Flow diagrams for natural resource applications using LaTeX and tikz

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1 Introduction

LaTeX is a powerful piece of typesetting software. Two areas where I find LaTeX really shines over point-and-clicky word processing applications are i) producing equations and ii) creating illustrations. This quick vignette concerns the latter.

I'm assuming enough familiarity with LaTeX/the TeX macro language to compile a .tex document into a .pdf (or output file of your choice). What I plan to cover here are three examples of water resources management diagrams produced using the 'tikZ' package for LaTeX. These three should be sufficient to give a flavor for how 'tikZ' works and introduce you to a few different types of illustrations that can be embedded in your LaTeX document using 'tikZ.' I recommend starting here: `http://www.texample.net/tikz/` for some more advanced applications.

2 a basic water supply schematic using tikz

A basic conceptual set-up for studying problems in freshwater allocation between ecological and human might include:

- a dam which impounds a river, creating a storage reservoir
- agricultural users who divert water from the reservior for irrigation

Figure 1 illustrates how water moves around this simplified regulated system. Water flows into the reservior where it is stored either for use in agricultural production or released into the river where it provides habitat for fish and wildlife. In this case we illustrate the trade-off between ecological and human water uses by labeling the allocation to agriculture (w_a) and the allocation to in-river flows (w_h). The agricultural water user's node is labled with the functional relationship ($y = f(w_a)$) to denote that water diverted to agriculture is used as input into the on-farm crop production function.

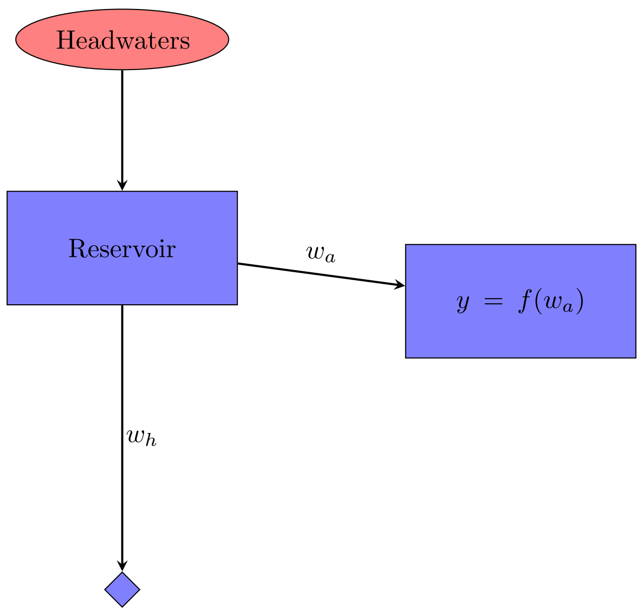

Figure 1: *Base Model* schematic

The syntax for Figure 1 is reasonably straightforward. We start by defining styles for our nodes:

```
\tikzstyle{decision} = [diamond, draw, fill=blue!50]
\tikzstyle{line} = [draw, -stealth, thick]
\tikzstyle{elli}=[draw, ellipse, fill=red!50,
minimum height=8mm, text width=5em,
text centered]
\tikzstyle{block} = [draw, rectangle, fill=blue!50,
text width=8em, text centered, minimum height=15mm,
node distance=10em]
```

In this case, we anchor the diagram around the 'Reservoir' node,

```
\node [block] (start) {Reservior}
```

Relative positions and offsets are then used to place remaining nodes,

```
\node [elli, above of=start, yshift=5em] (user) {Headwaters};
\node [block, right of=start, xshift=5em, yshift = -2em]
(process2) {$y=f(w_a)$};
\node[decision, below of=start, yshift=-10em](decision1){};
```

Paths are defined with the aptly constructed 'path' syntax,

```
\path [line] (user) -- (start);
\path [line] (start) -- node[xshift=0.75em]{$w_h$} (decision1);
\path [line] (start) -- node[yshift=0.75em]{$w_a$}(process2);
```

Also note the ease with which we can use math script to label our nodes. The $ operator indicates that what follows will be an equation.

3 another irrigation water supply diagram

Figure 1 shows a system where agricultural water use if purely consumptive. To convey the concept of return flow, I wanted to produce a surface water system with two agricultural plots, one primary point of diversion from the source to the ag plots, secondary points of diversion from a main canal to the ag plots and some arrows indicating how water moves around the system.

Here the node and edge styles are defined just as in Figure 1,

```
\begin{figure}[!htp]
\centering

\tikzstyle{decision} = [diamond, draw, fill=blue!50]
\tikzstyle{line} = [draw, -stealth, thick]
\tikzstyle{elli}=[draw, ellipse, fill=blue!50,minimum height=8mm,
text width=5em, text centered]
\tikzstyle{block} = [draw, rectangle, fill=green!25, text width=8em,
text centered, minimum height=15mm, node distance=10em]
```

The node and edge placements follow the same syntax as Figure 1...there are just more of them.

```
\begin{tikzpicture}
\node [elli] (start) {Reservoir};
\node [elli, above of=start, yshift=5em] (user) {Headwaters};
\node [block, right of=start, xshift=10em, yshift = -2em] (process2) {$I_{i}$};
\node [decision, left of=process2, xshift=-50](diversion1){$d_{i}$};
\node [block, below of=process2, yshift = 1.25em] (process3) {$I_{j}$};
```

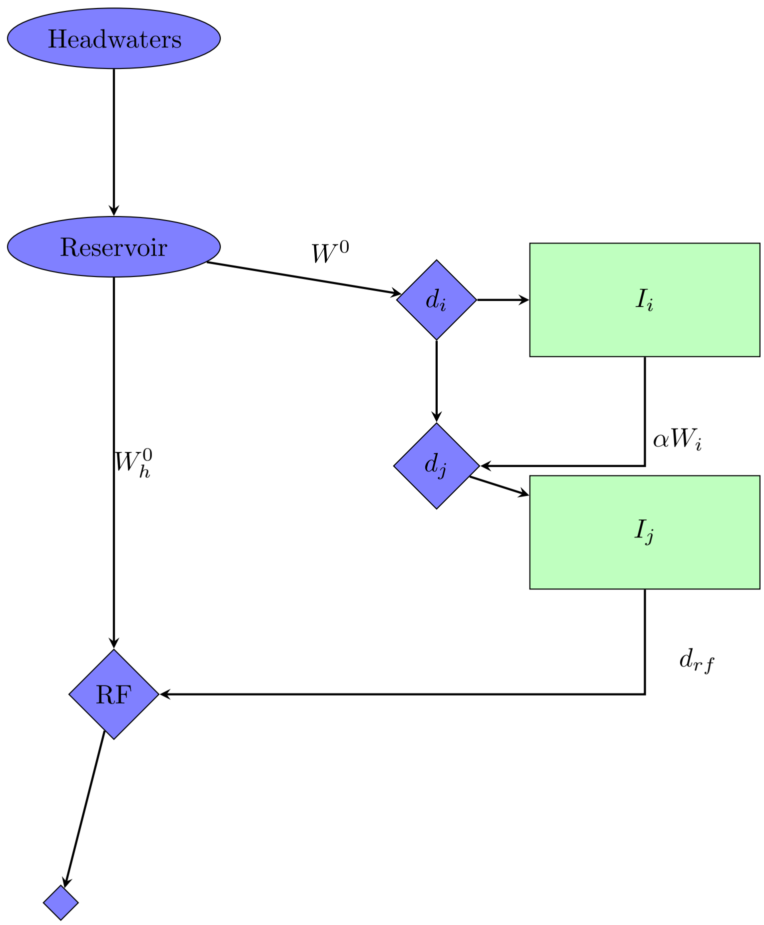

Figure 2: Water supply schematic with return flows

```
\node [decision, left of=process3, xshift=-50,yshift=25](diversion2){$d_{j}$};

\node[decision, below of=start, yshift=-14em](decision1){RF};
\node[decision, below of=decision1, xshift=-2em,yshift=-5em](decision2){};
\path [line] (user) -- (start);
\path [line] (start) -- node[xshift=0.75em]{$W_h^0$} (decision1);
\path [line] (start) -- node[xshift=1em, yshift=1em]{$W^0$}(diversion1);

\path [line](diversion1) -- (diversion2);
\path [line](diversion1)--(process2);
\path [line](process2) |- node[xshift=1.25em,yshift=1em]{$\alpha W_{i}$}(diversion2);
\path [line](diversion2) -- (process3);
\path [line](decision1) -- (decision2);
\path [line](process3) |- node[xshift = 2em, yshift=1.25em]{$d_{rf}$}(decision1);
\end{tikzpicture}

\caption{Water supply schematic with return flows}
\label{fig: return_flow}
\end{figure}
```

4 a dynamic programming problem

In addition to diagramming physical processes, I sometimes find illustrations can help simplify the presentation of decision problems. This section presents an example of a box and arrow diagram I cooked up to illustrate the payoffs involved in a contingent water purchase contract between an agricultural rights-holders and a regulator representing environmental interests.

First refer to Figure 3 which illustrates a basic contingent contract to purchase surface water from an agricultural rights holder. A *contingent contract*, for the present discussion, is a water purchase contract between an agricultural water user (who has a right to divert and use a certain amount of water) and a regulator representing the interests of fish and wildlife who also require that sufficient water be left in the river to provide aquatic habitat. The contract says that the regulator will purchase a pre-specified quantity of water from the rights holder for a specified price any time a particular condition (such as total inflow into the system less than a threshold value) is met.

Figure 3 shows that with probability p_t the inflow target will not be reached. In this case the current period benefits (V_t)to the irrigator from having stock w_t available will be given by the farm profits associated with choosing optimal on-farm water use ($\pi(x_t)$) and the amount collected from supplying h percent of supply at the contract price r. The second equation illustrates the change in the stock from t to $t+1$. The initial stock is reduced by water released for salmon habitat ($w_t h$) and the amount used for irrigation (x_t). This holdover quantity is subject to evaporative loses captured by the parameter δ which is assumed less than one. The holdover stock is then augmented by next periods inflows, a_{t+1}. With probability $1 - p_t$, the contract is not triggered and the irrigator choses his optimal on-farm water use and collects $\pi(x_t)$. In this case, the stock available next period is given by the holdover quantity ($w_t - x_t$), discounted by evaporative lose and augmented by next periods inflow.

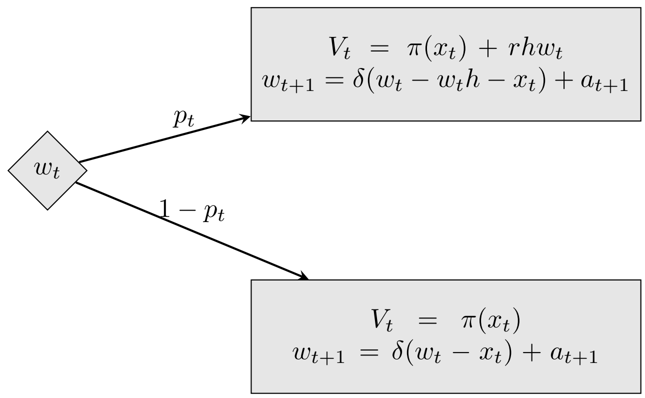

Figure 3: Contingent contract scheme for the *total stored water* contract

Next we will provide numerical illustration subject to to following assumptions:

- two irrigators (one junior and one senior) share storage (a reservoir)
- storage capacity is 2 units
- both irrigators demand 1 unit of water
- junior irrigators profits are a function of water, $\pi(x) = e^x$
- the junior irrigator's supply is subject to the amount of stored water and is defined as follows:
  - w can take values [0,0.5,1,1.5,2,2.5,3]
  - the junior irrigator's corresponding water supply is [0,0.125,0.5,0.5,1]
- reservior inflow takes the values [0.5,1,1.5,2] each with probability 0.25.
  - for expositional clarity we label these states: *critically dry*, *dry*, *wet*, and *very wet*
- the contingent contract is defined as an agreement between the junior irrigator and regulator to supply 1/2 of the irrigator's allocation anytime inflow is less than 1.5.
- we assume a two-period model with initial reservoir storage $w_0 = 1$
- future profits are discounted by the factor $\beta = 0.97$

- we assume the junior irrigator is risk averse with utility of profits defined by $U(\pi) = \sqrt(\pi)$
- $\delta = 0$

Our numerical illustration will show that there is a contingent storage contract which provides greater expected utility than the expected utility of the storage and use right, even while providing lower expected profits. We also show that there is such a contract that can result in lower expected payout from the regulator than an annual water lease.

To start, we calculate the expected value of the junior irrigator's right to store and use 1 unit of water. Figure 4 shows the valuation of the junior irrigator's storage and use right for the two period model. The expected value is calcuated as the probability weighted sum of state-dependent discounted total profits, 4.441. Expected utility is calculated likewise, 2.931.

The style code for our box-and-arrow diagram is:

```
\begin{figure}[!htp]
\centering

\tikzstyle{decision} = [diamond, draw, fill=gray!20]
\tikzstyle{line} = [draw, -stealth, thick]
\tikzstyle{elli}=[draw, ellipse, fill=red!50,minimum height=8mm,
text width=5em,
text centered]
\tikzstyle{block} = [draw, rectangle, fill=gray!20, text width=6em,
text centered, minimum height=12mm, node distance=5em]
```

The node and placement is rather repetative for this particular example so we paste only a sample here:

```
\begin{tikzpicture}
\node [decision] (start) {$w_0=1$};
\node [block, right of=start,
xshift=7em,
yshift = 3em] (process2) {$a_t=0.5$ \\ $w_t=1.5$ \\$x_t=0.5$};
\node[block, below of=process2,
xshift=0em,
yshift = -0.25em] (process3) {$a_t=1$\\$w_t=2$\\$x_t=1$};
\node[block, below of=process3,
xshift=0em,
yshift = -0.25em] (process4) {$a_t=1.5$\\$w_t=2.5$\\$x_t=1$};
\node[block, below of=process4,
xshift=0em,
yshift = -0.25em] (process5){$a_t=2$\\$w_t=3$\\$x_t=1$};
```

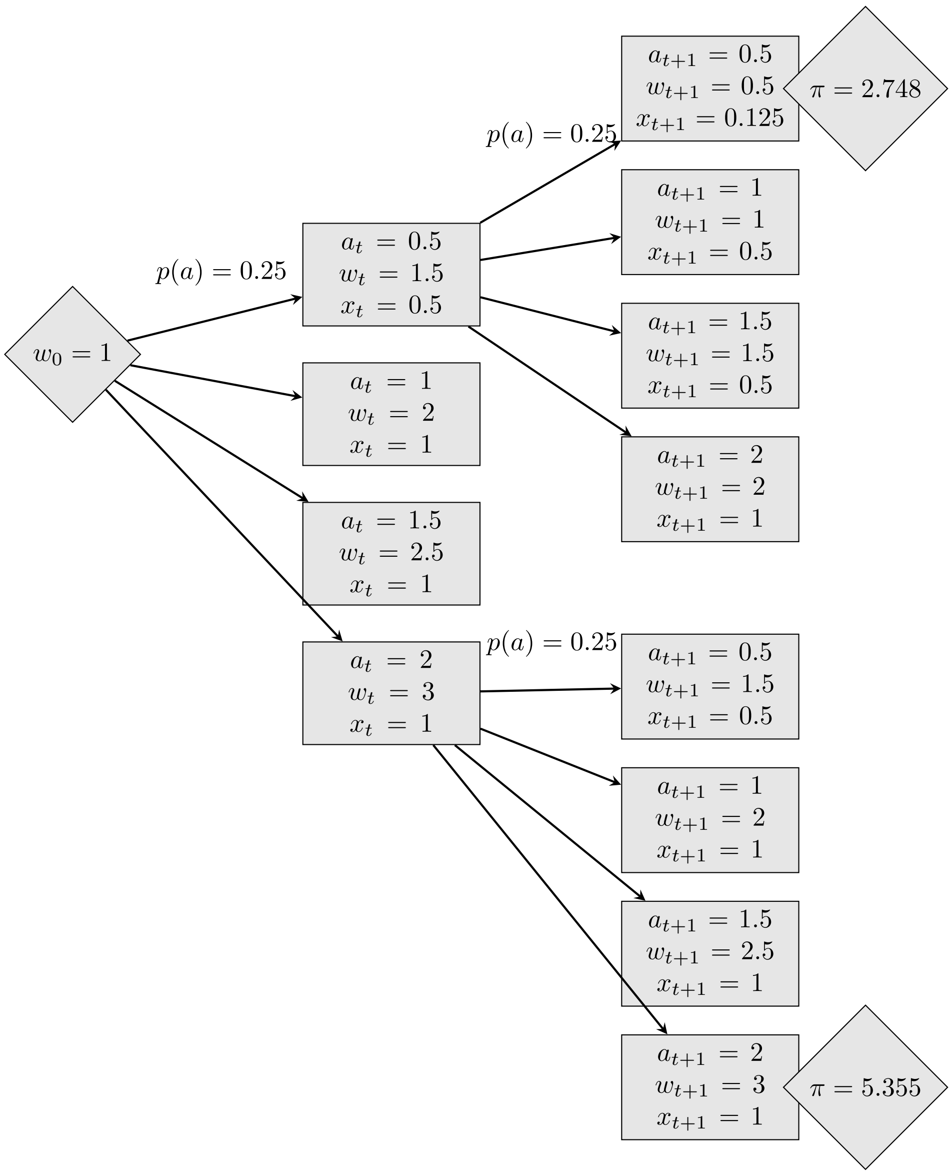

Figure 4: Value of storage and use right

A sample of the edge connectors:

```
\path [line] (start) -- node[xshift=0.25em,yshift = 1.75em]{$p(a)=0.25$} (process2);
\path [line] (start) -- node[yshift=0.75em]{}(process3);
\path [line] (start) -- node[yshift=0.75em]{}(process4);
\path [line] (start) -- node[yshift=0.75em]{}(process5);

\path [line] (process2) -- node[xshift=0.05em,yshift = 1.75em]{$p(a)=0.25$} (process6);
\path [line] (process2) -- node[yshift=0.75em]{}(process7);
\path [line] (process2) -- node[yshift=0.75em]{}(process8);
\path [line] (process2) -- node[yshift=0.75em]{}(process9);

\path [line] (process5) -- node[xshift=0.05em,yshift = 1.75em]{$p(a)=0.25$} (process10);
\path [line] (process5) -- node[yshift=0.75em]{}(process11);
\path [line] (process5) -- node[yshift=0.75em]{}(process12);
\path [line] (process5) -- node[yshift=0.75em]{}(process13);
%\path [line] (decision1) -| node[yshift=0.5em, xshift=10em] {yes} (process1);
%\path [line] (decision1) -| node[yshift=0.5em, xshift=-10em] {no} (process2);
\end{tikzpicture}

\caption{Value of storage and use right}
\label{fig: cc_water_value}
\end{figure}
```