SDDP
Generation and Transmission Planning Model

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for

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Stochastic Dual Dynamic Programming

- What is SDDP
- Purpose of this project
- Other users
- Why was SDDP selected
- Main Features
- Typical outputs and applications
- How it works

What is SDDP?

- Stochastic Dual Dynamic Programming
- Very detailed hydro-thermal power system optimal dispatch
- Detailed in both generation & transmission aspects
- Global optimum, as would be determined by a central dispatcher

Project Objectives

- Assemble a data base
  - no comprehensive publicly available data base of electricity system parameters
- Demonstrate the capabilities of a detailed model
- Make available a resource for planning studies within Transpower and elsewhere
- Enable Transpower to fulfill new roles

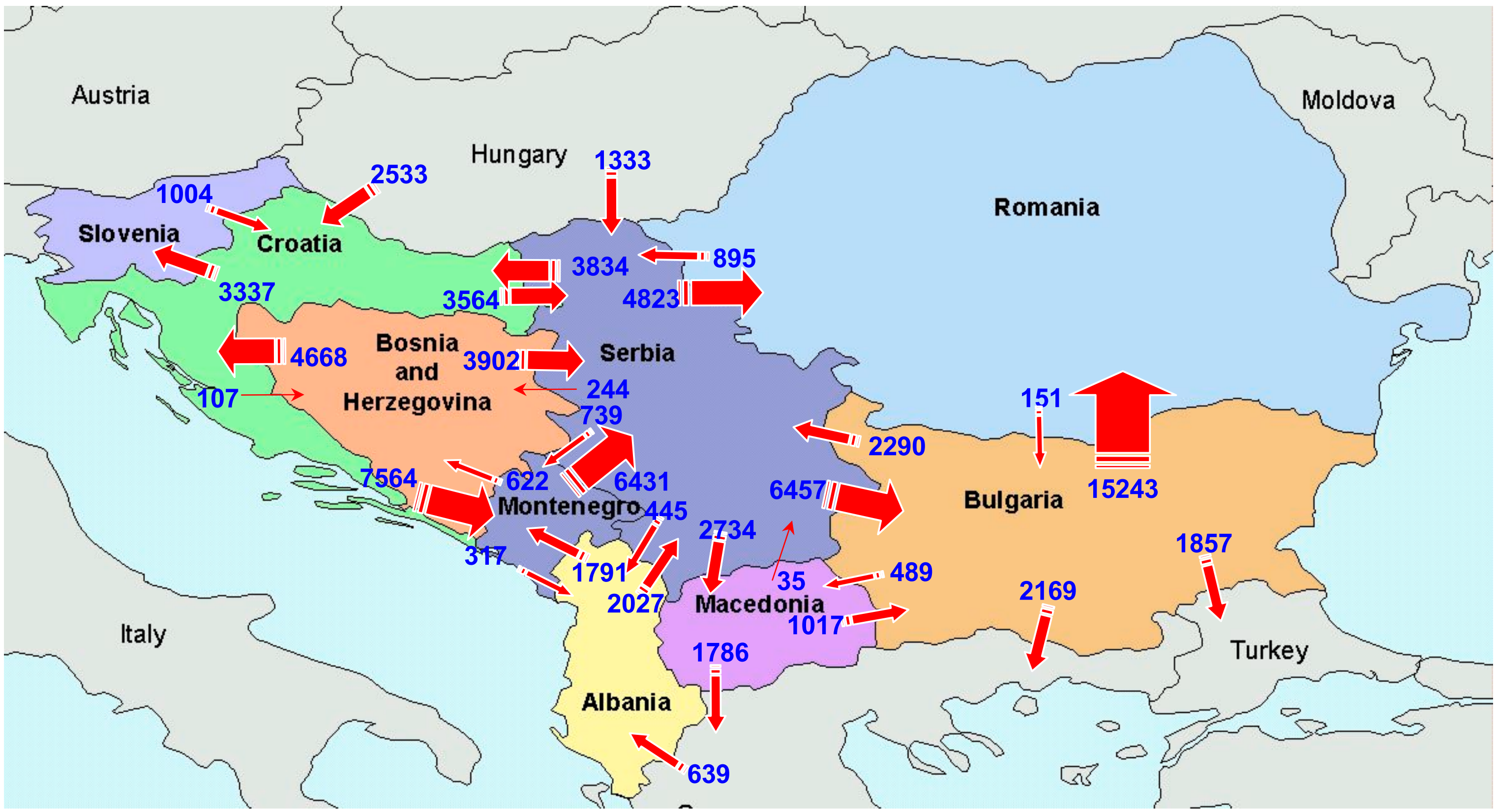
Other Users of SDDP

- First used to analyse the six Central American countries - World Bank study
- Consultants, generation companies, grid operators, regulators, government planners
- Licenced in:

  Argentina, Austria, Bolivia, Brasil*, Chile, China, Colombia*, Costa Rica, Dominican Republic*, Ecuador, El Salvador*, Guatemala*, Honduras, Nicaragua, Panama*, Scandanavia*, Spain, US Pacific Northwest*, Venezuala, United States by companies with international portfolios

Scenarios Analysis and Simulation Results:

Energy Exchanges Between Countries under Scenario 1 --- 2010 (GWh)



Why SDDP was Selected

- Tested by ECNZ 1995
- Stochastic
- Multi-reservoir
- Generation & transmission
- Provides most features required
  - some of these added 1994/95 for ECNZ
- Extensive use elsewhere & on-going support
- Ease of testing - demonstration copy, documentation, available at no cost
- Good relationship with vendor

Selection of SDDP (continued)

- Model information available is most unusual
  - algorithm published in Mathmatical Programming
  - manuals describe the maths in detail
  - source code has been studied
  - vendors answer every question
- Usually only a functional specification available, but no implementation details
- Source code usually kept secret

Stochastic Model

- Two main categories of stochastic models
  – stochastic LP solves a scenario tree structure
  – stochastic dynamic programming generally not practicable beyond three dimensions due to computation requirements
- SDDP overcomes dimensionality problem by sampling - build an accurate function only where it is needed
- Iteratively builds a function for each time step
  – cost-to-go as a function of reservoir level and last week's inflows

Solution Methodology

- Rigorous mathematical basis
- Solve a large number of one week optimal dispatch problems using linear program
- LP gives
  - sensitivity information
  - consistent results
- Mathematics aids understanding

SDDP Capabilities (1)

- Weekly or monthly time step
  - weekly for NZ study
- Time horizon 360 stages (or more)
  - limits set at compile time
- Load duration curve, up to 5 blocks
  - NZ not peak capacity constrained, 5 blocks adequate
- HVDC and AC transmission system
  - various options for AC model

SDDP Capabilities (2)

- Each large hydro reservoir modeled
  - no aggregation of reservoirs
- Each hydro station included, actual flow paths
  - Tekapo spills to Benmore
  - Residual flows for Project Aqua
- Roxburgh - part on 220 kV, part 110 kV
- Seasonal variations in
  - lake maximum levels
  - minimum flows

SDDP Capabilities (3)

- Inflow data from the “Power Archive”
  - 71 year record
  - Mangahao data not released
  - Tongariro total diversion only since 1997
  - Waikaremoana data not available last 18 months
- Synthetic inflows for optimization
  - spatial correlation
  - auto correlation (correlation in time)
- Final simulation with historical record

SDDP Capabilities (4)

- Each thermal plant modeled
  - constraints on fuels shared by several stations
- Multiple fuels possible at each station
- Unit commitment
- Huntly coal stockpile modeled as a hydro reservoir with specified inflows
- Maintenance generally modeled as a derating
  - put in explicit schedules if known

SDDP Capabilities (5)

- Transmission system model similar to SPD
- DC link handled directly by LP
- AC system represented by DC power flow
  - Solve one stage dispatch, then solve DC loadflow, identify constrained lines, add these to the dispatch optimization
  - optional AC system loss calculation, piecewise linear, iterative solution
  - nodal prices available

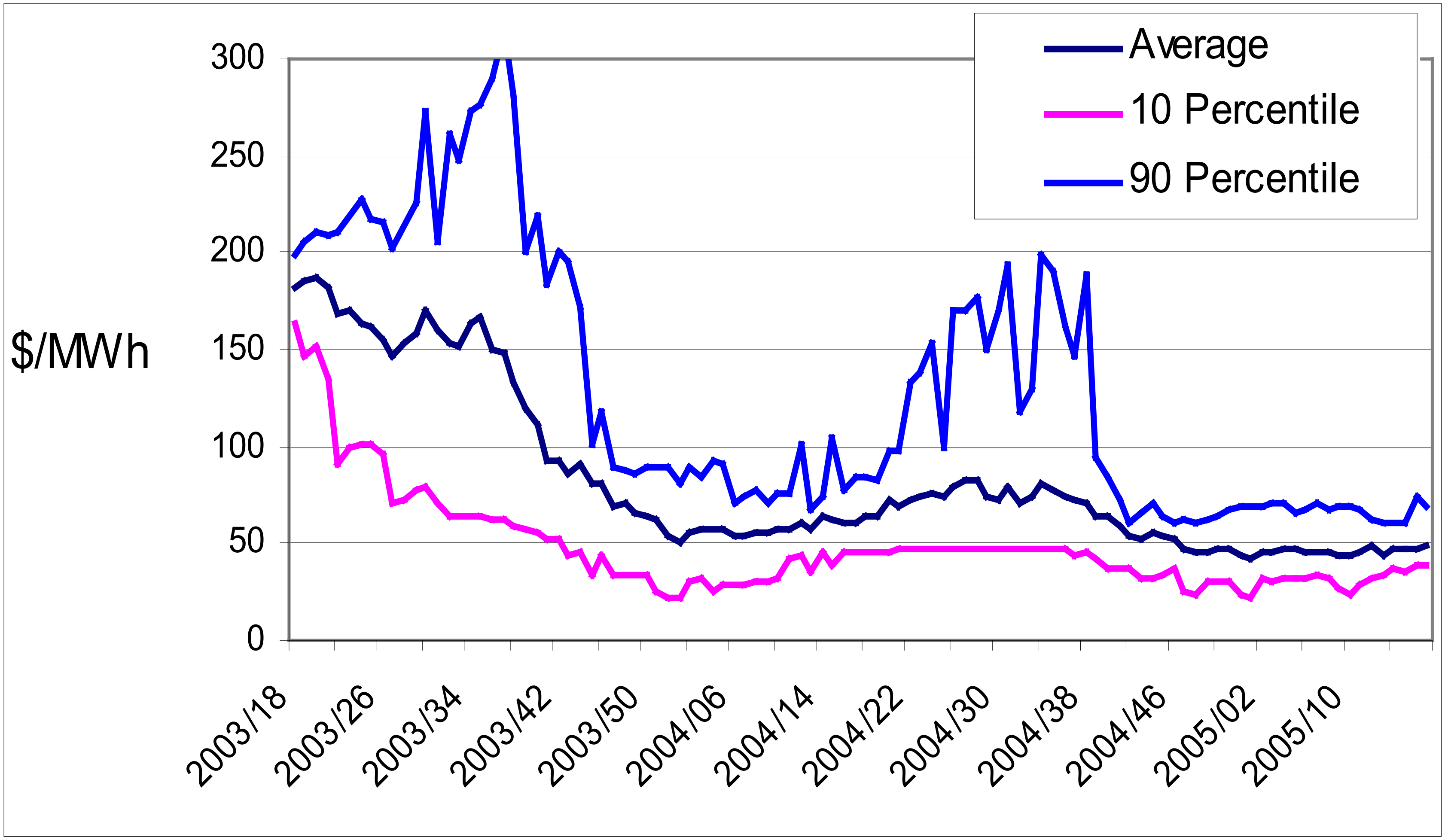
SDDP Capabilities (6)

- 300 lines, 120 busses in simplified system
  - most of 220 & 110 kv systems
  - more lines & busses if required
- Contingency constraints
  - outages studied for up to 10 lines
  - examine up to 5 lines in each case for overload

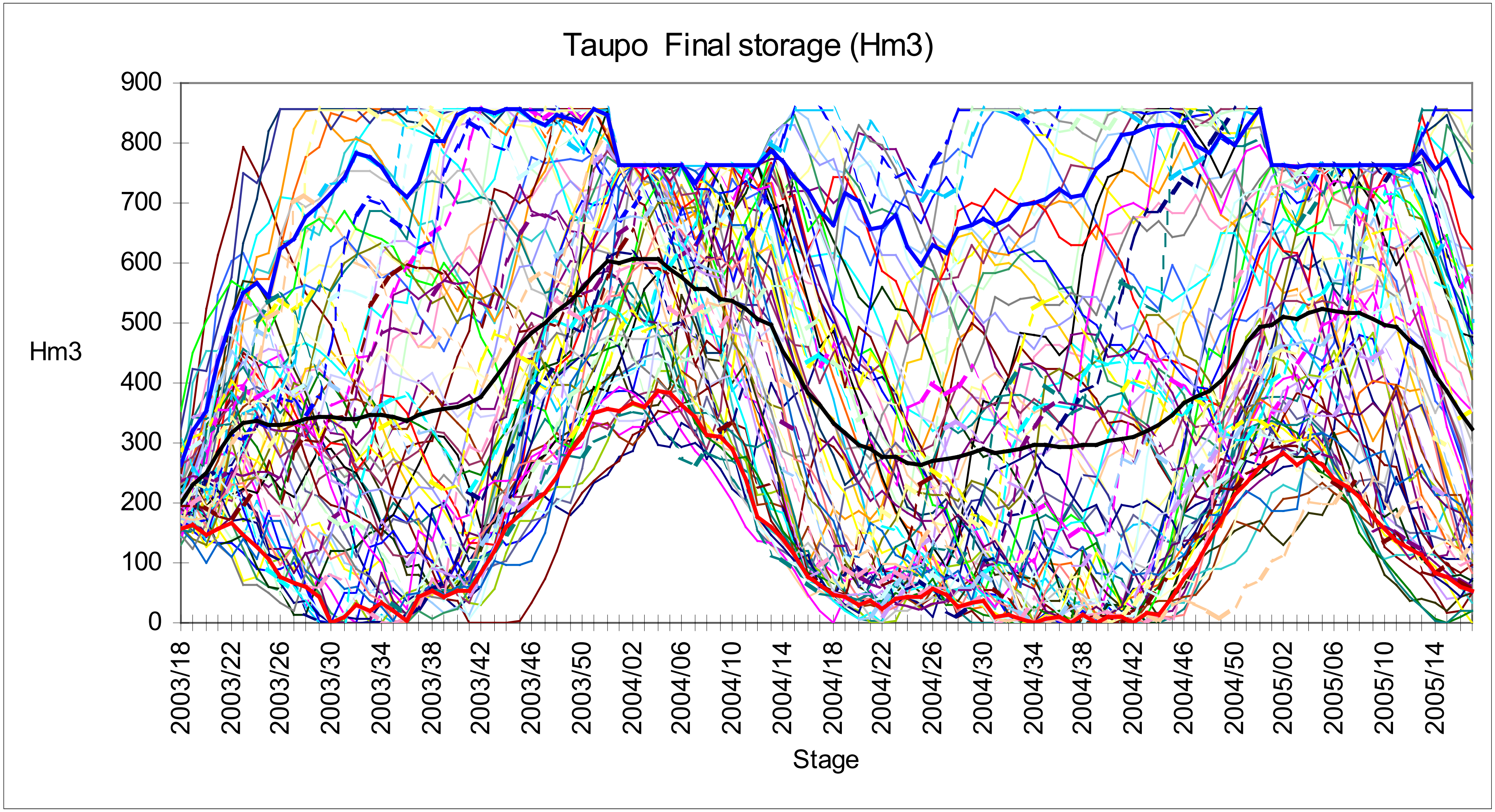
Software Configuration

- Runs on a Windows PC
- Fortran executable
- VB interface
- Output:
  - summary report, text
  - select from 98 csv files
- 4 year optimization (weekly) approx 19 hours (1.8 GHz laptop)
- Simulation approx 2.7 hours with transmission system model

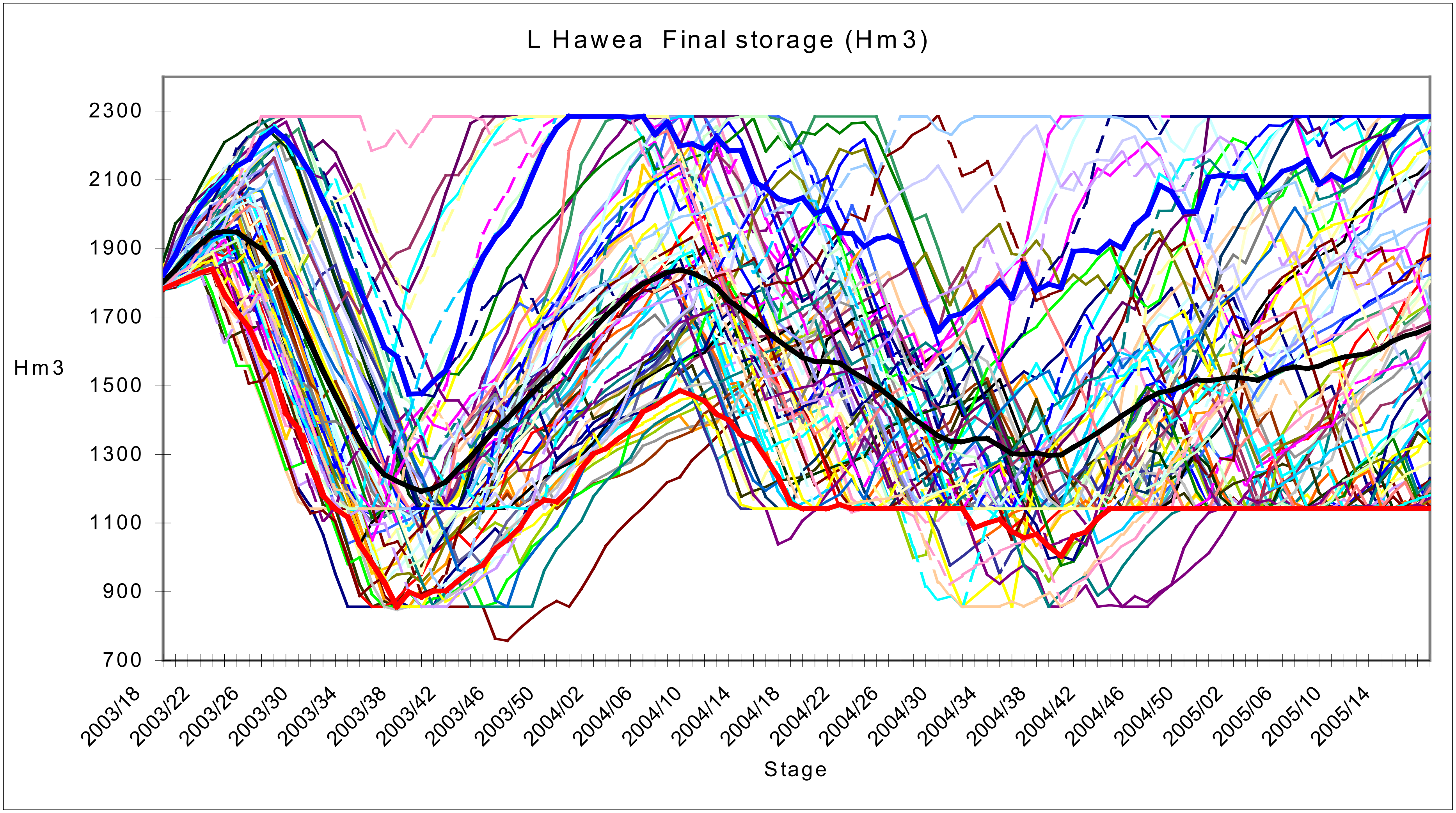
NI Marginal Cost, Weekly Average



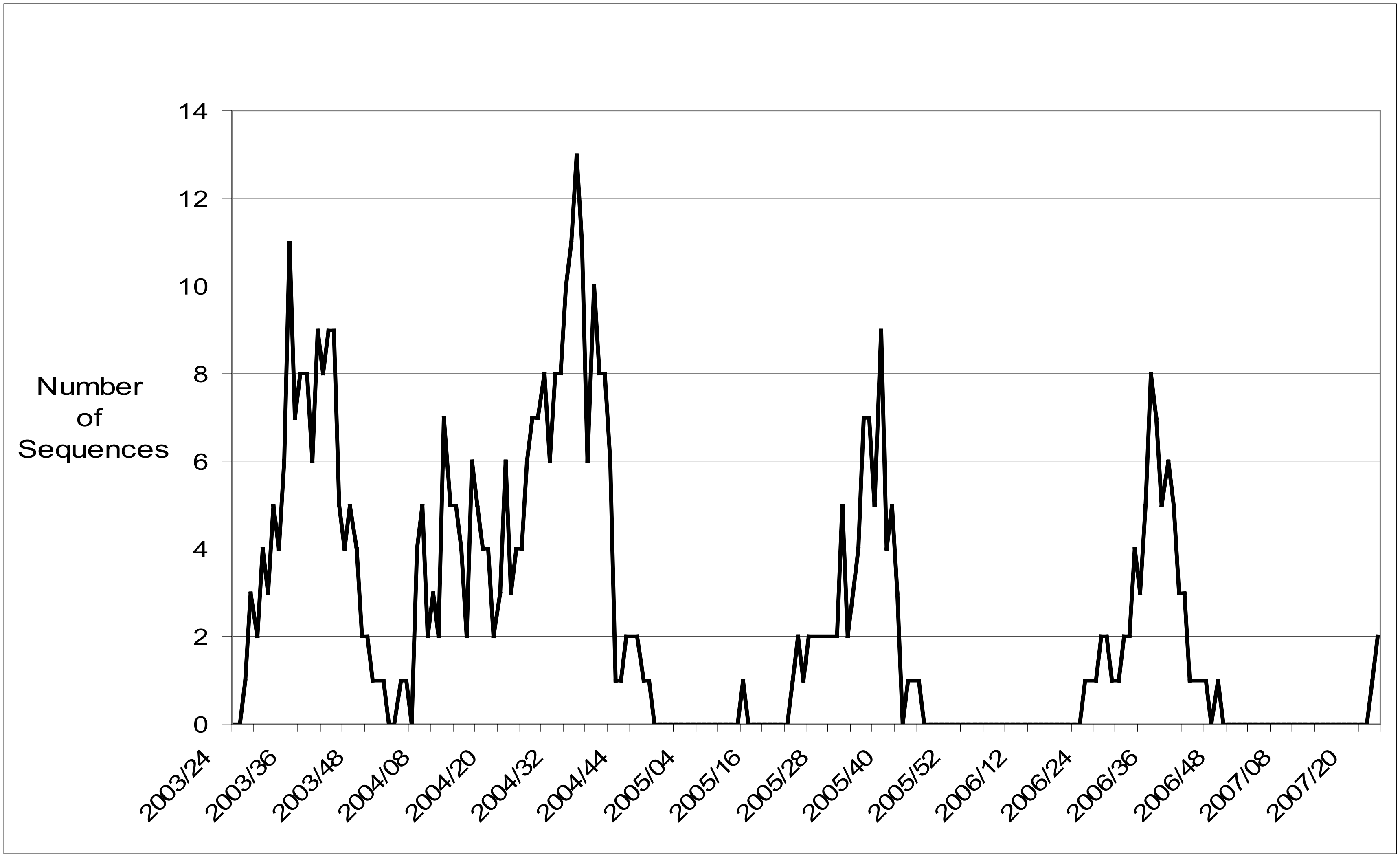
Taupo Storage



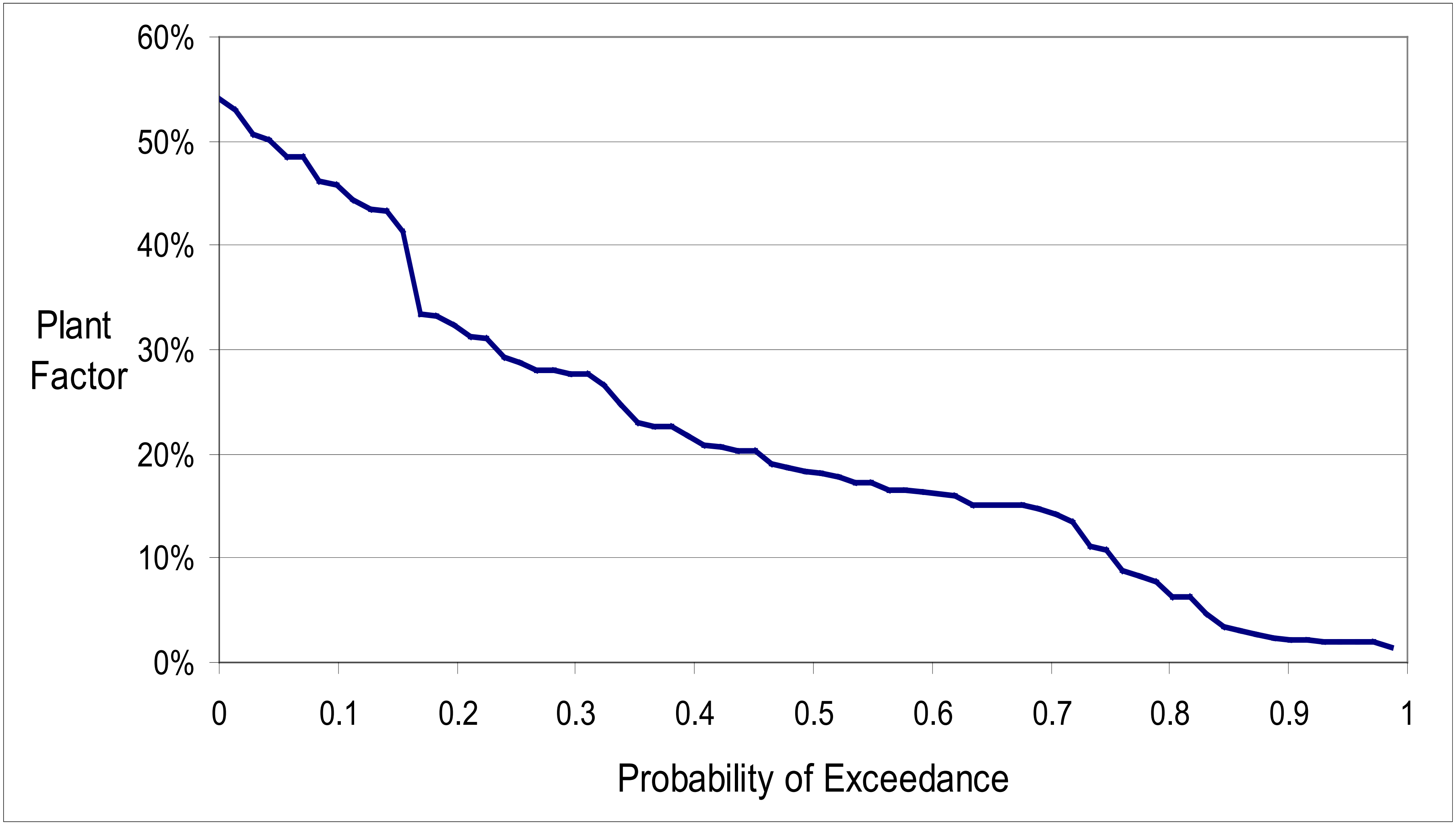
L Hawea Storage



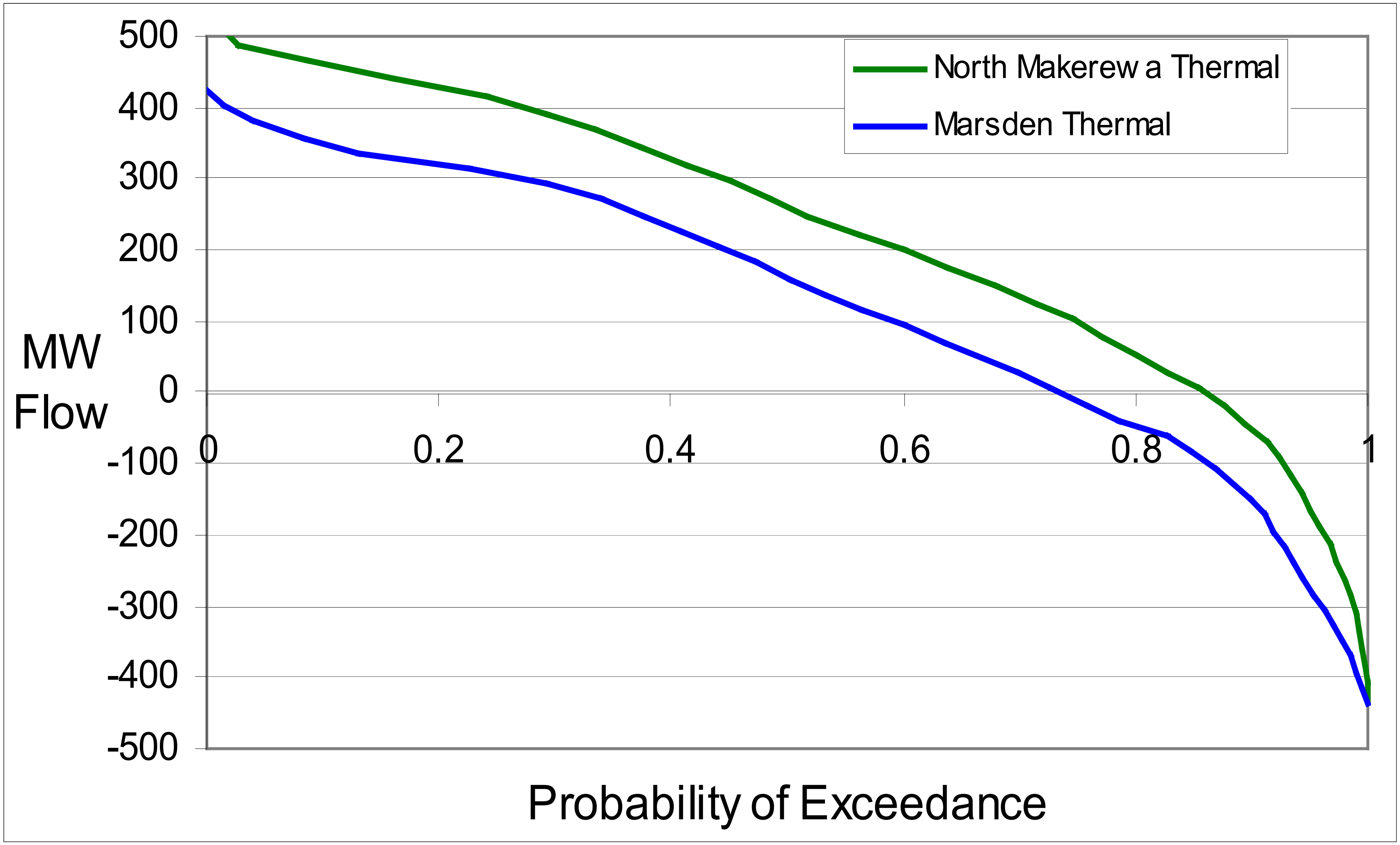
Number of Sequences with Shortfall



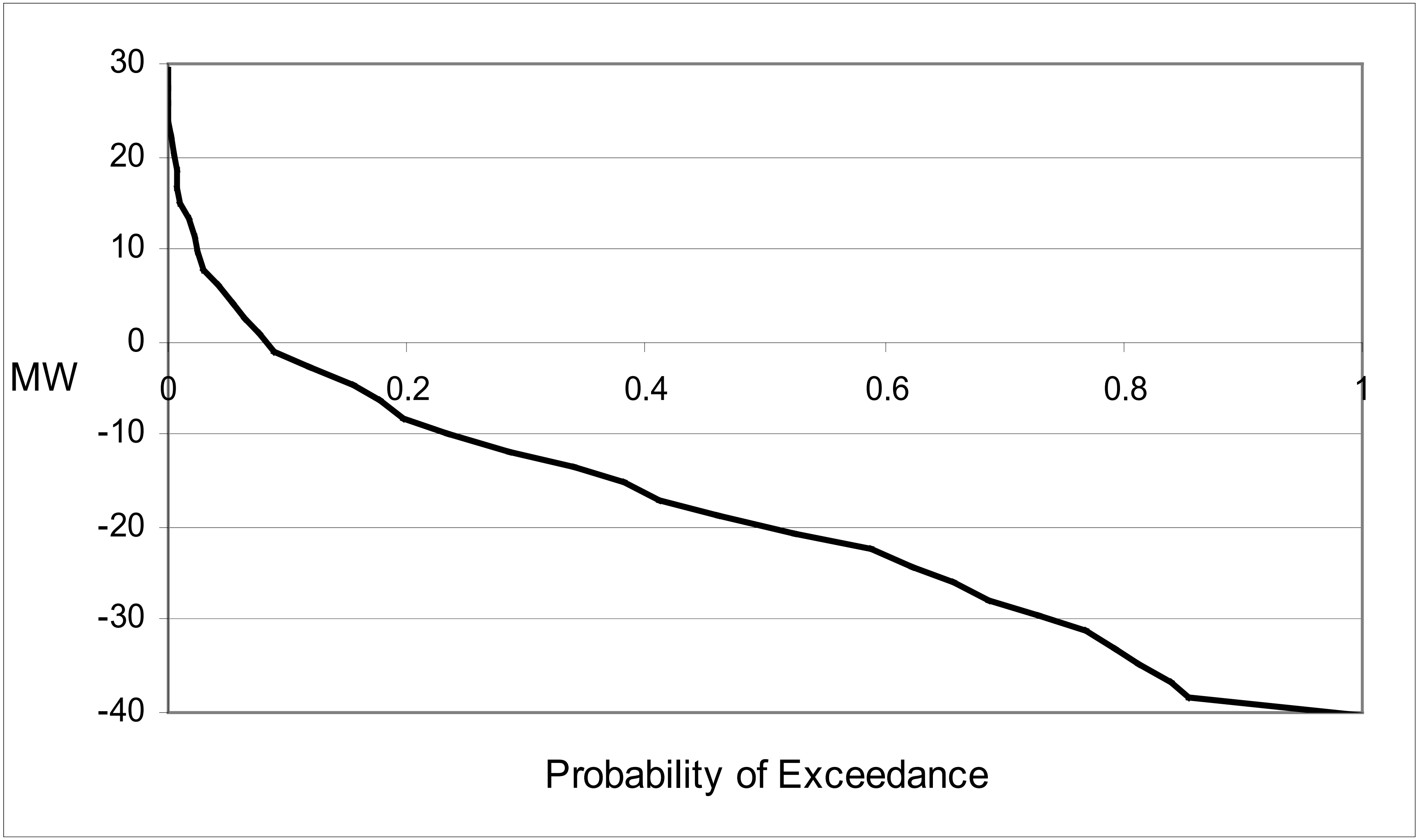
New CT Annual Plant Factor 2004/05



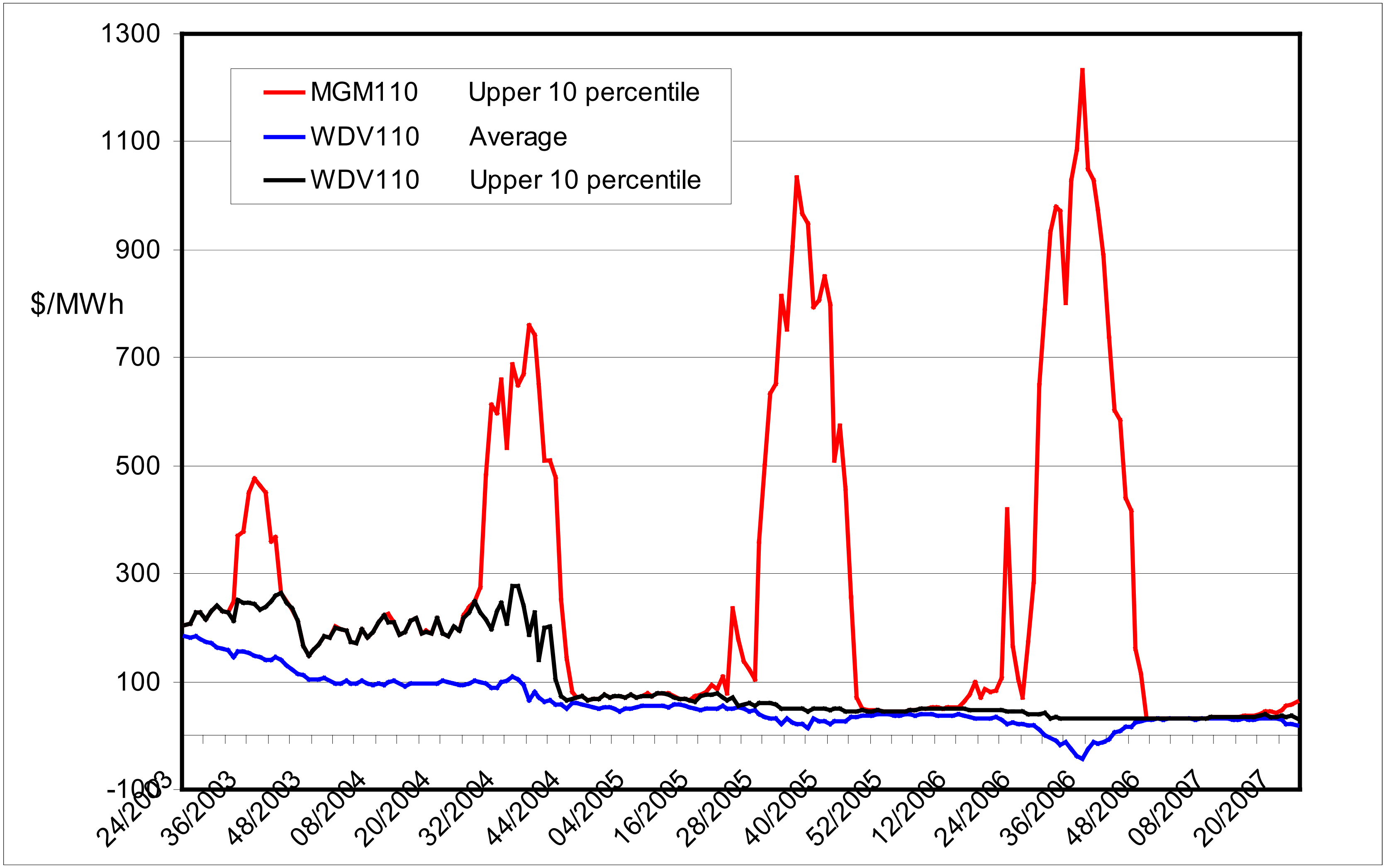
Clyde - Twizel Line flow for 2007



Mangamaire - Woodville Line Flow



Bus Marginal Costs in the Wairarapa

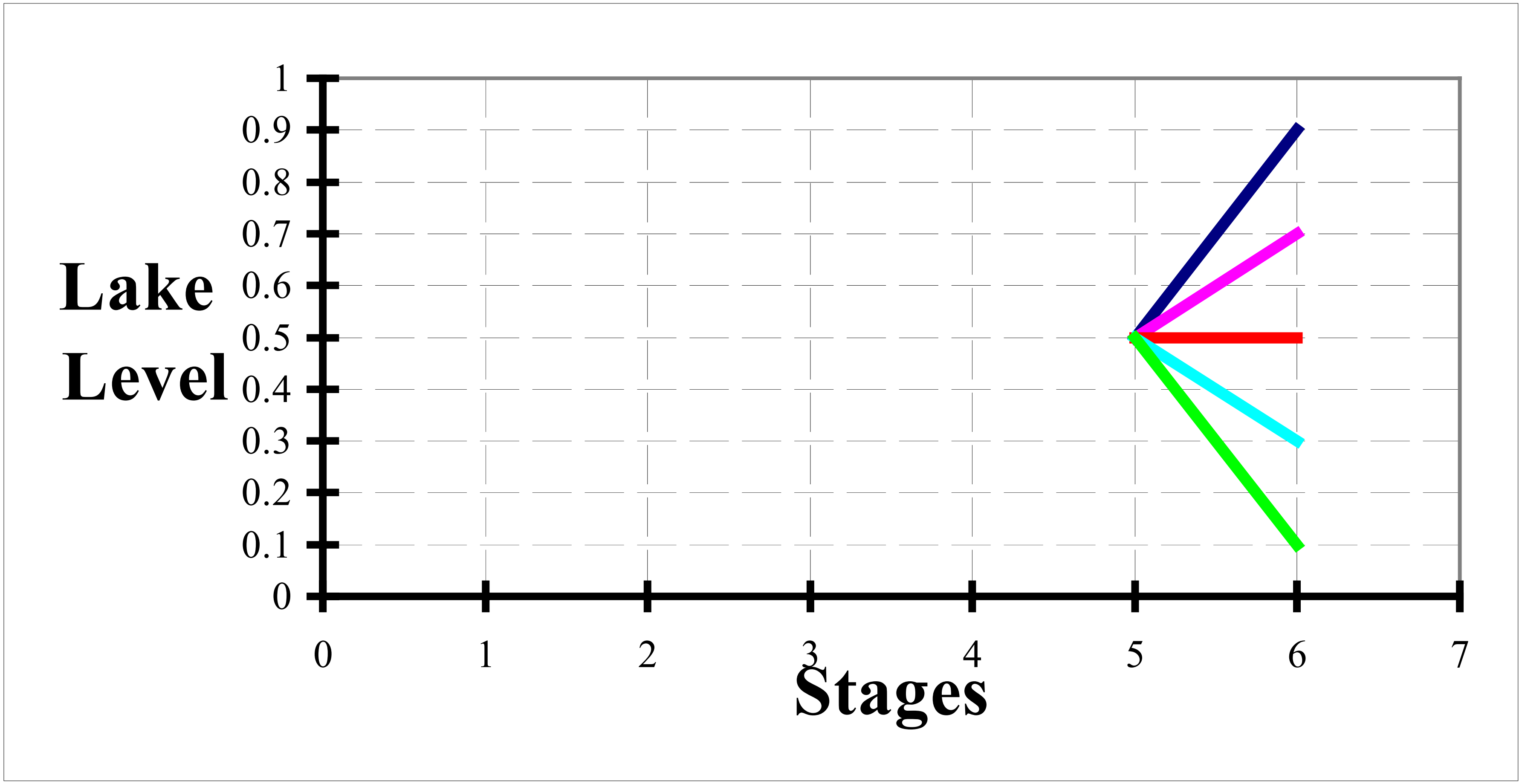


Where to now?

- Useful to outside organizations
- Anyone can buy or lease the model
- All data is in public domain, except some flow data
- Transpower lease of the model for the remainder of this year

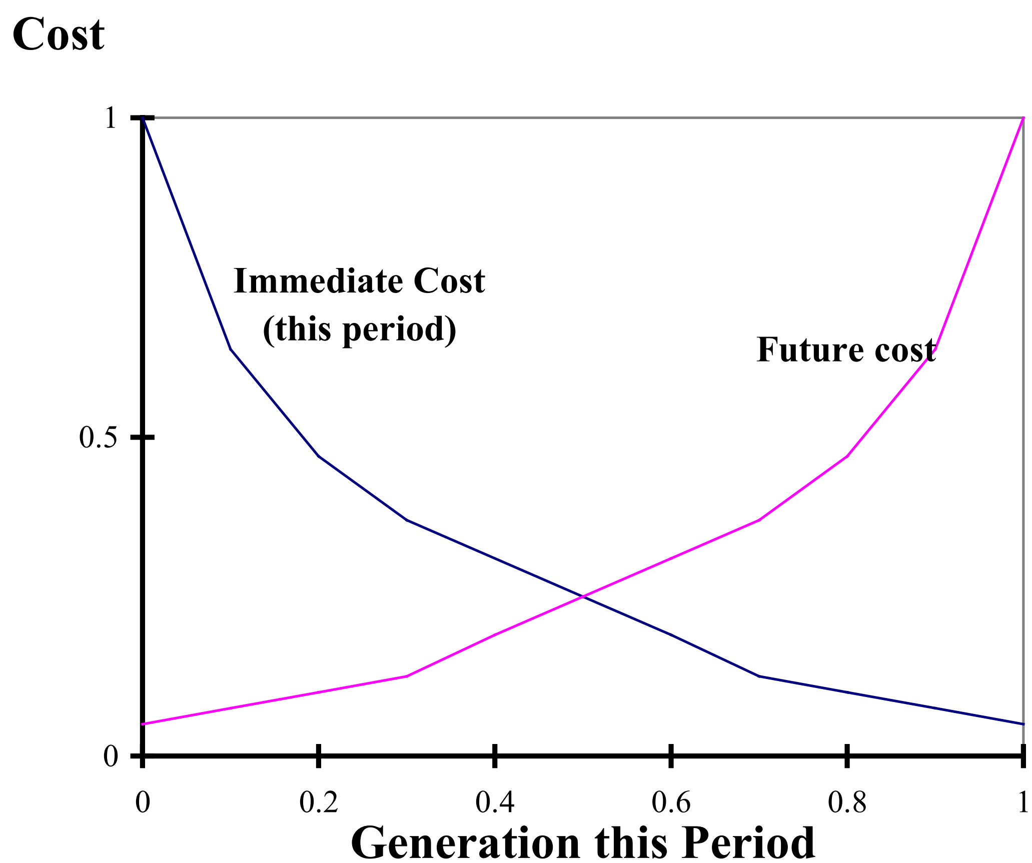
SDDP Algorithm

Begin with backward pass as for conventional stochastic DP

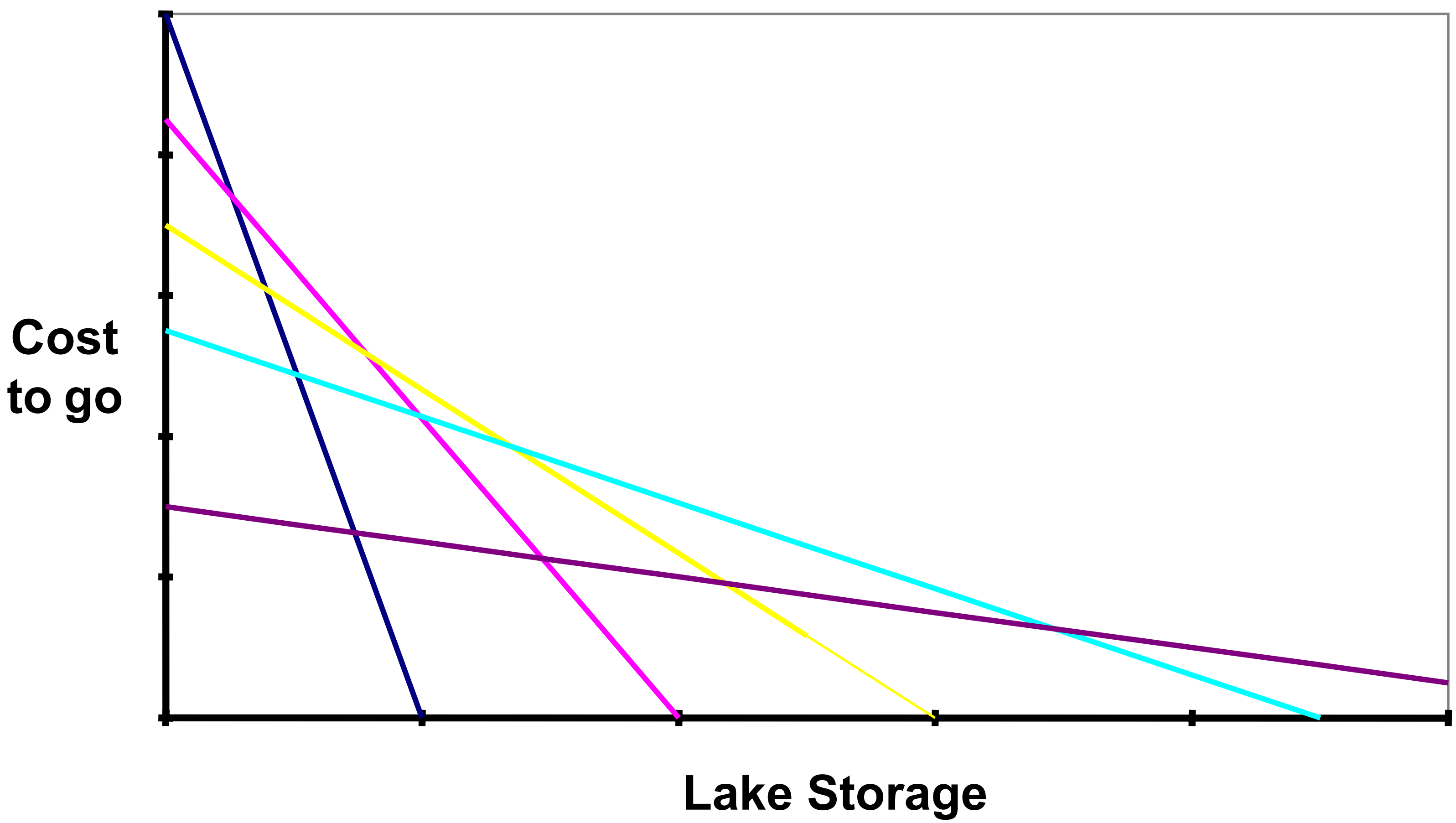


LP solved for each flow outcome

- Deterministic
- Minimise sum of immediate cost (this period) + future cost
- Trades off use of water now with storage for later use



Add a plane to cost to go function at each storage point



At each storage point

- Generate (eg 15) random inflow outcomes using a multivariate autoregressive model
- Consistent with flow outcome for preceding time period, ie autocorrelation preserved
- Solve for each inflow outcome using LP
- Store average slope in each dimension = average multiplier on flow balance equation, and cost axis intercept
- Typically 50 points per time period, 15 flow outcomes

Forward simulation

- Used to determine upper bound
- Storage values passed through form new points for next backward optimisation pass
- Can use different flows, plant availability, etc using existing policy (result of an optimisation) to simulate changes in the system

Iterative Process

- Optimise in backward direction.
- Simulate in forward direction using this policy - cost must be higher than optimal as have a sub-optimal policy.
- Optimise again, backward, using storage levels that the simulations passed through. Gives a lower bound.
- Each optimisation adds more information to the cost-to-go function. When detailed enough, process is converged.

SDDP Recursive Equation

For each time step, each point in state space, each flow outcome

$Cost_t^k(v_t) = \text{Min } c_t(u^t) + \alpha_{t+1}$

subject to	$v_{t+1} = v_t - u_t - s_t + a_t^k$	water balance
	$v_{t+1} \leq v_{max}$	max volume
	$u_t \leq u_{max}$	max flow
	$\alpha_{t+1} \geq \varphi^n_{t+1} v_{t+1} + \delta^n_{t+1}$	future cost