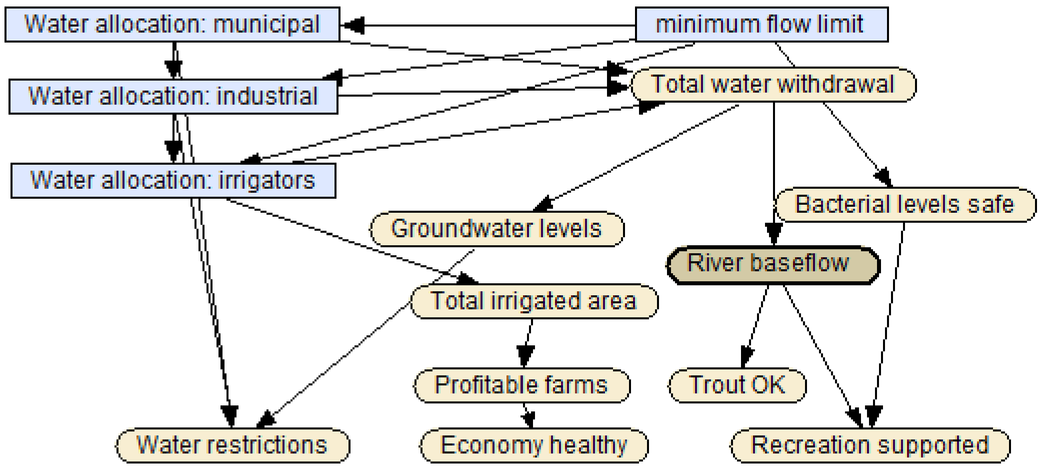

Figure 1 A portion of a possible BN. The light blue rectangular nodes represent decisions, i.e. practices or management decisions that can be changed. The yellow rounded nodes represent results of the decisions, and those at the bottom represent values. Arrows represent cause-effect relationships.

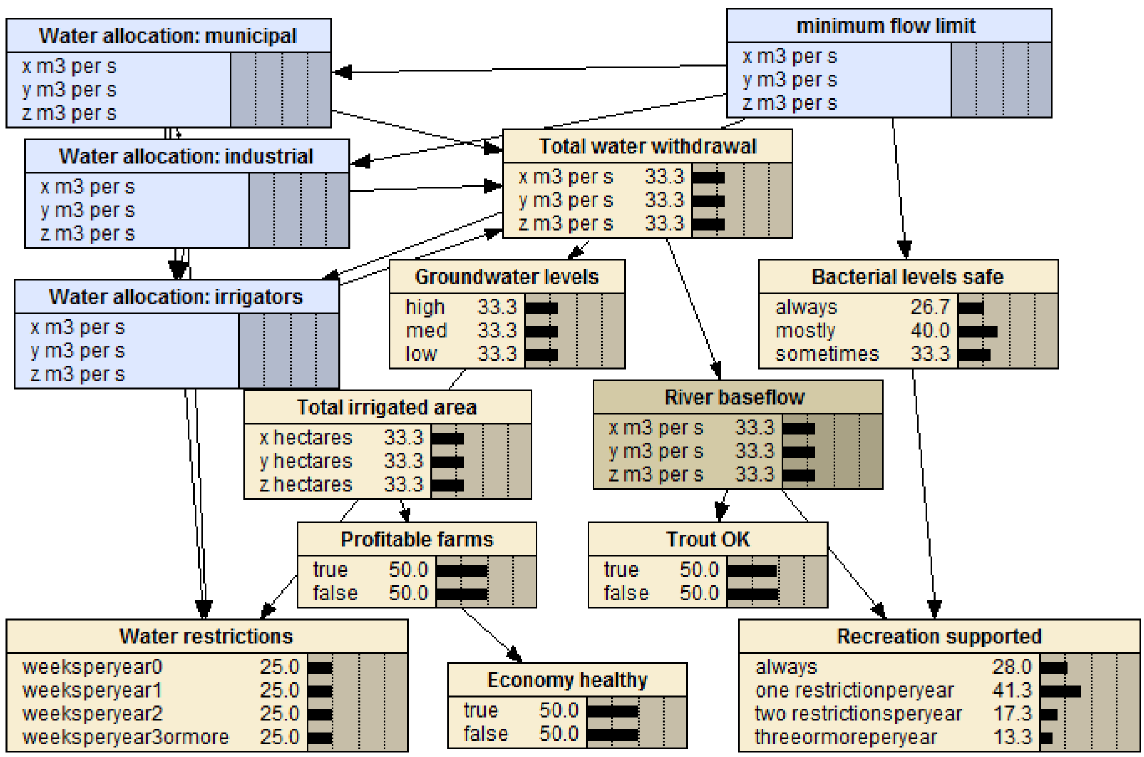

Figure 2: the same BN as in Figure 1, showing the nodes with states and belief bars. Belief bars show the % probability that the node is in each of the states. The belief bars of the blue nodes are set

directly by the user because they represent decisions. Those of the yellow nodes are calculated by the computer based on the relationships set by the user.

BNs can be developed by a group of stakeholders or a community group. Therefore, they are a useful way for a group to develop a common understanding of how a river catchment system works and how the different values and the various components in the system relate to each other. Once the group have shared their ideas on how the river system works, it is helpful for “experts” with specialist knowledge to make the diagram more accurate or complete. Defining the different states of the nodes and adding numbers to the probability tables will almost certainly require experts with access to relevant scientific studies. After this expert input, the final BN should still seem sensible and realistic to the stakeholder group. It should be possible to resolve any differences of opinion so that everyone agrees the BN represents how the system works.

You can find more information about Bayesian Networks, and some examples, at http://www.spiritone.com/~brucem/bbns.htm

A free version of the software can be downloaded from https://www.norsys.com/download.html