Selection and Agreement on the most appropriate modelling platform to develop Operating Rules for the Save Basin

10 February 2014

In support of: CRIDF UK AID From the British People

Prepared by: wrp A Miya Group Company

Terms of Reference

1) General background to the modelling system.
2) The use of the model in transboundary systems in SADC – with examples.
3) The use of the model to support water resources planning and the development of operational rules.
4) The kind of management support that is provided.
5) The way the model addresses climate variability and climate change.
6) Discussion on whether changes to the modelling software or its application would be needed to address the needs of the Save Joint Basin Commission and CRIDF.
7) Any model licensing fees are required as either a once off or an annual fee.
8) Available training courses and back up support in the region.

Background to the modelling system

- **Introduced to SA in the early 1980's, developed from "*Acres Reservoir Simulation Program*" – Canadian origin.**
- **Major enhancements for Southern African conditions:**
  - Risk based analysis accounts for runoff variability and long droughts.
  - Drought restriction rules applying priority based multi-user risk criteria.
  - Salinity modeling – blending, dilution rules & evaluate effect of pollution management measures.

Validation and Renewal

- **Verification by SA and International Experts**
  - Prof J.R. Stedinger and Prof D.P. Loucks (Cornell University, USA)
  - Prof Fontanne and Prof Grieg (Colorado State University)
  - Prof O'Connell – Newcastle University
  - Prof G.G.S. Pegram, Dr M.S. Basson and Dr R.S McKenzie (SA based)
- **Continuous upgrading of the software systems:**
  - Object Orientation Design (from Fortran to Delphi Pascal).
  - Modern user interface.
  - Additional features such as groundwater-surface water Interaction.
  - Ongoing research funded SA Water Research Commission.

Reference: "Probabilistic Management of Water Resources and Hydropower Systems"
(Basson, Allan & Pegram., 1994)

(ToR: 1)

Core simulation engines

- **Linear network solver:**
  - Optimising flows in time step (monthly) according to user-defined weights which implements the required operating regime.
  - Supply priority hierarchy achieved irrespective of the position of the abstraction in the system.
  - Account for physical, continuity and connectivity constraints.
- **Risk analysis:**
  - Rigorous multi-site stochastic stream flow generator accounting for cross and serial correlations and maintain historical statistical characteristics.

Purpose of WRYM and WRPM

- Water Resource Yield Model:
  - Constant development simulations to perform long-term historical and stochastic (risk based) yield analysis.
  - Optimisation of inter sub-system operating rules.
  - Generate short-term yield reliability characteristics as input to WRPM, driver of risk based drought restriction rules.
- Water Resource Planning Model:
  - Projection analysis for operational and development planning decision support.
  - Dynamic changing water use, new infrastructure, maintenance schedule and project the risk of drought curtailments.

Similar modelling systems

- CALSIM II, California
- REALM, Australia
- MODSIM
- OASIS
- RiverWater
- WEAP

A Strategic Review of CALSIM II and its Use for Water Planning, Management, and Operations in Central California

Submitted to the

California Bay Delta Authority Science Program
Association of Bay Governments
Oakland, California

by

A. Close, W.M. Haneman, J.W. Labadie, D.P. Loucks (Chair), J.R. Lund, D.C. McKinney, and J.R. Stedinger

December 4, 2003

Applications in SADC:

- All major water resource systems in SA , including most stand alone system providing water to significant towns and villages.
- Orange-Senqu River Commission: RSA, Lesotho, Botswana & Namibia.
- Mozambique and Zimbabwe: Save, Buzi and Ruvuma Rivers
- Mozambique: Incomati, Maputo, Pungwe River & Nacala Dam
- Swaziland: Umbeluzi River
- Namibia: Fish River, Neckertal Dam, Central Area Water Master Plan
- Lesotho: Metolong Dam, Annual State of Water Resources
- Botswana: Ntimbale Dam, allocation from Molatedi Dam
- Seychelles: La Gogue Dam
- Limpopo Watercourse Commission (LIMCOM)

  (Limpopo River Basin Monograph)

Model use in water resource management

- Development planning
  - Vaal River System
- Allocation planning (reallocation)
  - Marico River System
- Operating rule development
  - Orange River System

All based on assessing the risk of water availability and how it compares against specific risk criteria

Model application in development planning processes

WRYM and WRPM

1 Identify the need for intervention

2 List all possible intervention options

→ Eng. / soc. / env. & inst. considerations and judgement

WRYM

3 Undertake initial screening process

→
- Historical yield analysis
- Preliminary economic analysis
- Determine URVs
- Eng. / soc. / env. & inst. cons.

4 List most feasible options

WRYM

5 Rank selected options

→
- Stochastic long-term analysis
- Prelim. implementation schedule
- Initial estimate filling times
- Re-determine URVs

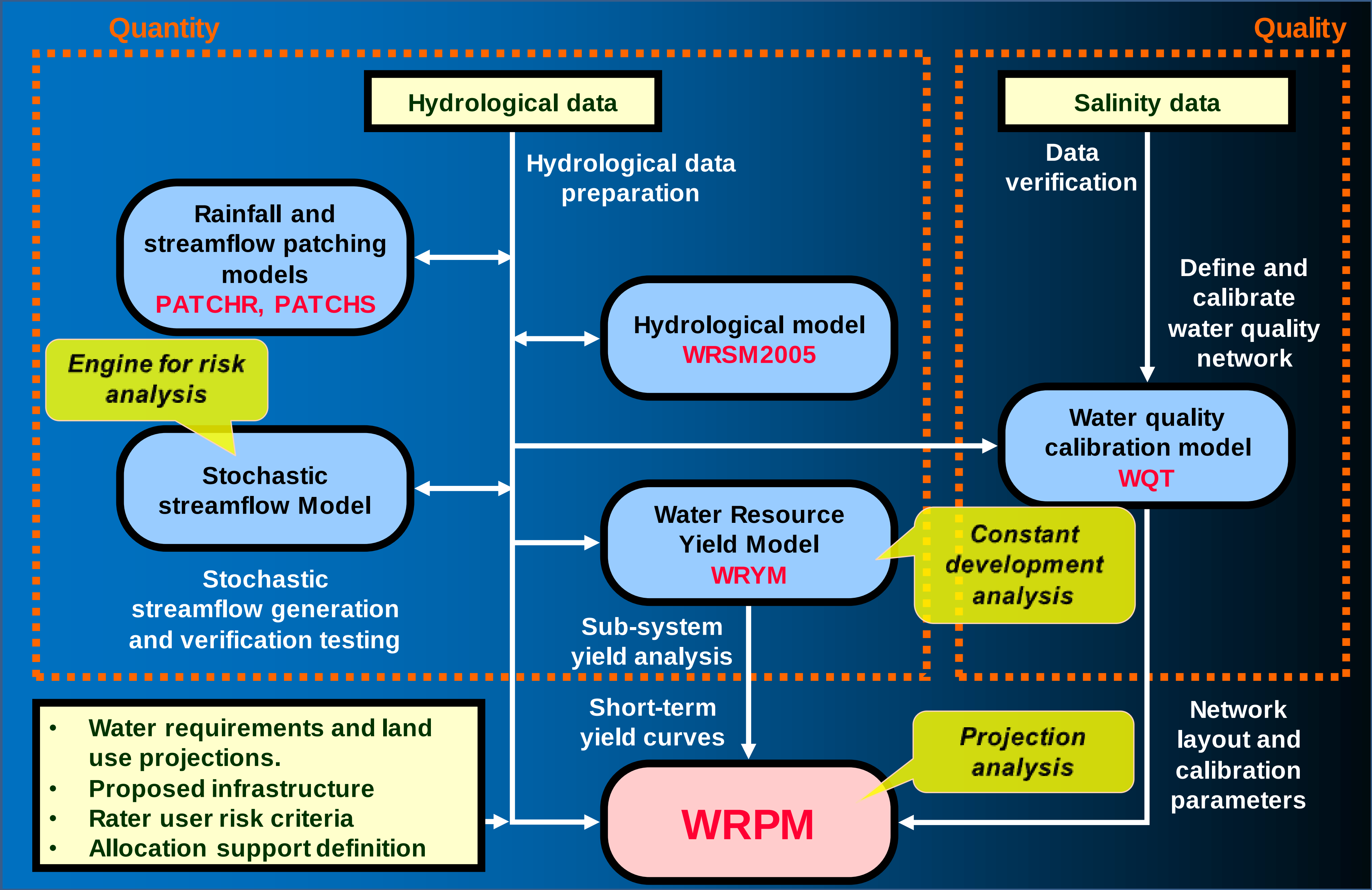
WRPM

6 Schedule selected option

→
- Establish commissioning dates
- Refine implementation schedule
- Finalise URVs

(ToR: 3 & 4)

Models in the analysis process



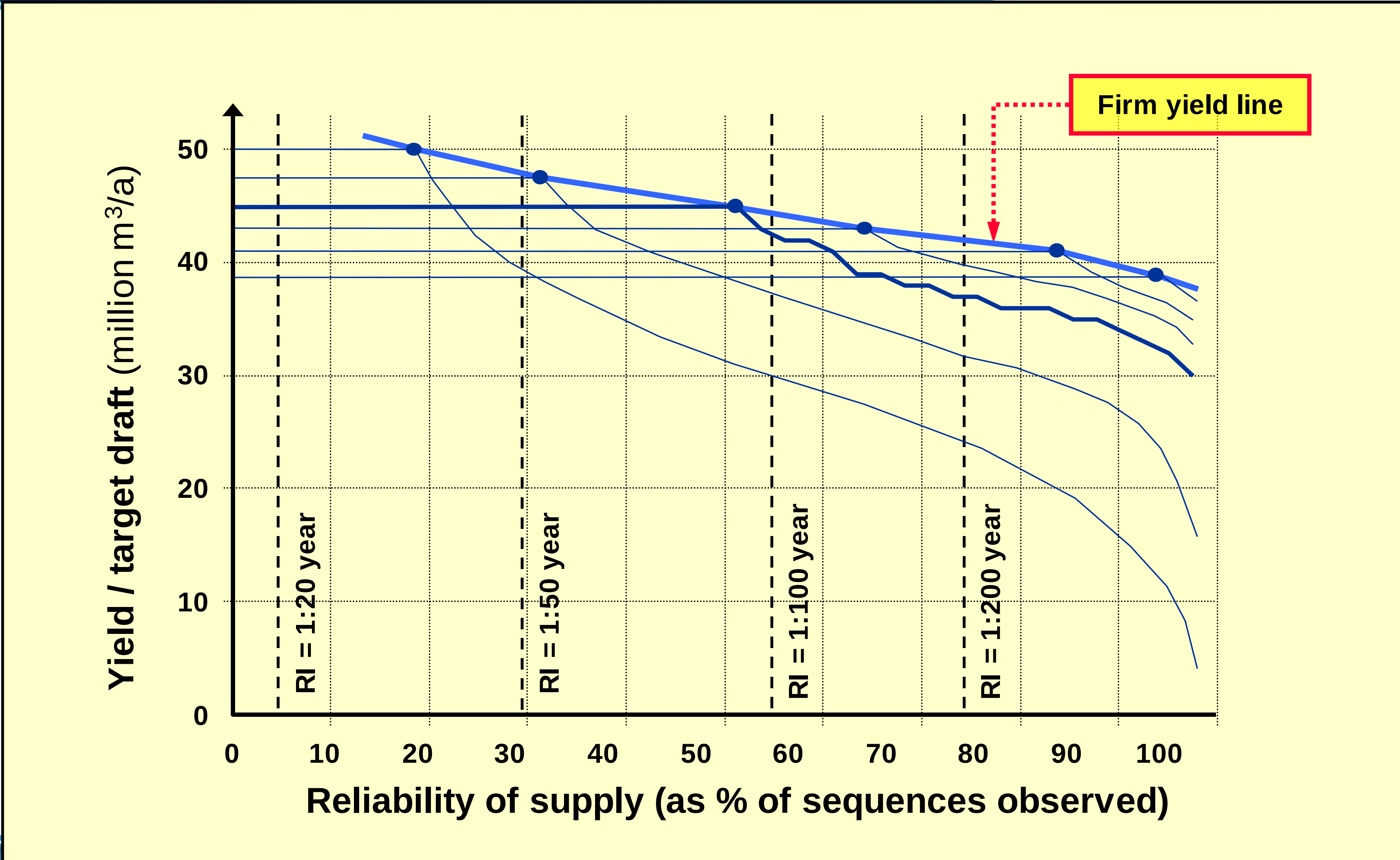
Why bother with risk analysis?

Period of analysis (hydrological years)	Number of years	Firm yield (million m^3/a)
1930 – 1934	5	81
1930 – 1939	10	69
1930 – 1949	20	69
1930 – 1969	40	69
1930 – 1989	60	36

(ToR: 3 & 4)

(Historical yield analysis at Midmar Dam)

The solution is to derive the yield-reliability relationship



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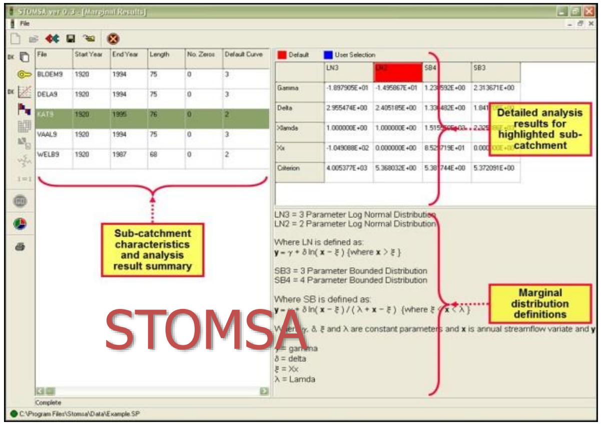
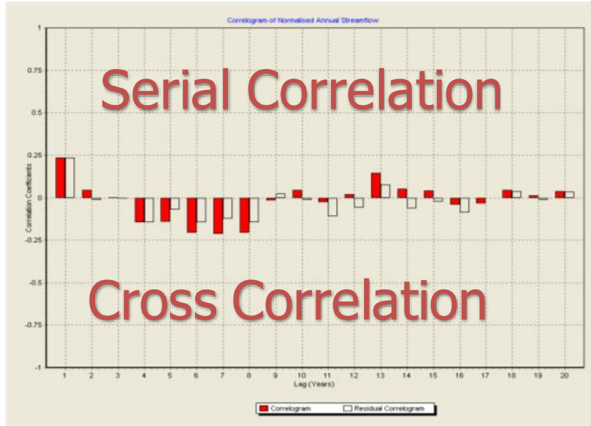
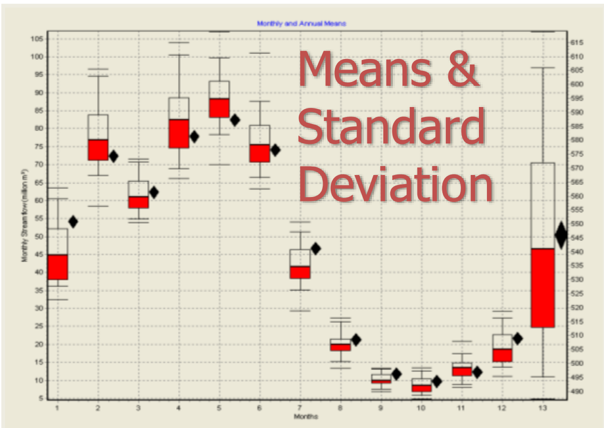
Stochastic Streamflow Generation

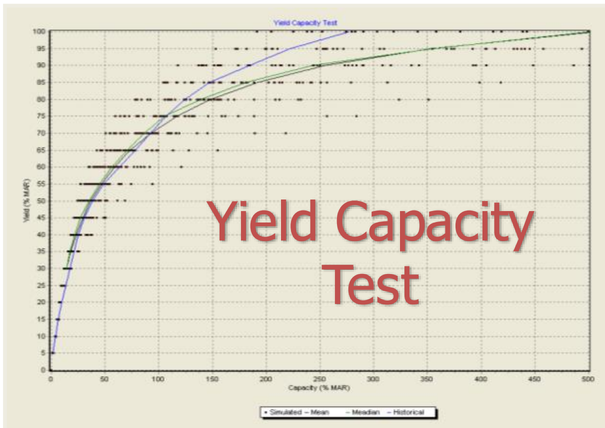
Parameter Estimation

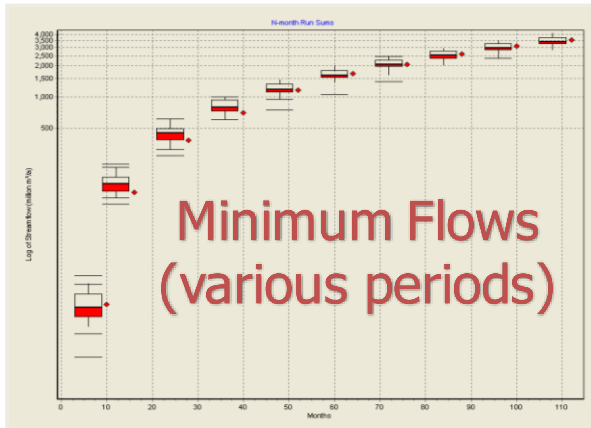




Validation Tests







(ToR: 3 & 4)

Model Features for Development Planning (WRPM)

- **Risk analysis for future planning:**
  - Changing abstraction, return flows & land use over planning horizon.
  - Progressive saving scenarios, Water Conservation and Water Demand Management programs.
  - Schedule of pollution management measures by simulating short, medium and long term options.
  - Analysis of alternative sequence schedules of options.
  - Assess filling time requirements of new dams.
  - Take account of the implication of current dam storage.
  - Drought restriction rules part of development planning.

Development Planning Example: Vaal River System

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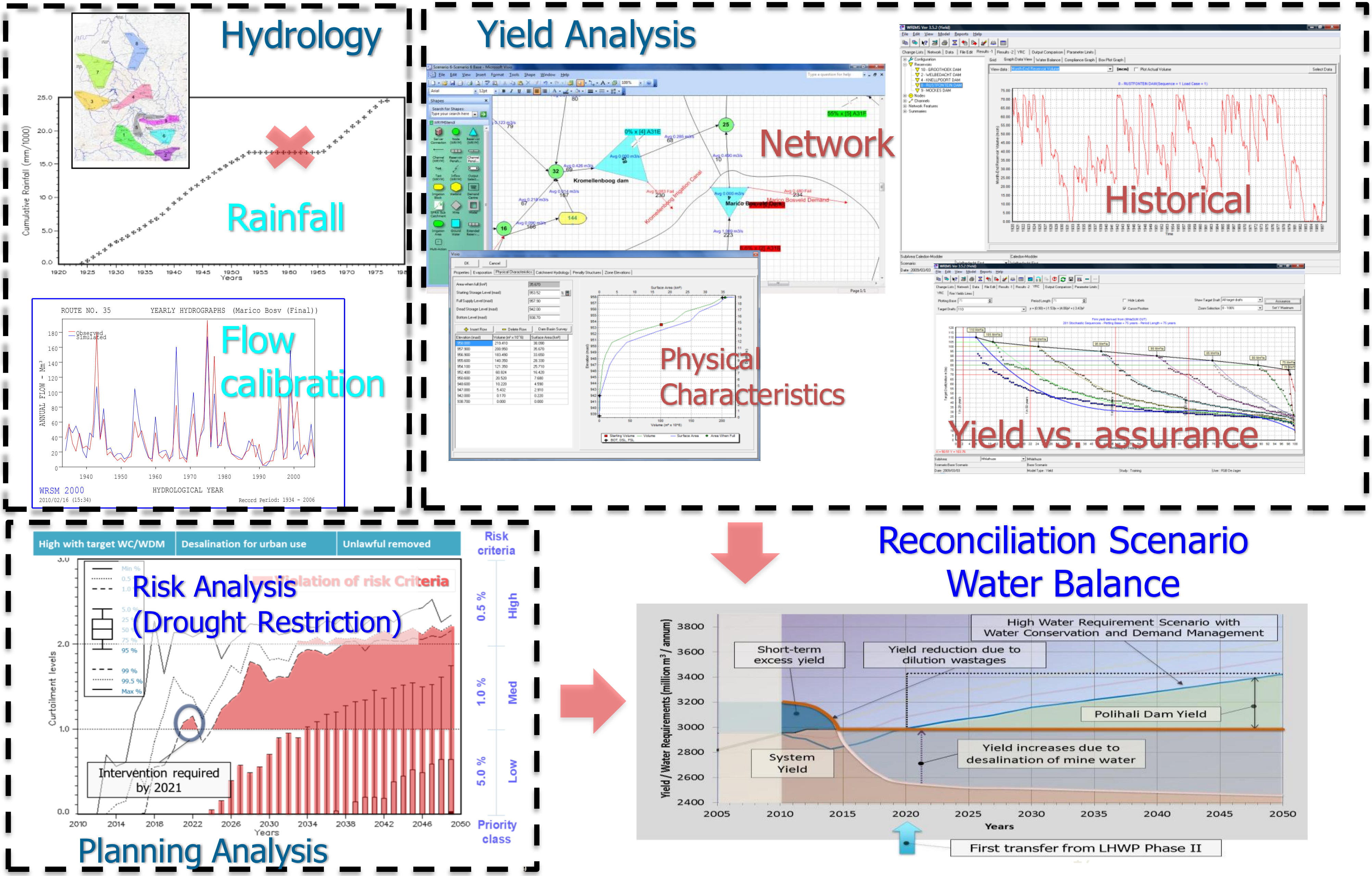
Example Assessment :Overview

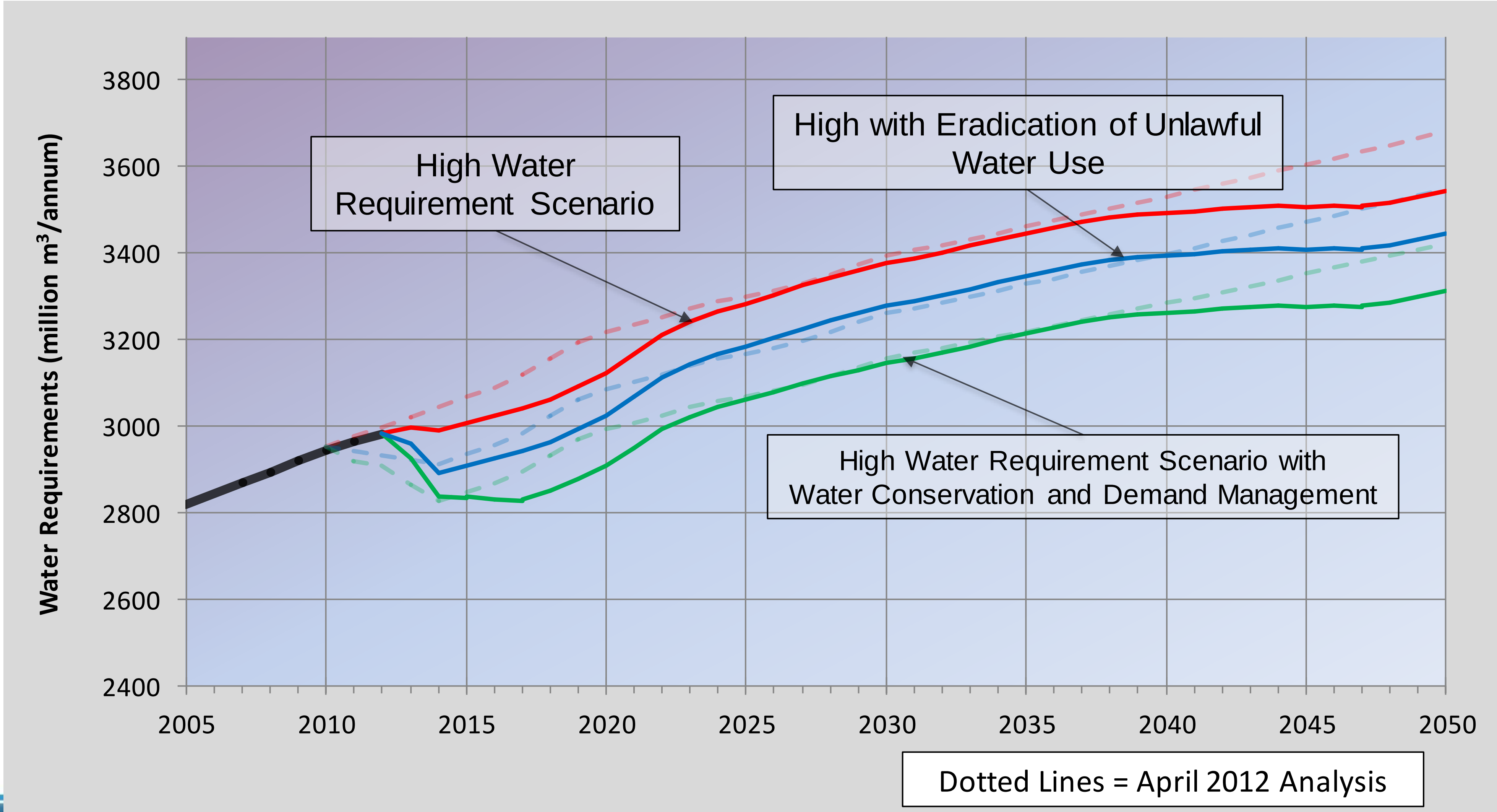


Example Scenarios

No	Water Requirements & Return Flows	Mine water Management (AMD)	Unlawful Water Use	LHWP Phase 2 (Polihali Dam)
1	High with target WC/WDM	Neutralisation and discharge into Vaal	Removed by 2014	Delivery 2020
2	High with target WC/WDM	Desalination for urban use 2016	Removed by 2014	Not implemented

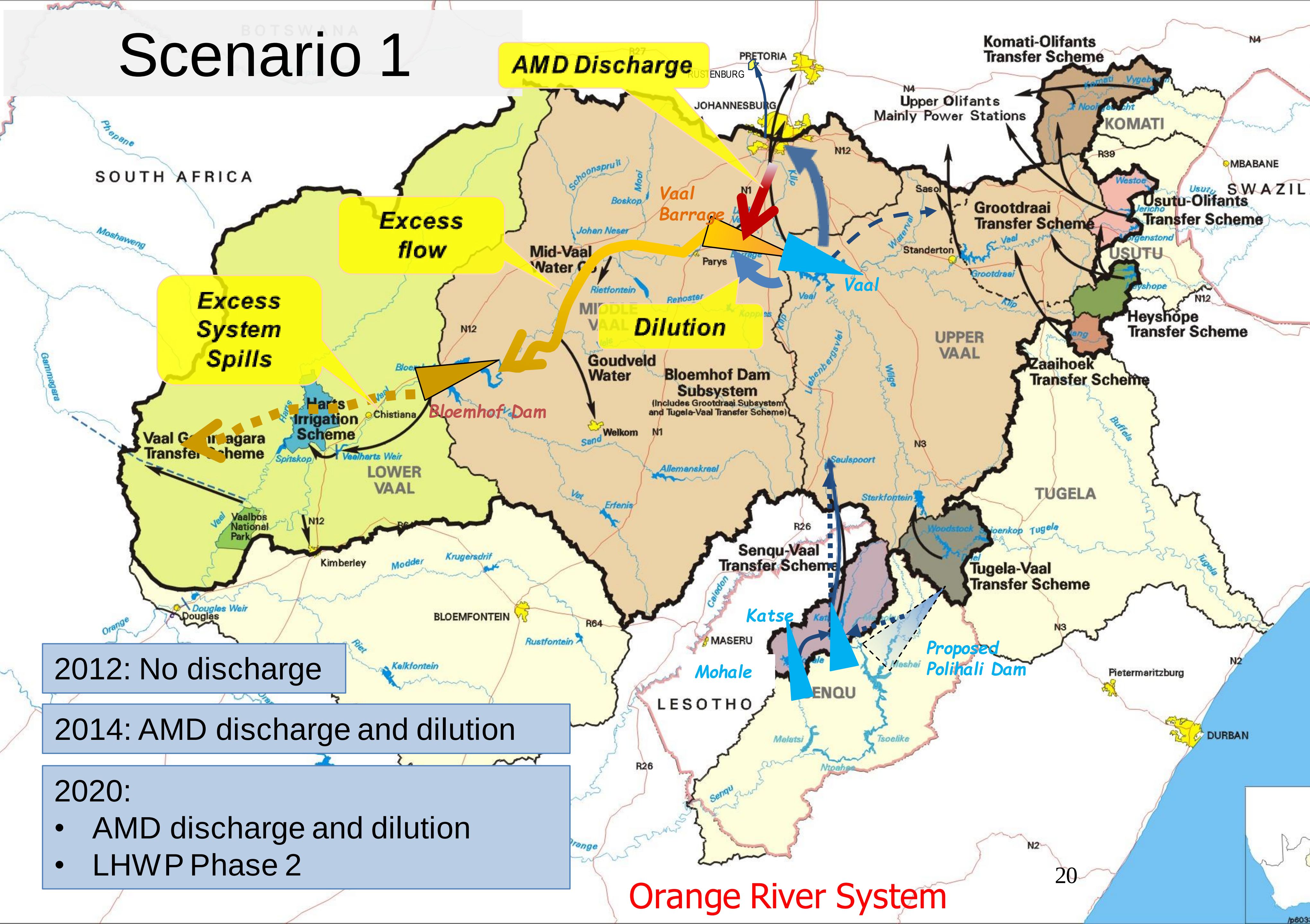
(ToR: 3 & 4)

Water Requirement Scenarios (Net System Demand)



(ToR: 3 & 4)

Scenario 1



2012: No discharge

2014: AMD discharge and dilution

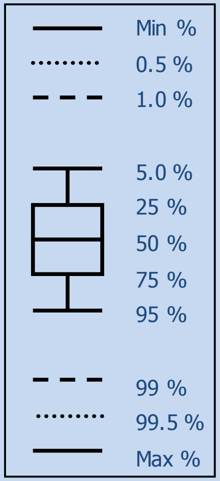
2020:
- AMD discharge and dilution
- LHWP Phase 2

Orange River System

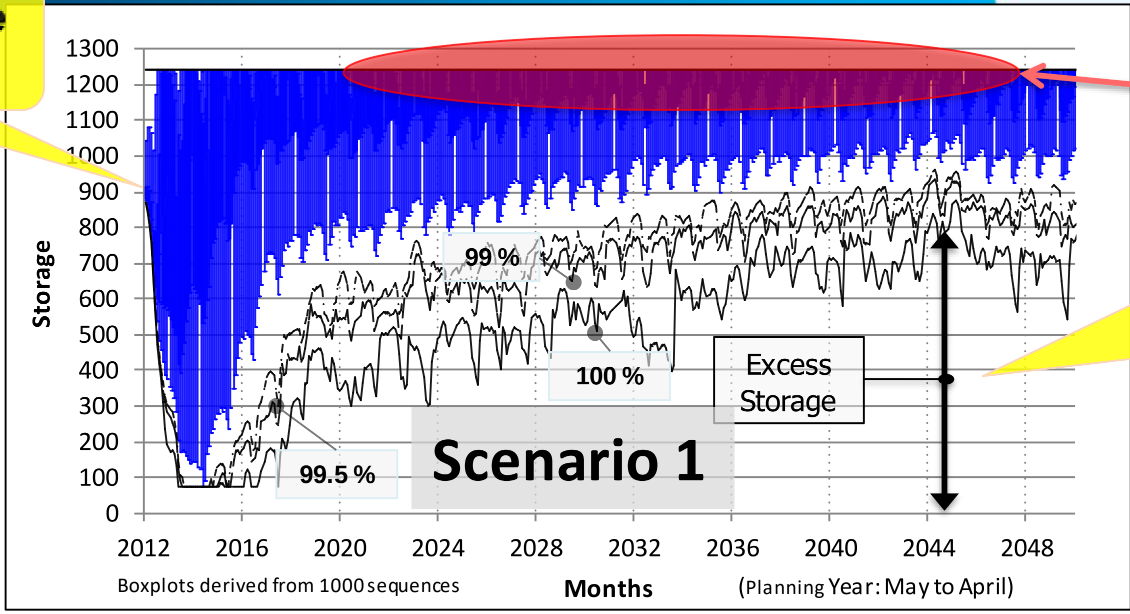
Model Results:
Scenario 1 & 2: Bloemhof Dam

Starting Storage May 2012

Probability Distribution



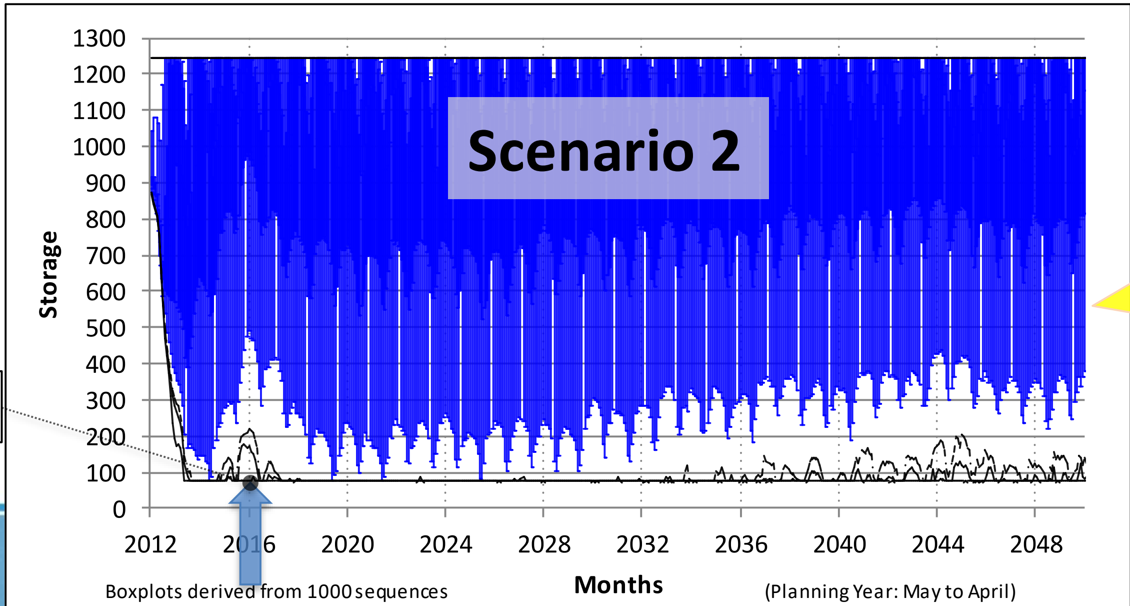
1000 Stochastic Sequences



Excessive Spills & Wastage

Implication of AMD discharge and dilution on Bloemhof Dam

Desalinate AMD



More efficient use of Bloemhof Dam when AMD is desalinated

(ToR: 3 & 4)

Example: Water User Risk Criteria

User Sectors	User priority classification (Criteria: risk of curtailments)		
	Low (5 %)	Medium (1 %)	High (0.5 %)
	Proportion of water demand (%)		
Domestic	30	20	50
Industrial	10	30	60
Strategic industries	0	0	100
Irrigation	50	30	20
Restriction levels: 0	1	2	3

Gardening Water (Domestic, Low)

Human Consumption Hygiene (Domestic, High)

Power Generation Petro Chemical Industry (Strategic industries, High)

Annual Crops (Irrigation, Low)

Permanent Crops (Irrigation, High)

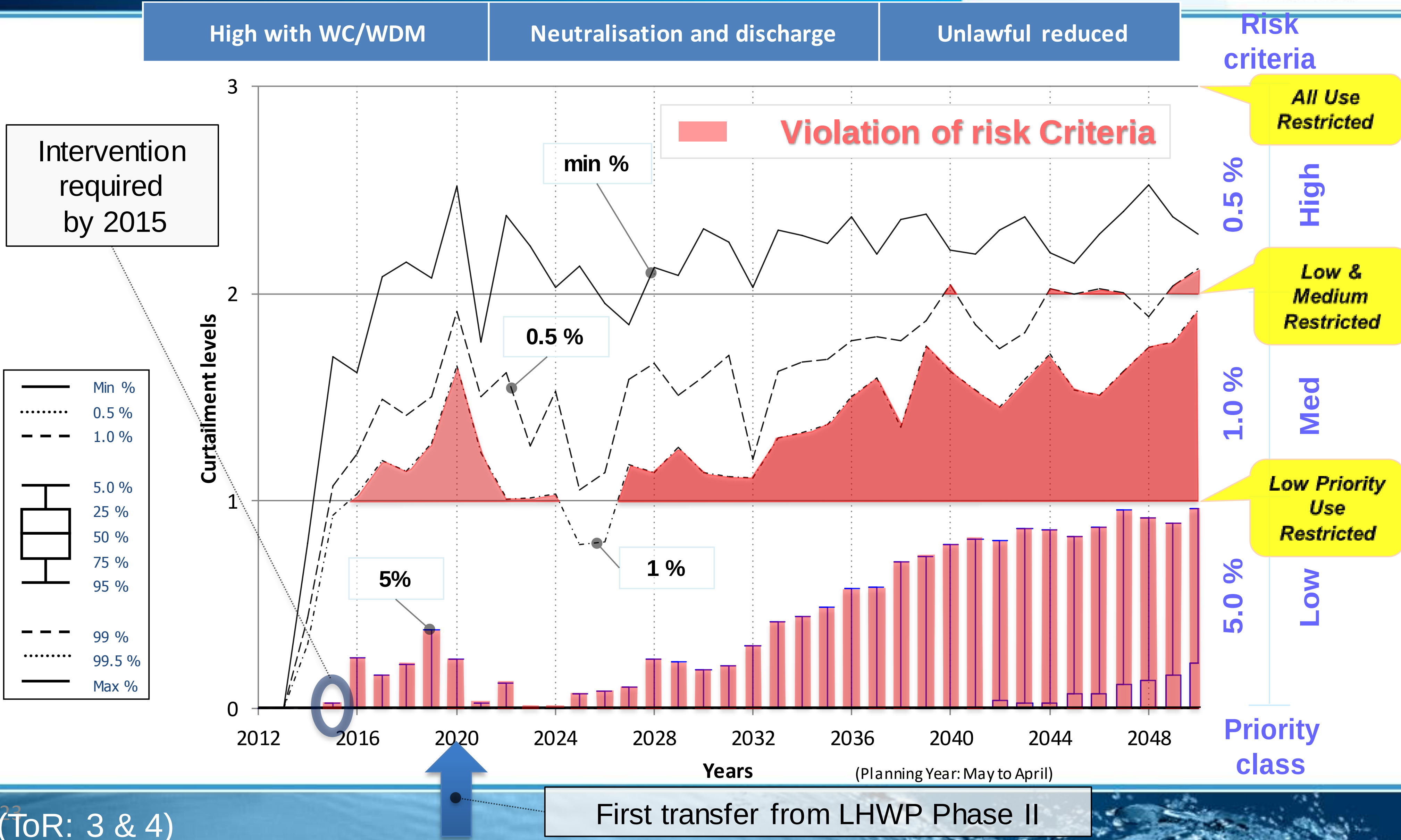
All Low Priority Use Restricted (Restriction level 1)

All Low & Medium Restricted (Restriction level 2)

All Use Restricted (Restriction level 3)

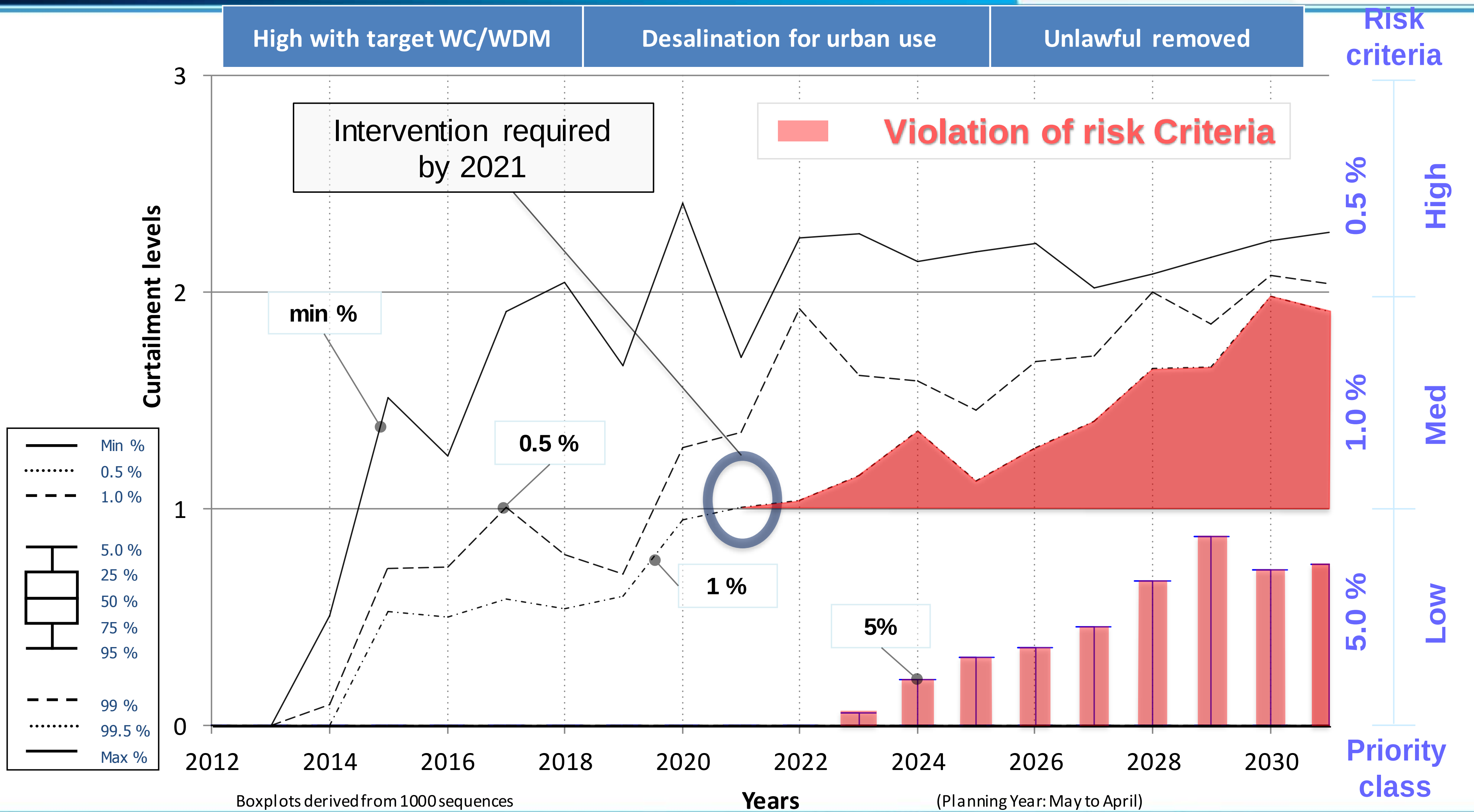
(ToR: 3 & 4)

Scenario 1: Projected Curtailments



(ToR: 3 & 4)

Scenario 2: Projected Curtailments

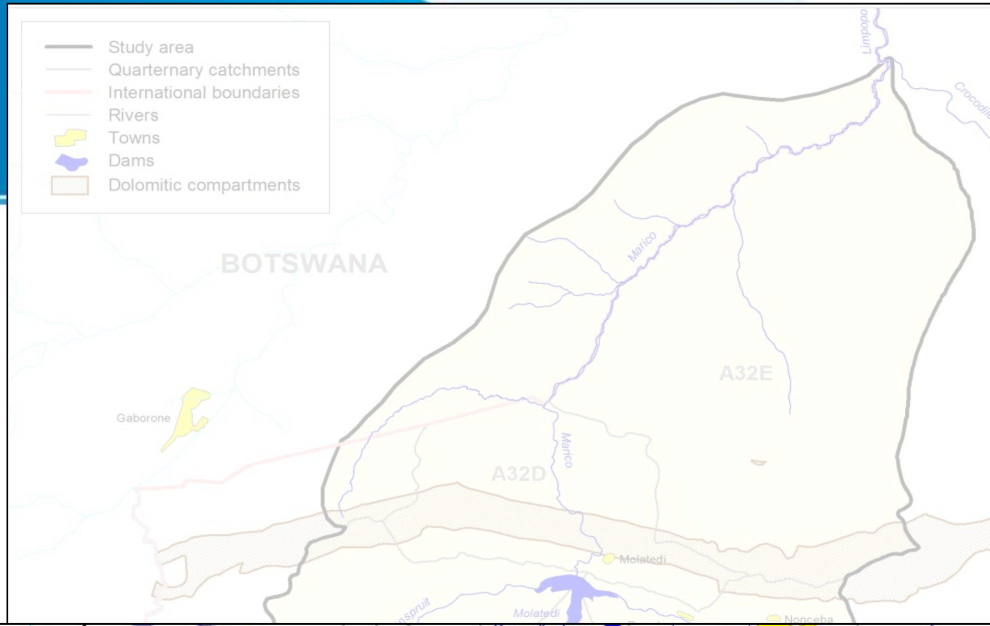


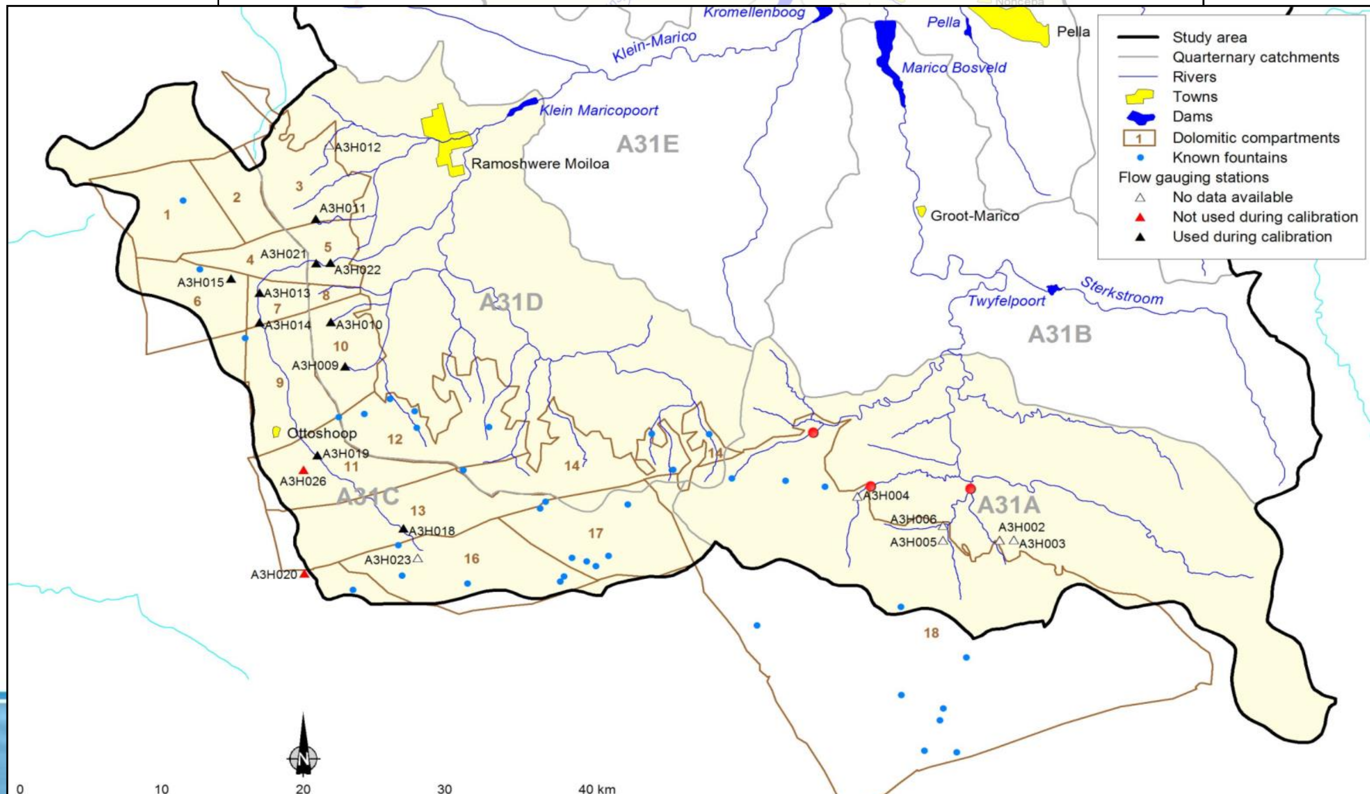
(ToR: 3 & 4)

Allocation planning (Reallocation)

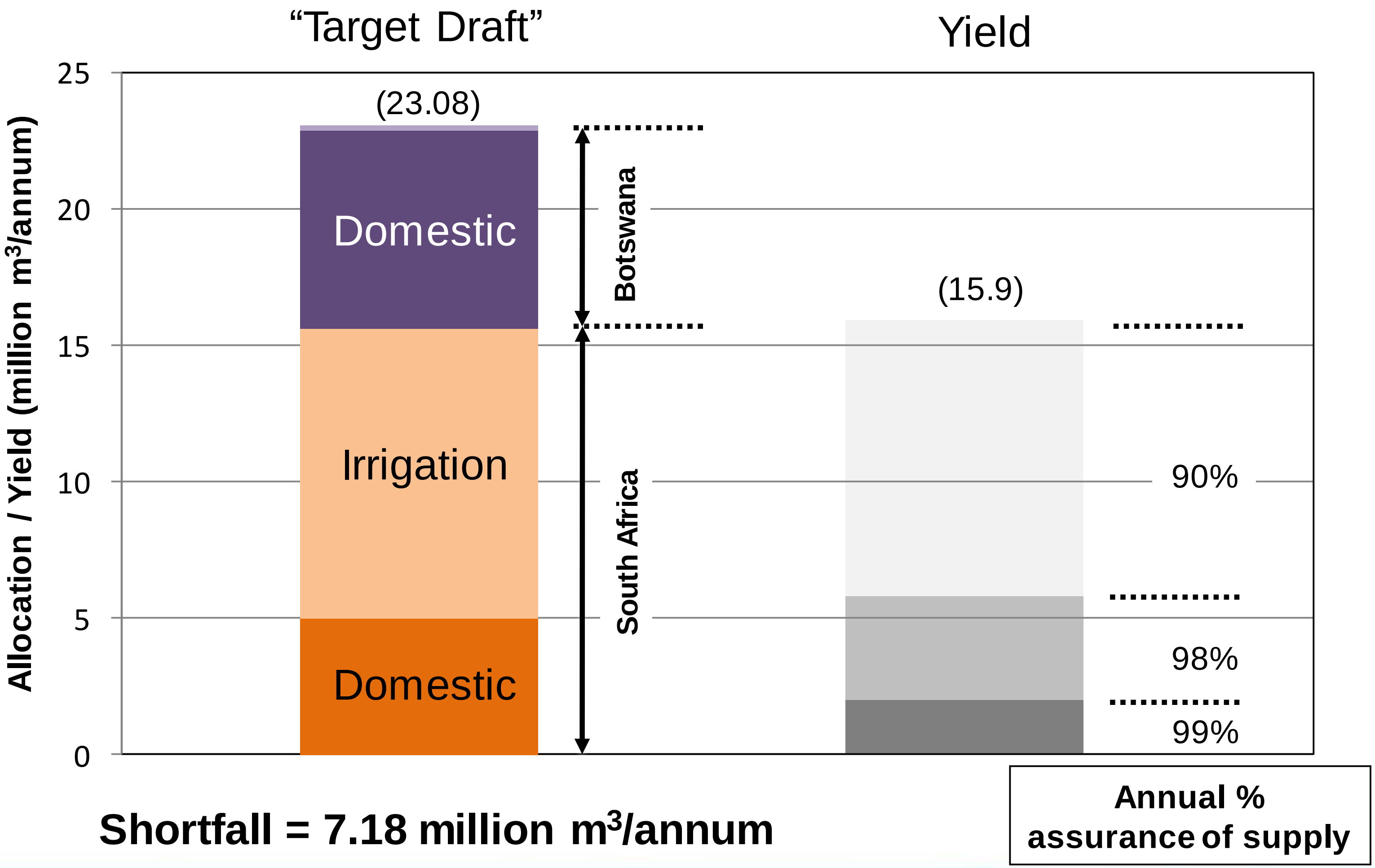
Study Area:

- Molatedi Dam shared between Botswana and RSA.
- Simulate groundwater-surface water interaction (dolomitic aquifers).





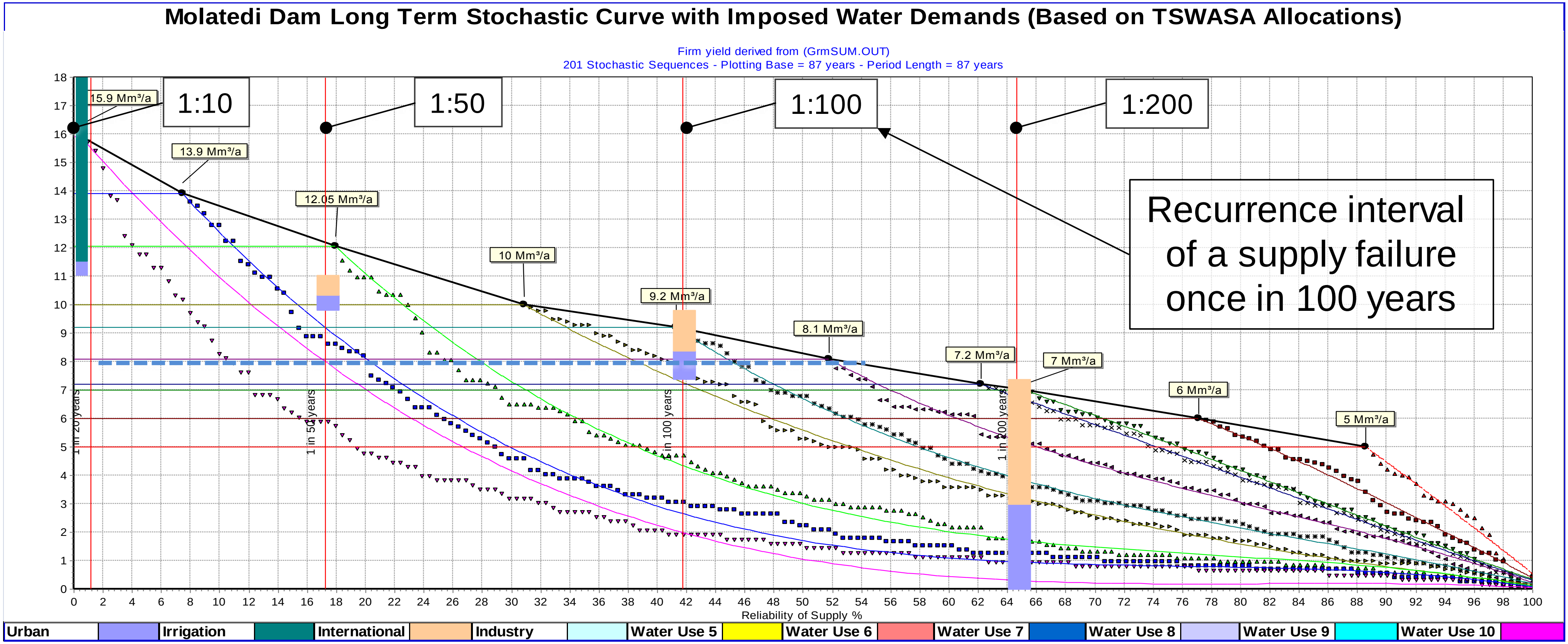
Molatedi Dam
(Allocations vs. Yield)



Shortfall = 7.18 million m³/annum

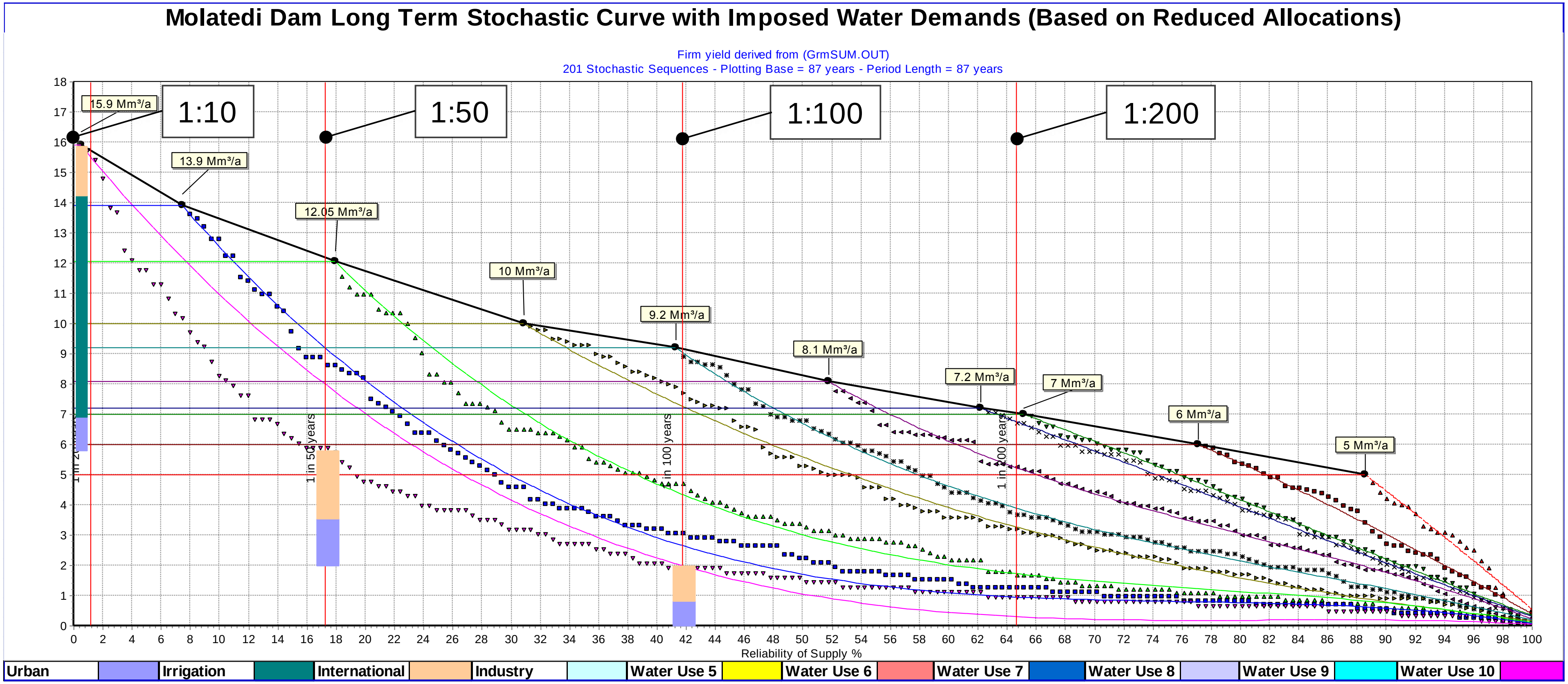
(ToR: 3 & 4)

Current Allocations vs. Availability



(ToR: 3 & 4)

Proposed reduced allocation



(ToR: 3 & 4)

Proposed Adjustments to Allocation Molatedi Dam

User Category	Tswasa Allocation (million m^3/a)	% of Total	Possible Allocation (million m^3/a)
RSA Urban	5	21.8	3.47
Botswana Urban	7.3	31.9	5.07
Irrigation	10.6	46.3	7.36
Total:	**22.9**	**100.0**	**15.9**

Description	Priority Classes (Recurrence Interval)			
	1:10	1:50	1:100	Total
RSA Urban	1.11	1.54	0.81	3.47
Botswana Urban	1.63	2.26	1.19	5.07
Total within Class	2.74	3.80	2.00	8.54
Cum Total:	8.54	5.80	2.00	
% In Class	32.1	44.5	23.4	
Irrigation	7.36	0.00	0.00	7.36
Total within Class	10.10	3.80	2.00	
Cum Total:	15.90	5.80	2.00	

Model Features for Operating Rule Development

- Water supply and transfer priority rules:
  - Relative weights defines priority of supply between uses (Losses, Ecology, Domestic, Strategic, Irrigation)
- Drought management:
  - Water user priority categories and risk criteria
  - Short-term yield vs. reliability characteristics
- Dilution rules:
  - Direct source for dilutions
  - Indirect or distance source for dilution

Water supply and transfer priority rules

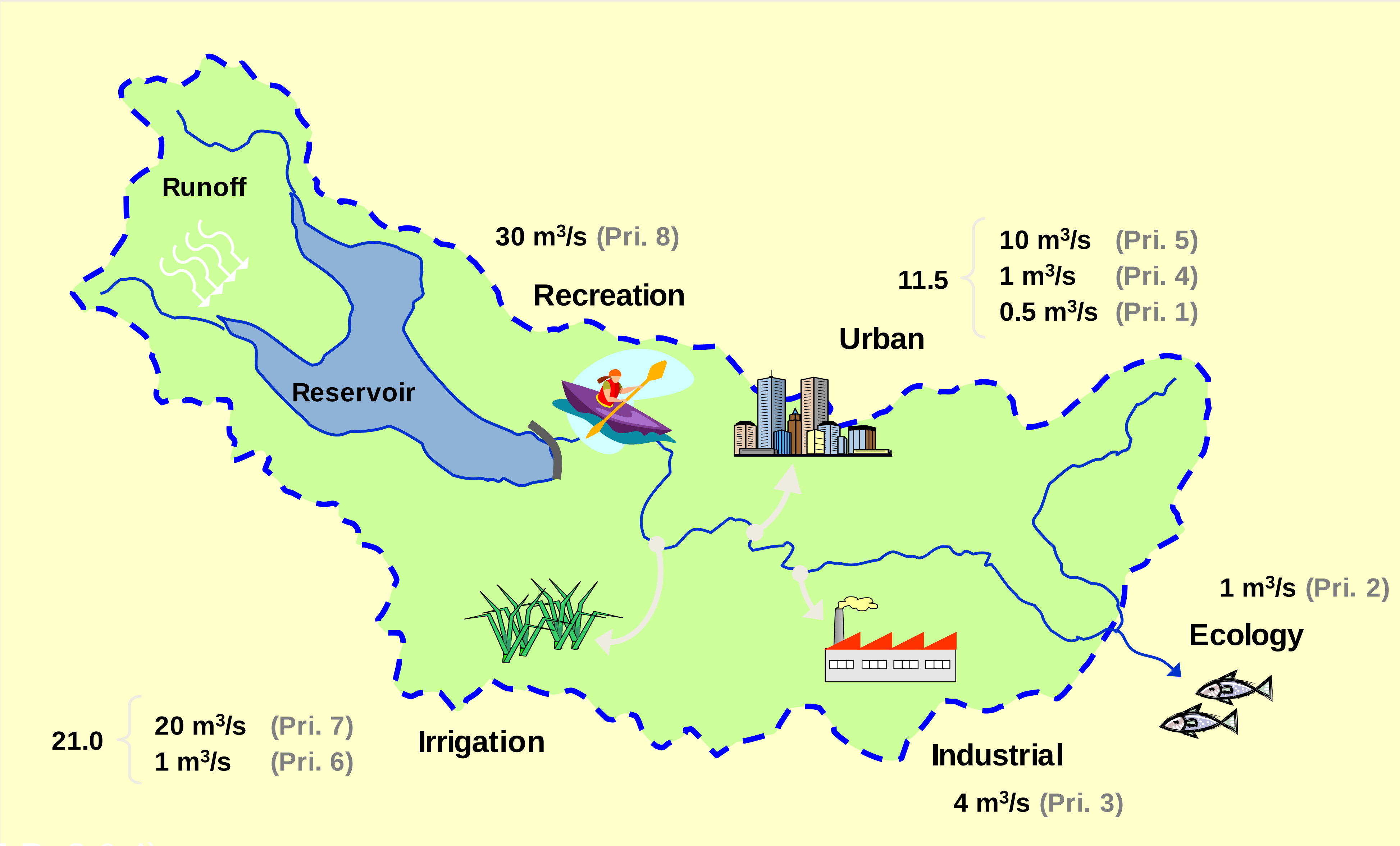
- Narrative description:

A distinguishing feature of several of these modeling systems is the use of optimization on a period by period basis (not fully dynamic) to "simulate" the allocation of water under various prioritization schemes, such as water rights, without the presumption of perfect foreknowledge of future hydrology and other uncertain information. This is a valid approach since use of optimization overcomes the disadvantage of employing numerous, unwieldy prescriptive rules governing water allocation. Systems employing optimization in this manner include: ARSP, MODSIM, OASIS, REALM, RiverWare, and WEAP and are therefore more akin to CALSIM

***Source: A strategic Review of CALSIM II and its Use for Water Planning, Management, and Operations in Central California", 2003*.**

*Link: www.calwater.ca.gov/science/**pdf**/calsim/**CALSIM_Review**.**pdf***

Water resource system



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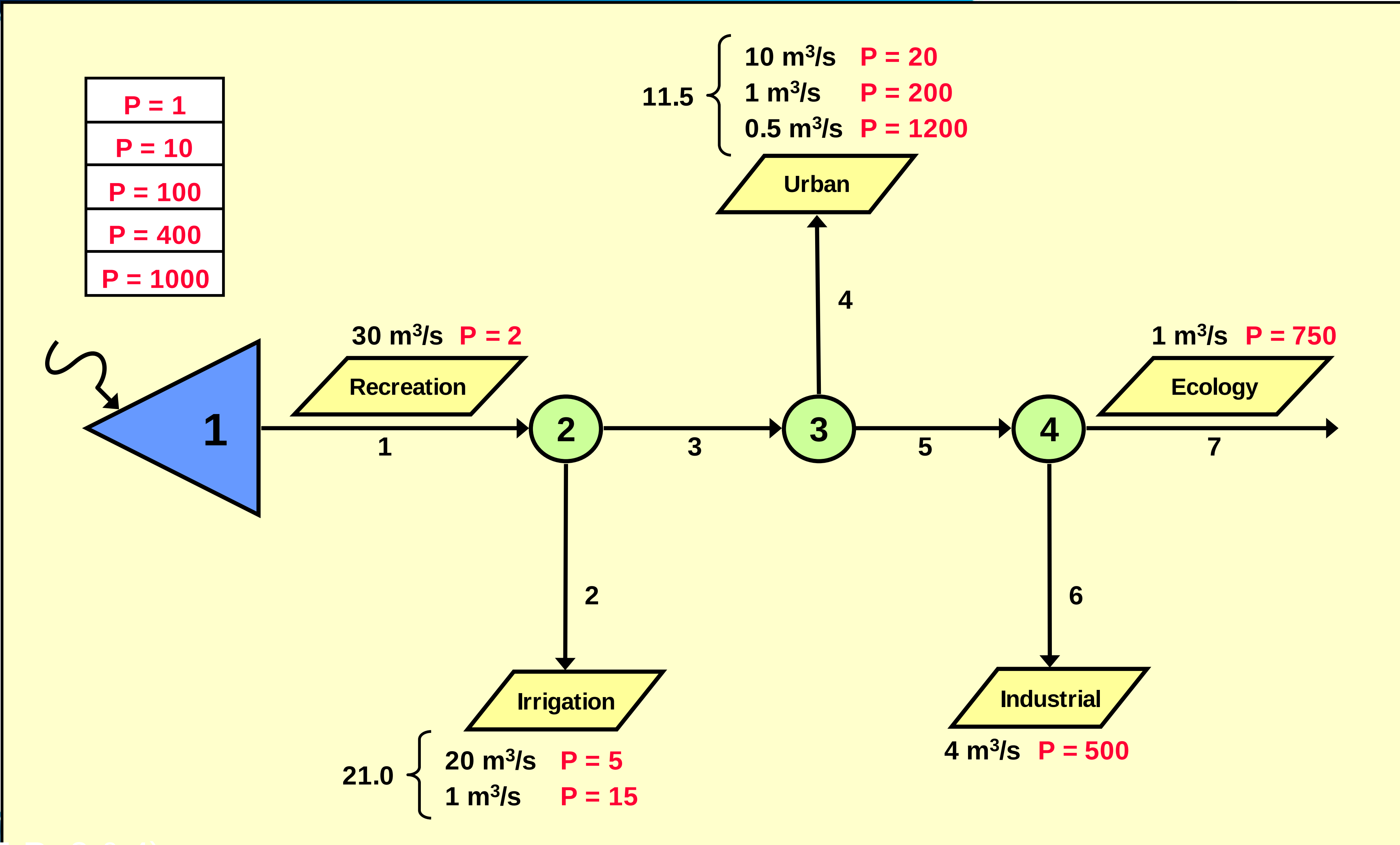
Network model with weights



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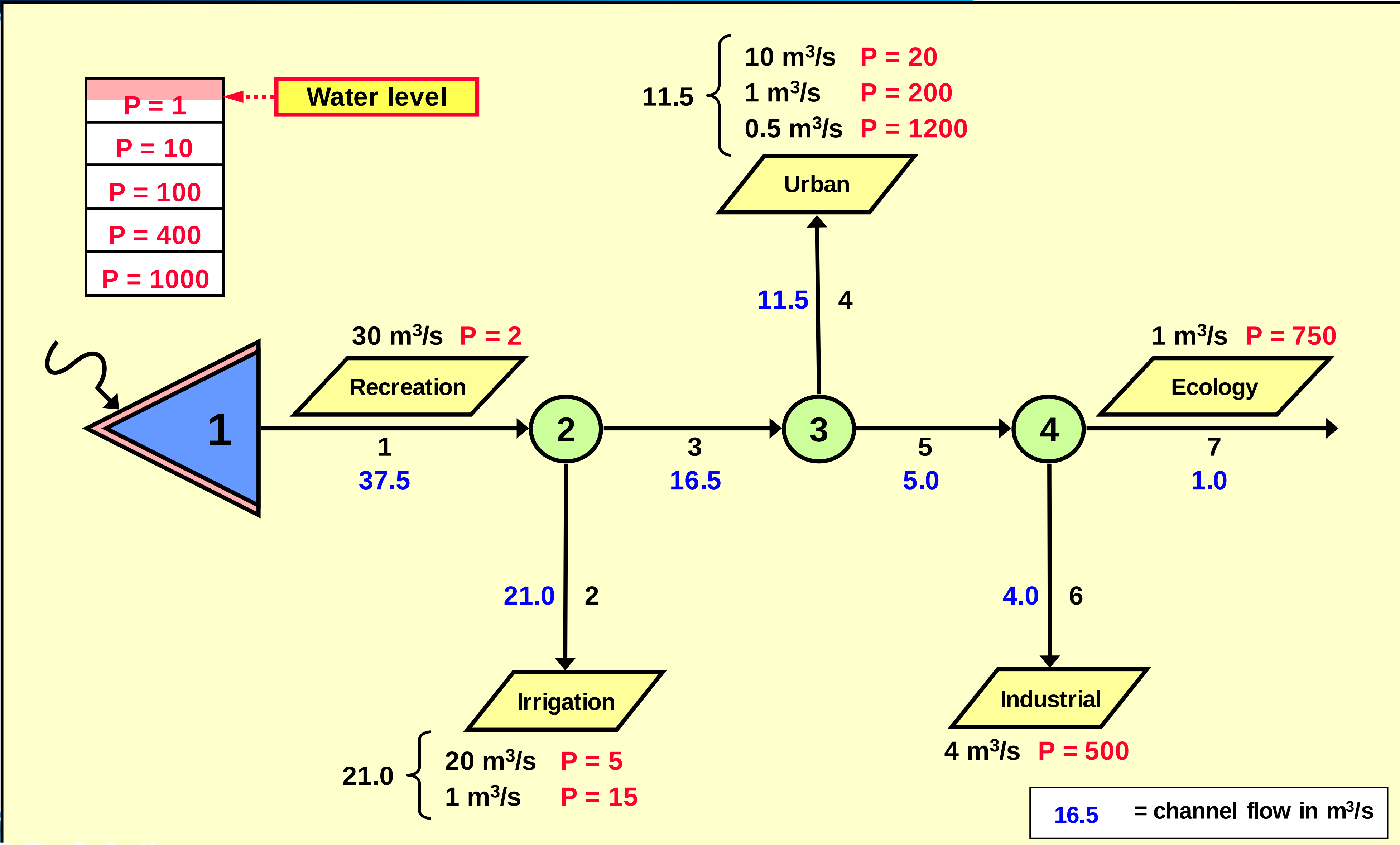
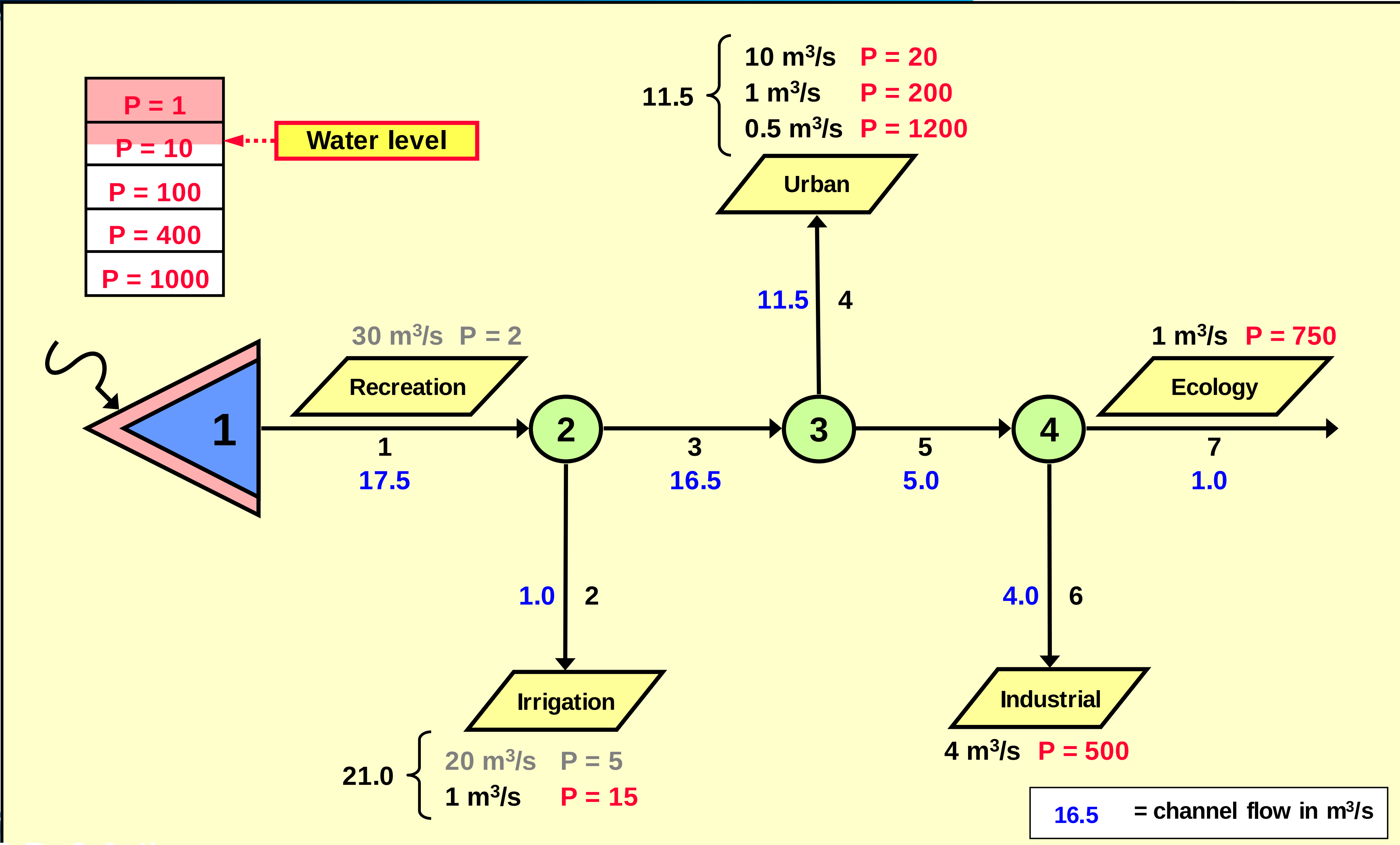
Case 1: Reservoir in zone 1



(ToR: 3 & 4)

Case 2: Reservoir in zone 10



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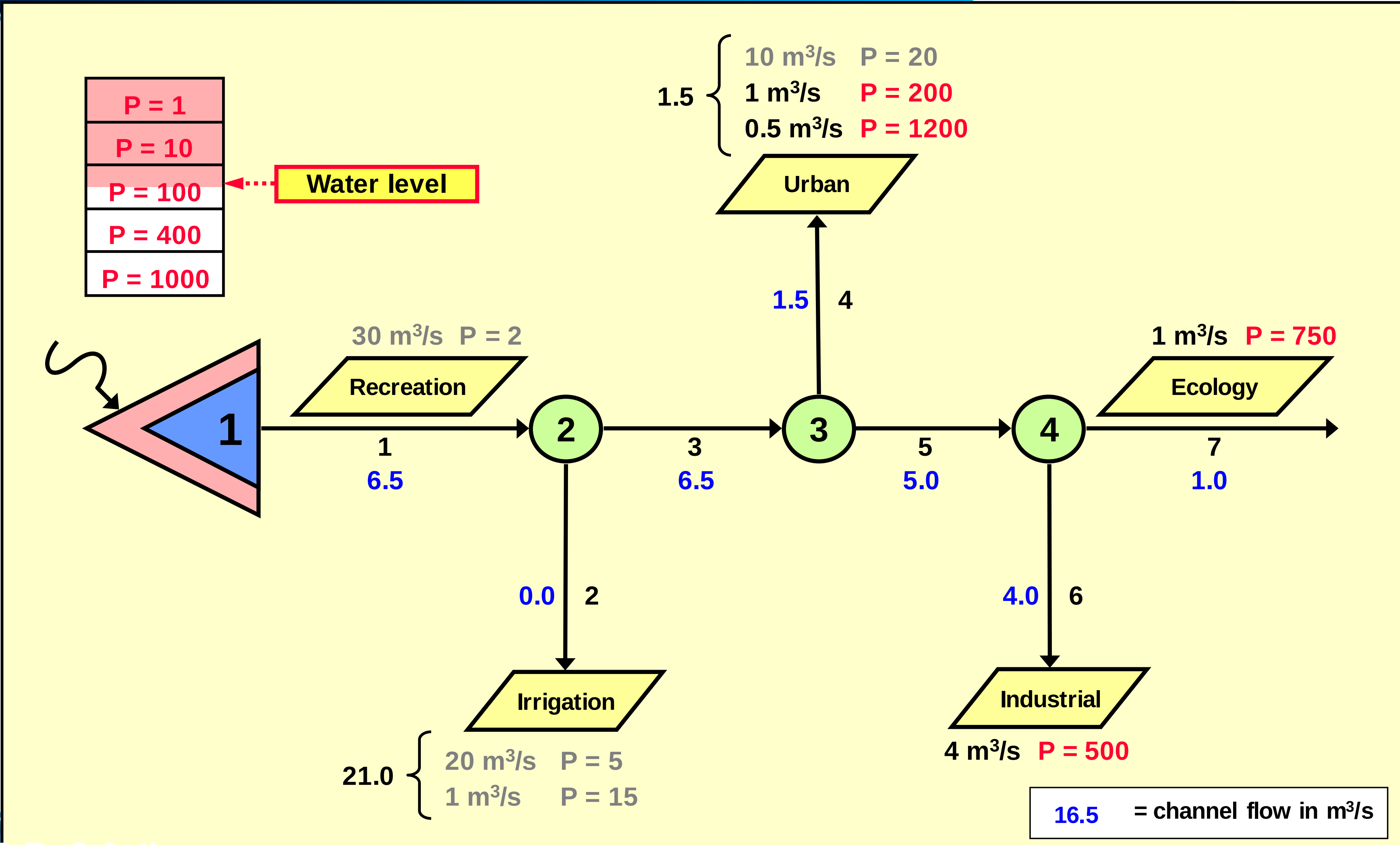
Case 3: **Reservoir in zone 100**



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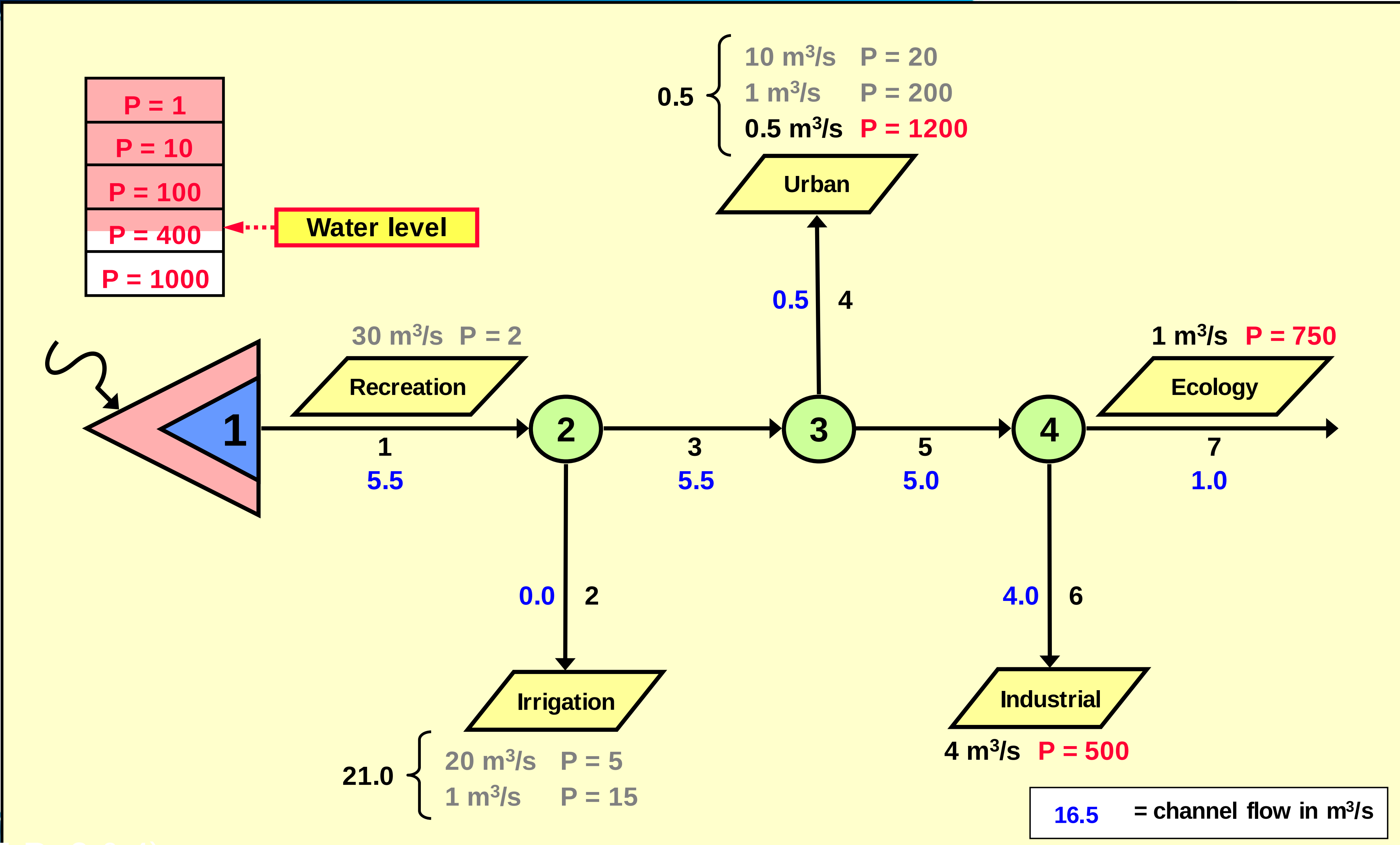
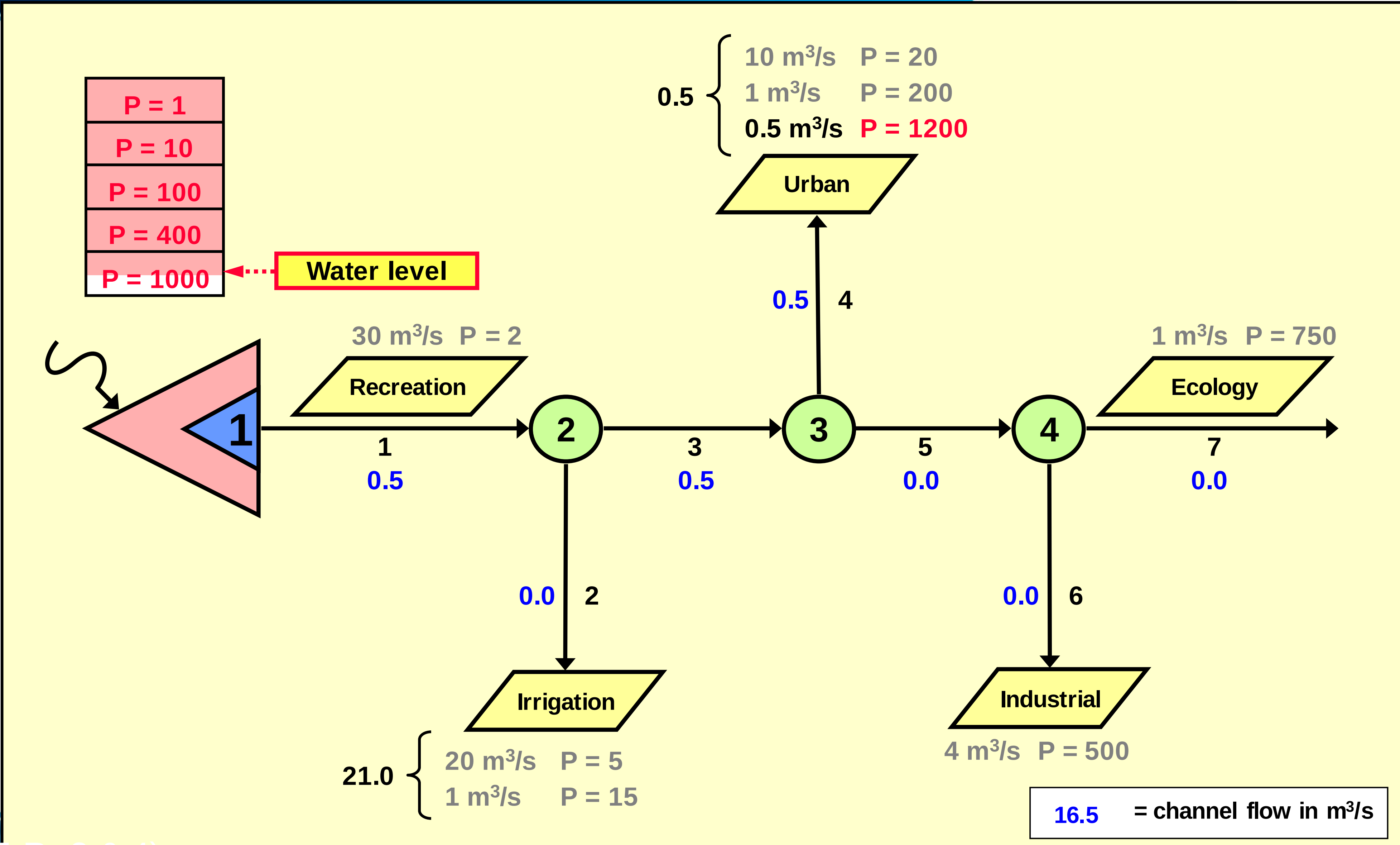
Case 4: **Reservoir in zone 400**



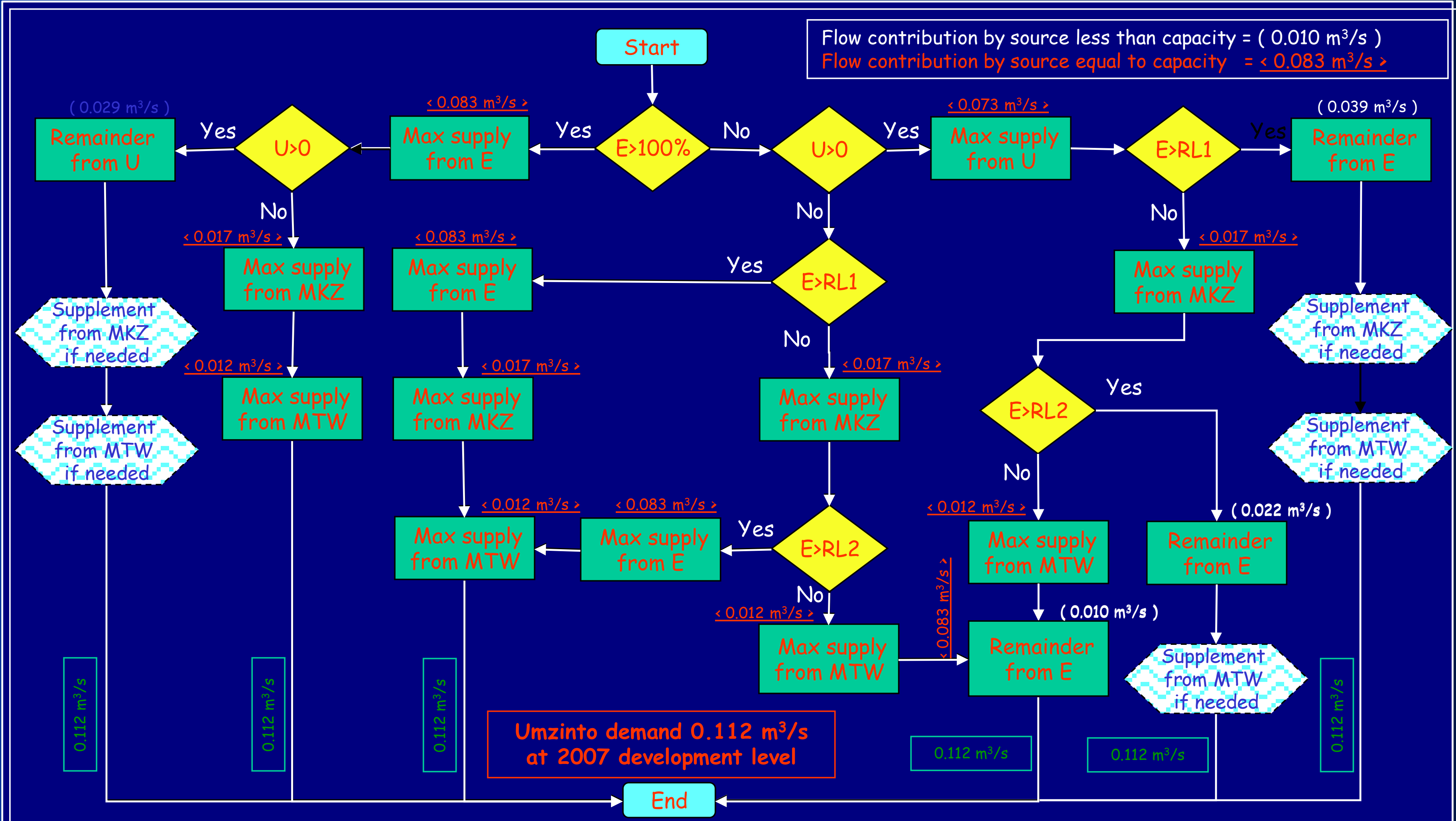
(ToR: 3 & 4)

Case 5: **Reservoir in zone 1000**



(ToR: 3 & 4)

Example operation decision diagram



Notes:

E	= EJ Smith Dam	RL1	= Rule Level 1 of EJ Smith Dam
U	= Umzinto System	RL2	= Rule Level 2 of EJ Smith Dam
MKZ	= Mkomazi River	Max	= Maximum supply to Umzinto demand centre
MTW	= Mtwalume River	Remainder	= Supply remainder of the demand to Umzinto demand centre

Drought management

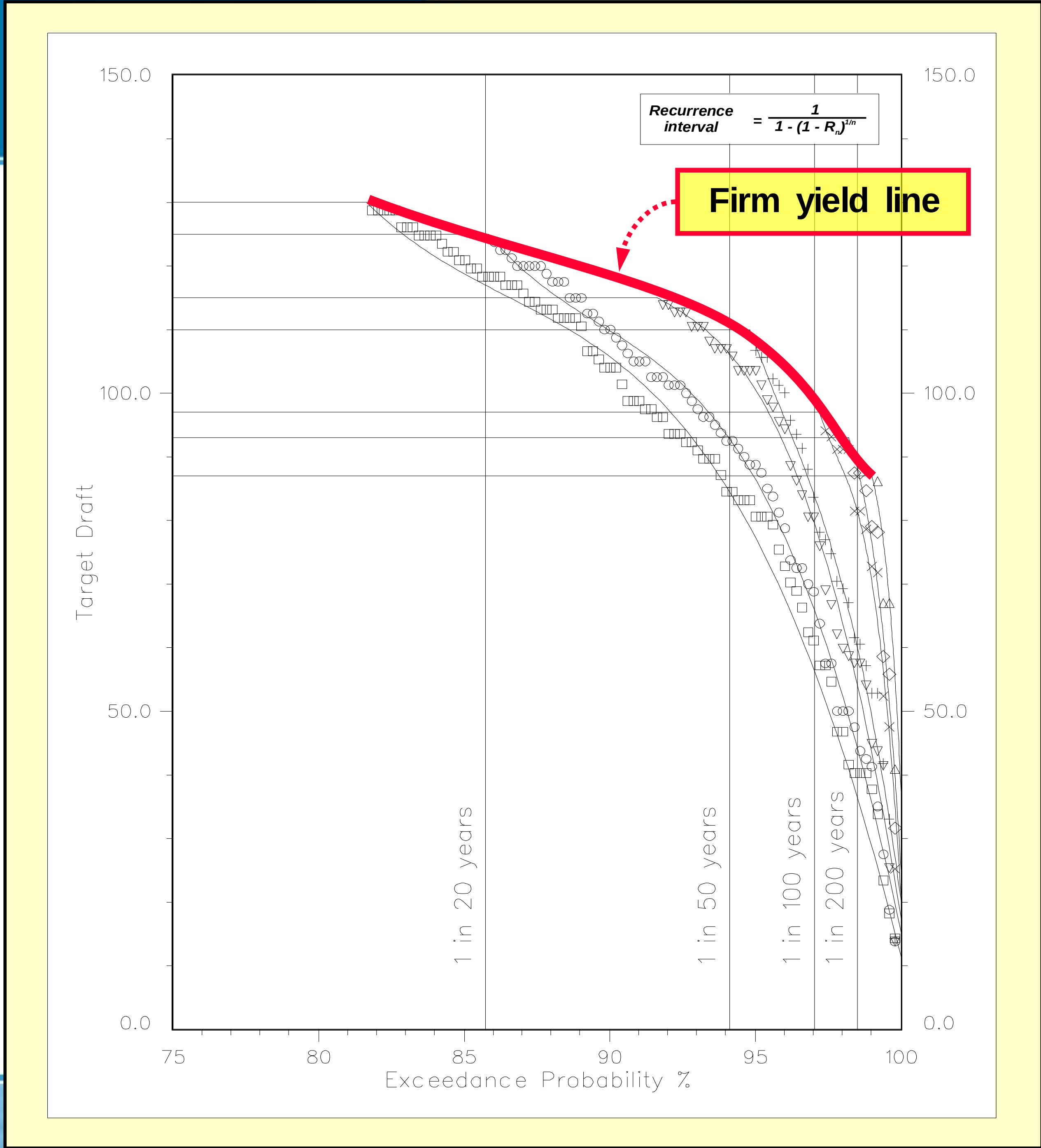
Water user risk criteria example

Description of water requirement components	Percentage of total requirement	Percentage allocated to indicated priority class			
		1:200 years (0.5 %)	1:100 years (1.0 %)	1:50 years (2.0 %)	1:20 years (5.0 %)
Losses	24.5	100	-	-	-
Wet industry	16.3	70	10	10	10
Dry industry	12.2	70	15	5	10
Domestic	47.0	40	20	20	20
Total	**100.0**	**63**	**13**	**12**	**12**
Priority class:		**H**	**MH**	**ML**	**L**
Restriction level:		4 ←	3 ←	2 ←	1 ←

(ToR: 3 & 4)

Short-term curves

- System starting storage 100%



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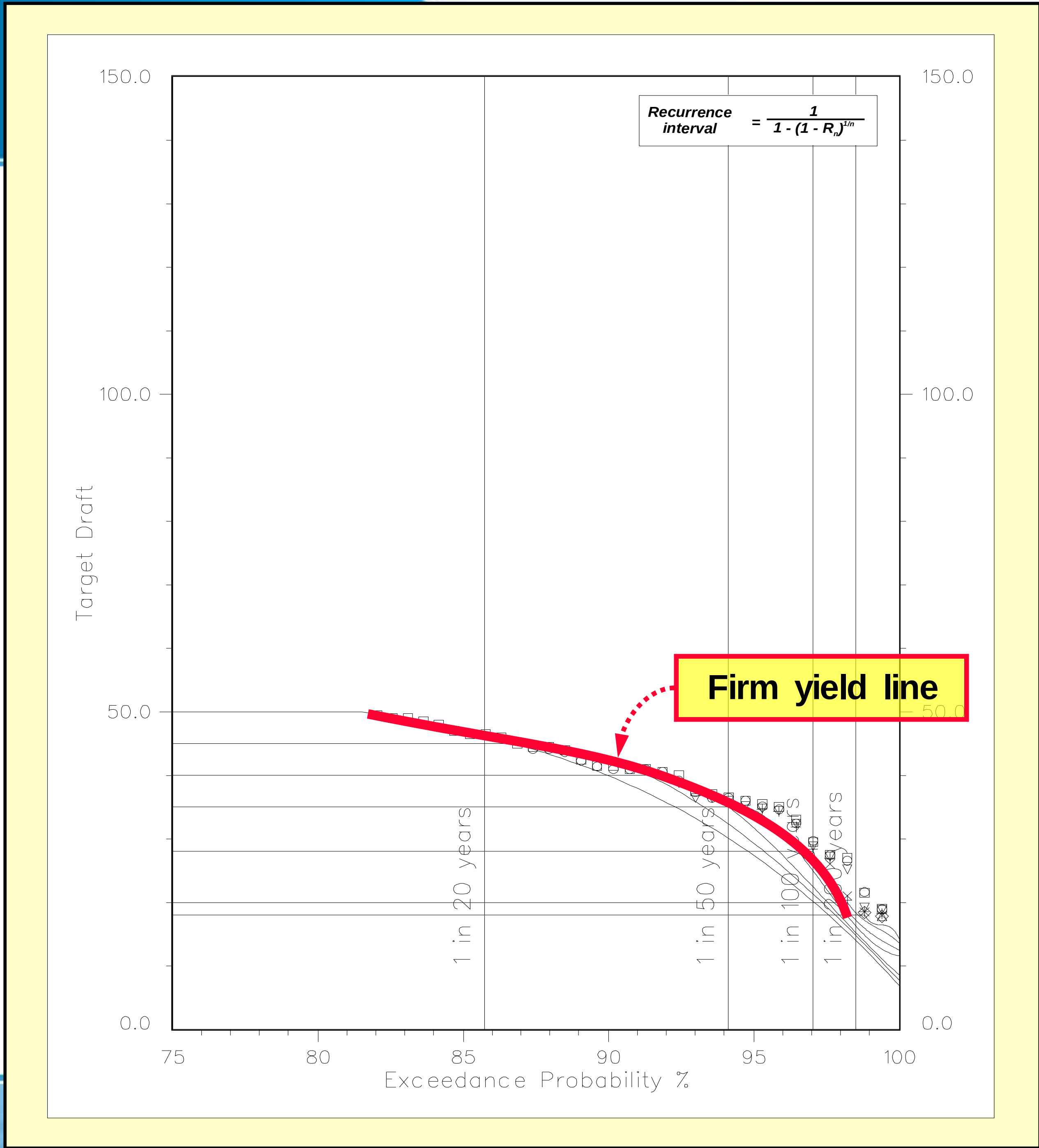
Short-term curves

- System starting storage 10%



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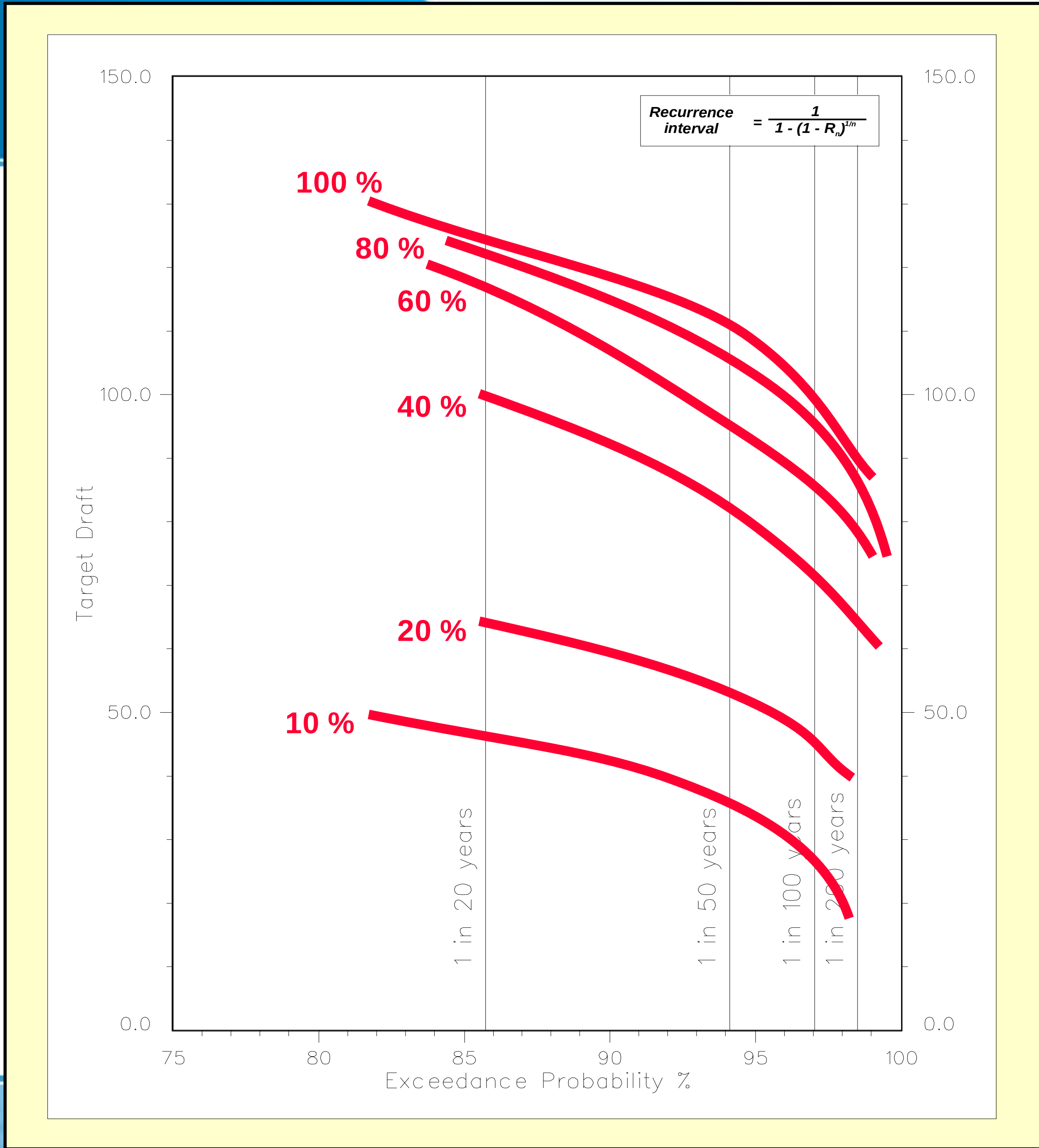
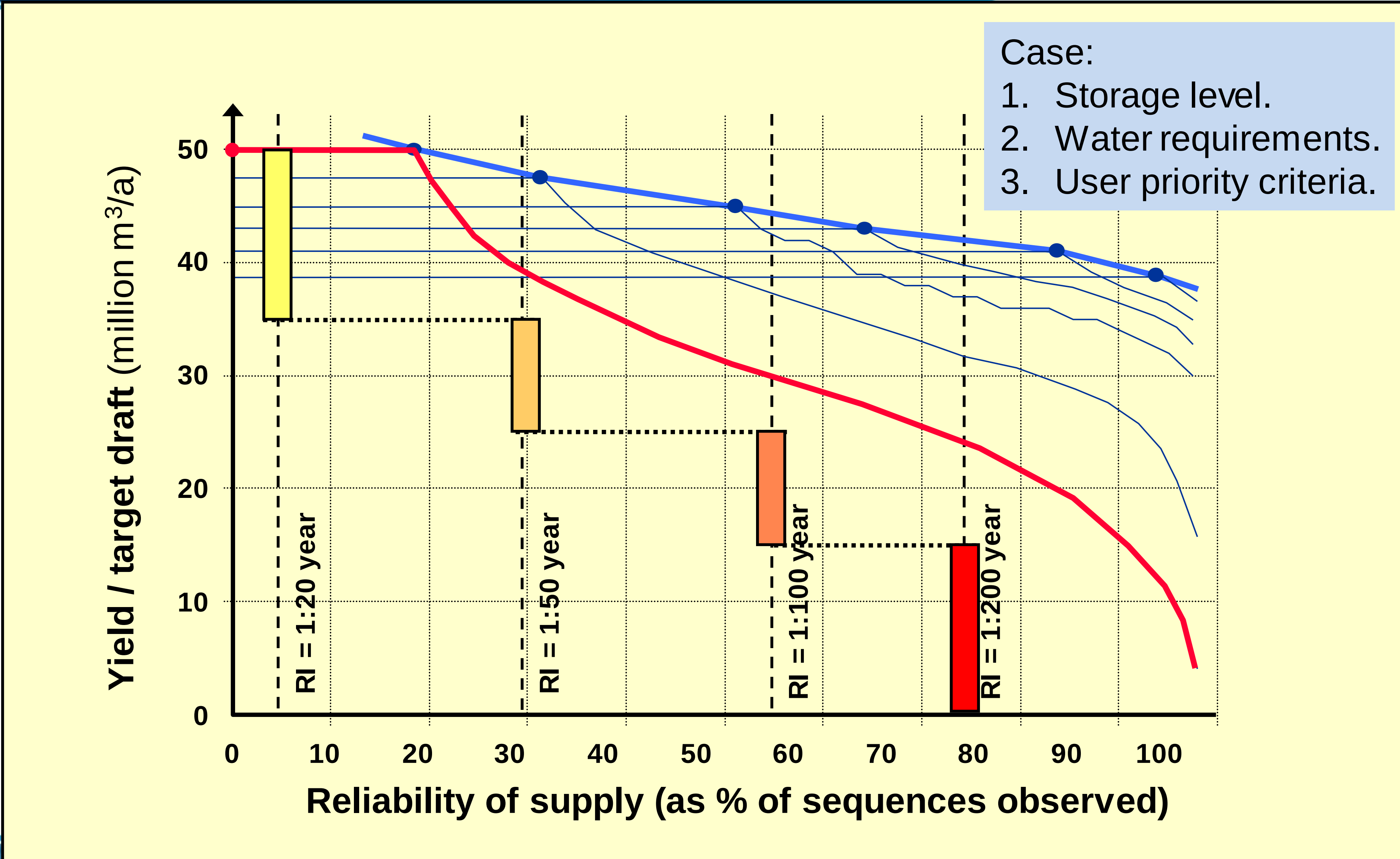
Short-term curves

- Range or Firm Yield Lines



Application of user criteria and Short term yield vs. reliability curves



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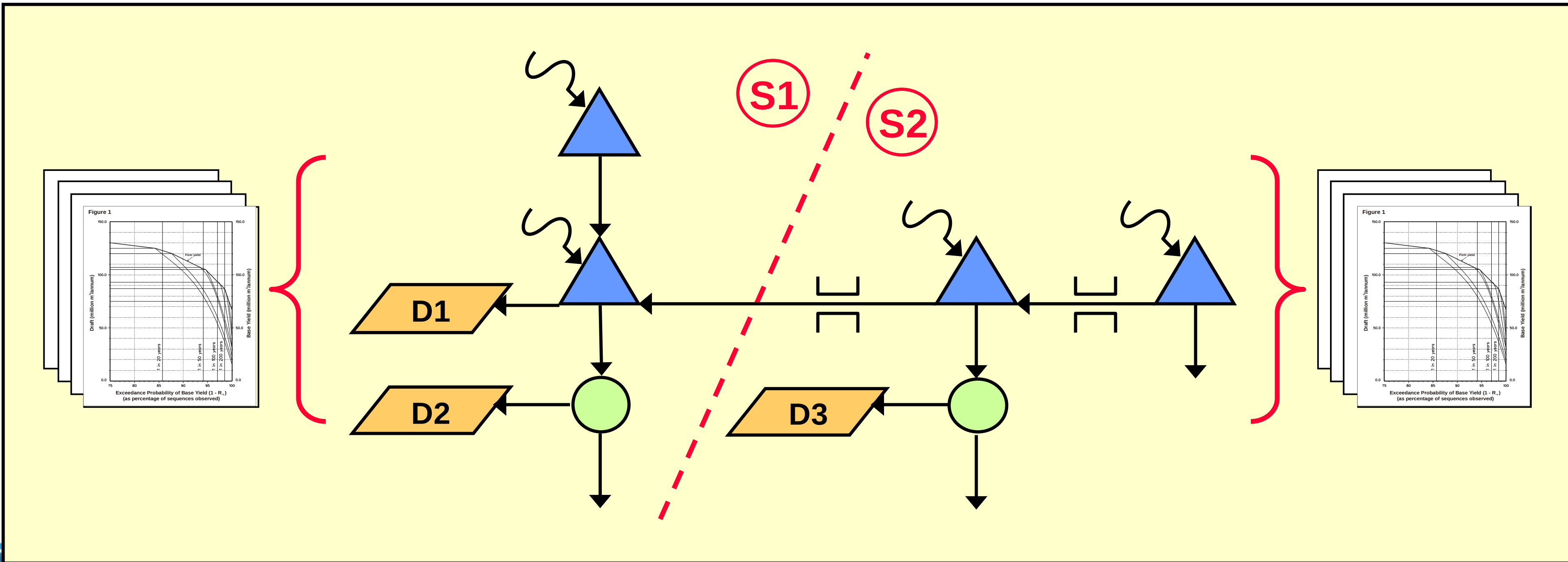
Subsystems & Short-term yield reliability

- Represent yield-reliability characteristics over short term (up to 5 years)
- Individual set for each defined subsystem



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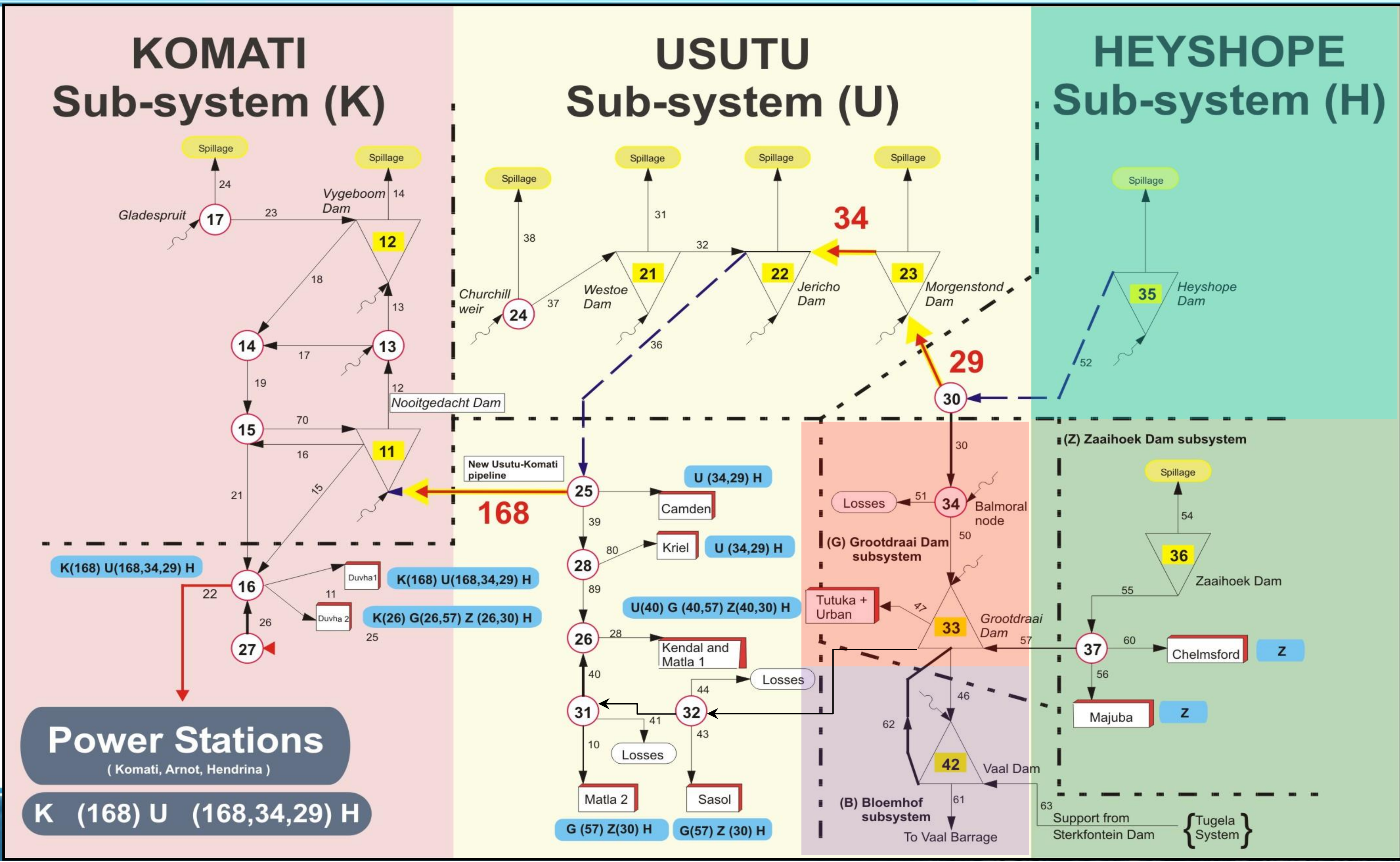
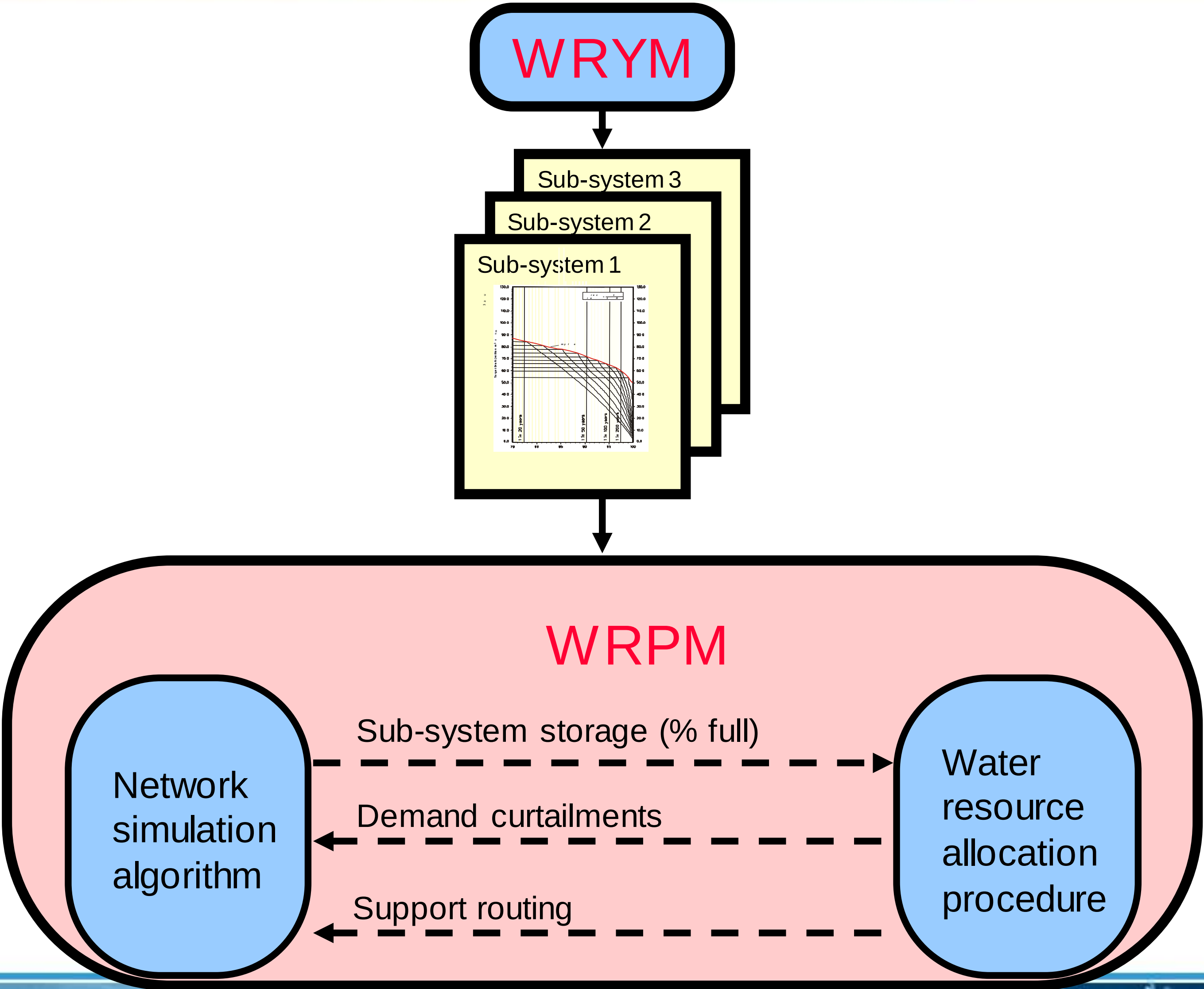
Example: User support definition



Overview of model function for operation planning



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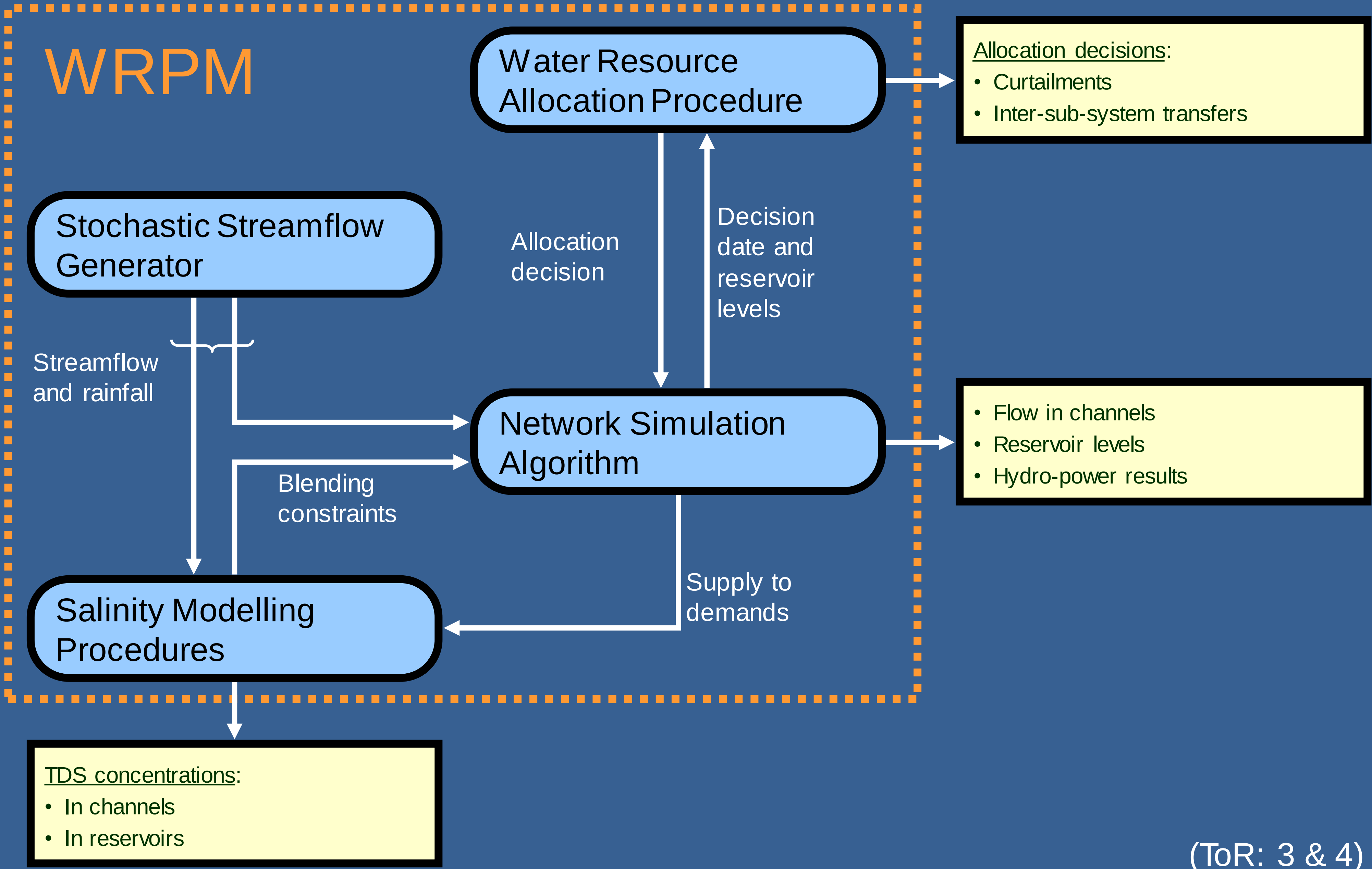
WRPM Structure



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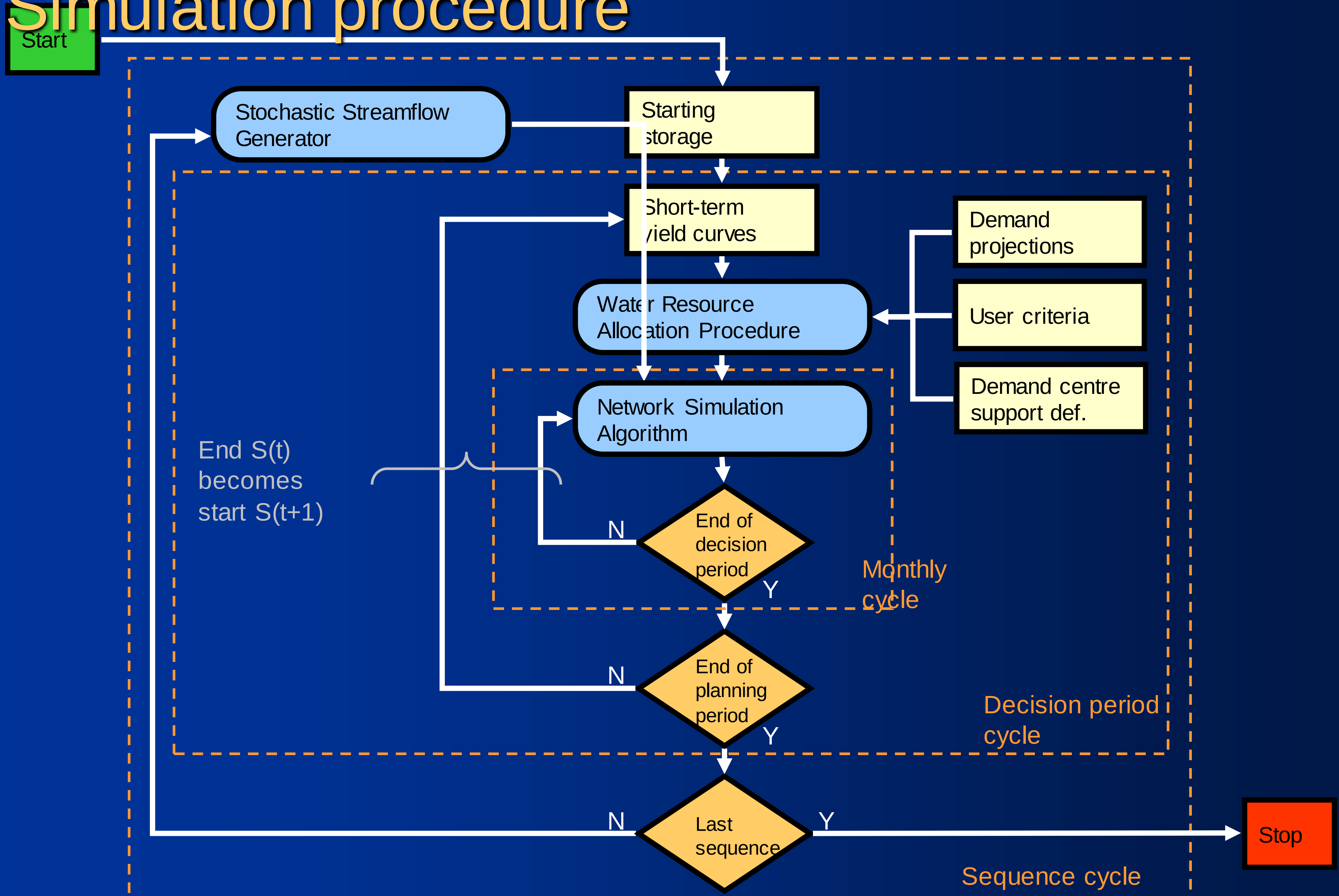
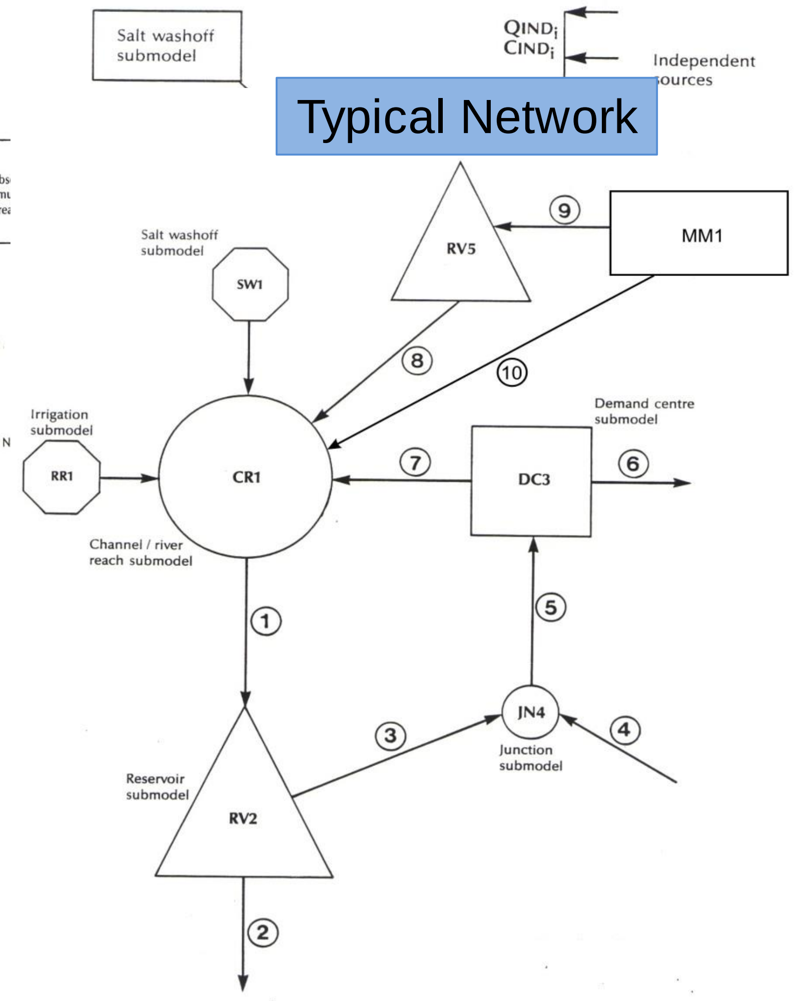
Simulation procedure



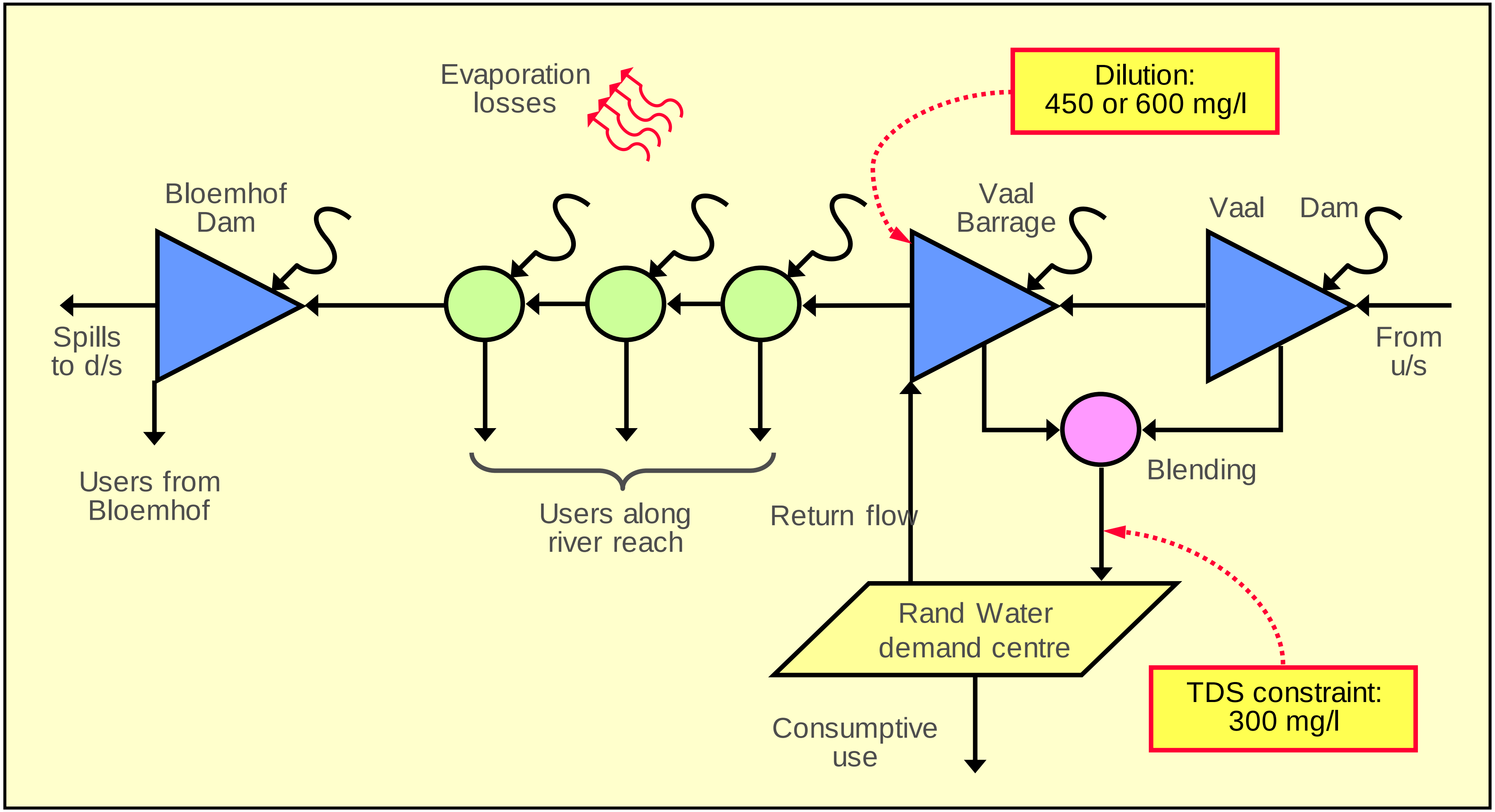
Salinity modules (optional)

Seven basic elements :

- Salt washoff sub-model
- River reach sub-model
- Irrigation block sub-model
- Demand Centre sub-model
- Junction sub-model
- Reservoir sub-model
- Mining sub-model



Dilution / blending alternatives



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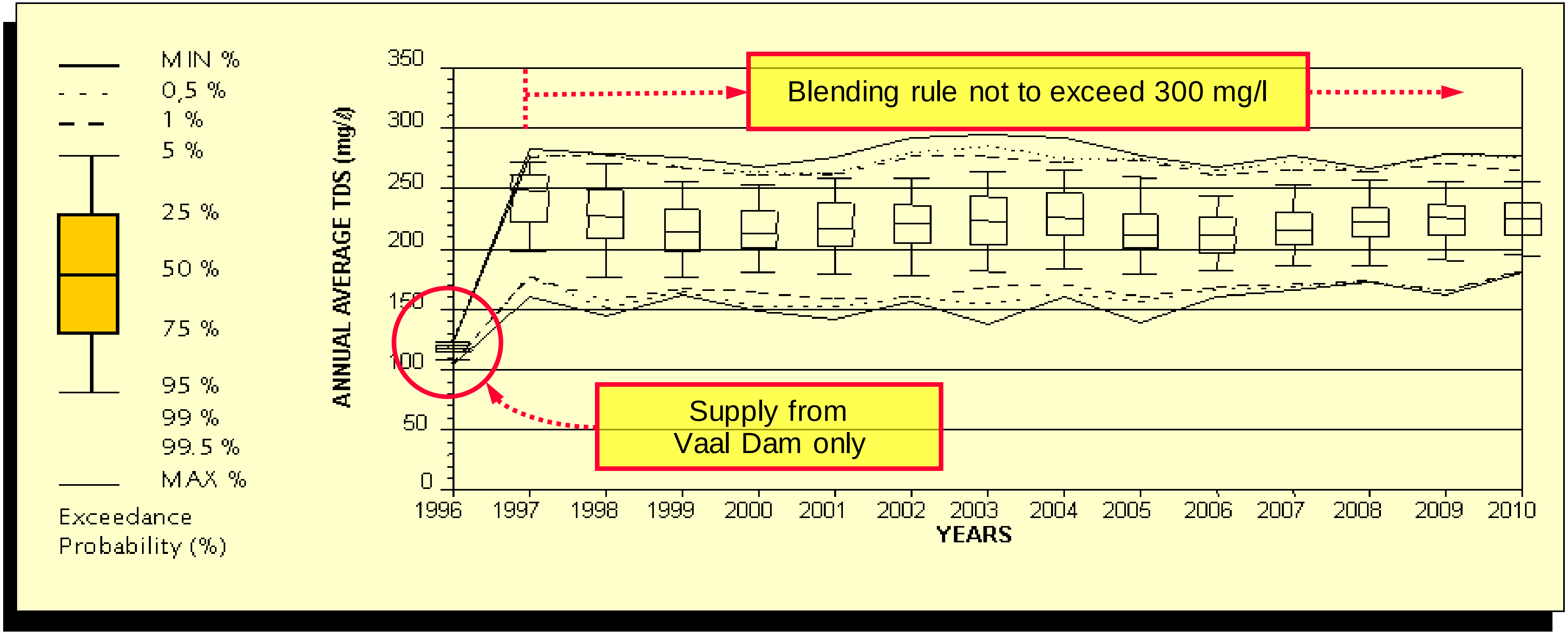
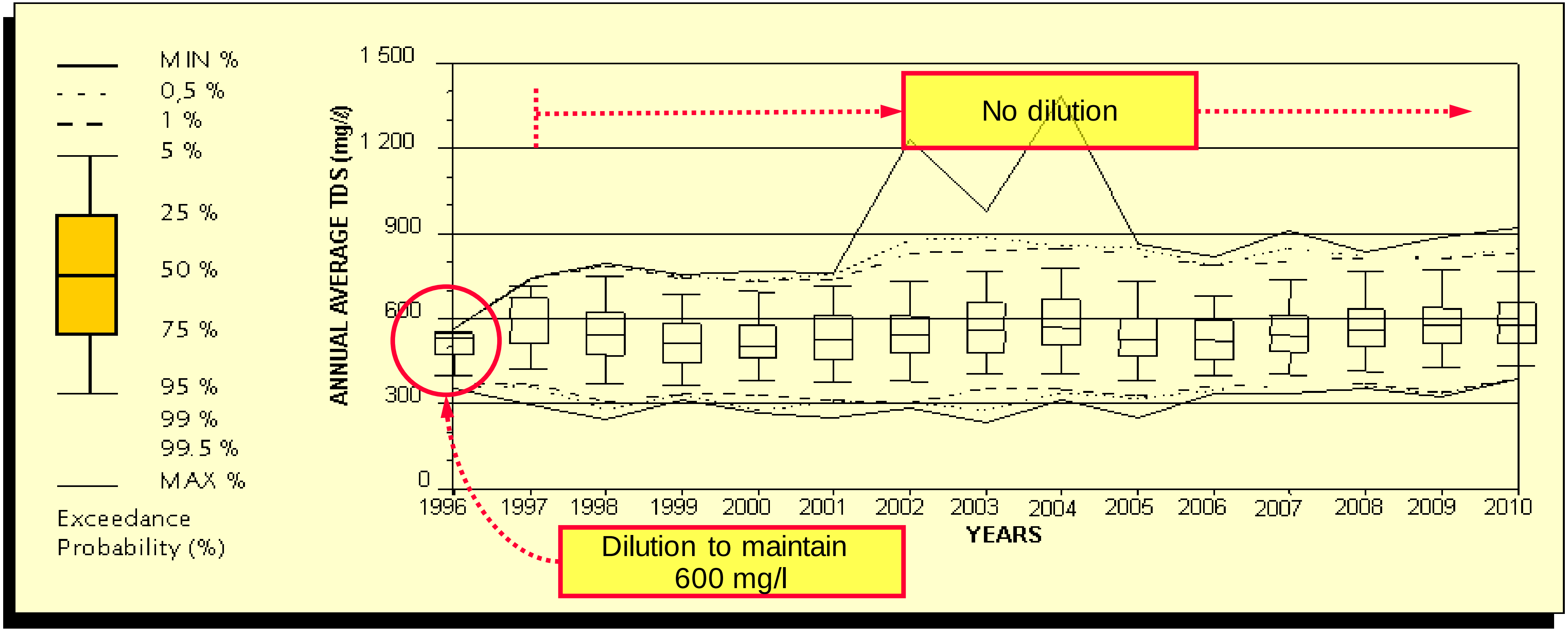
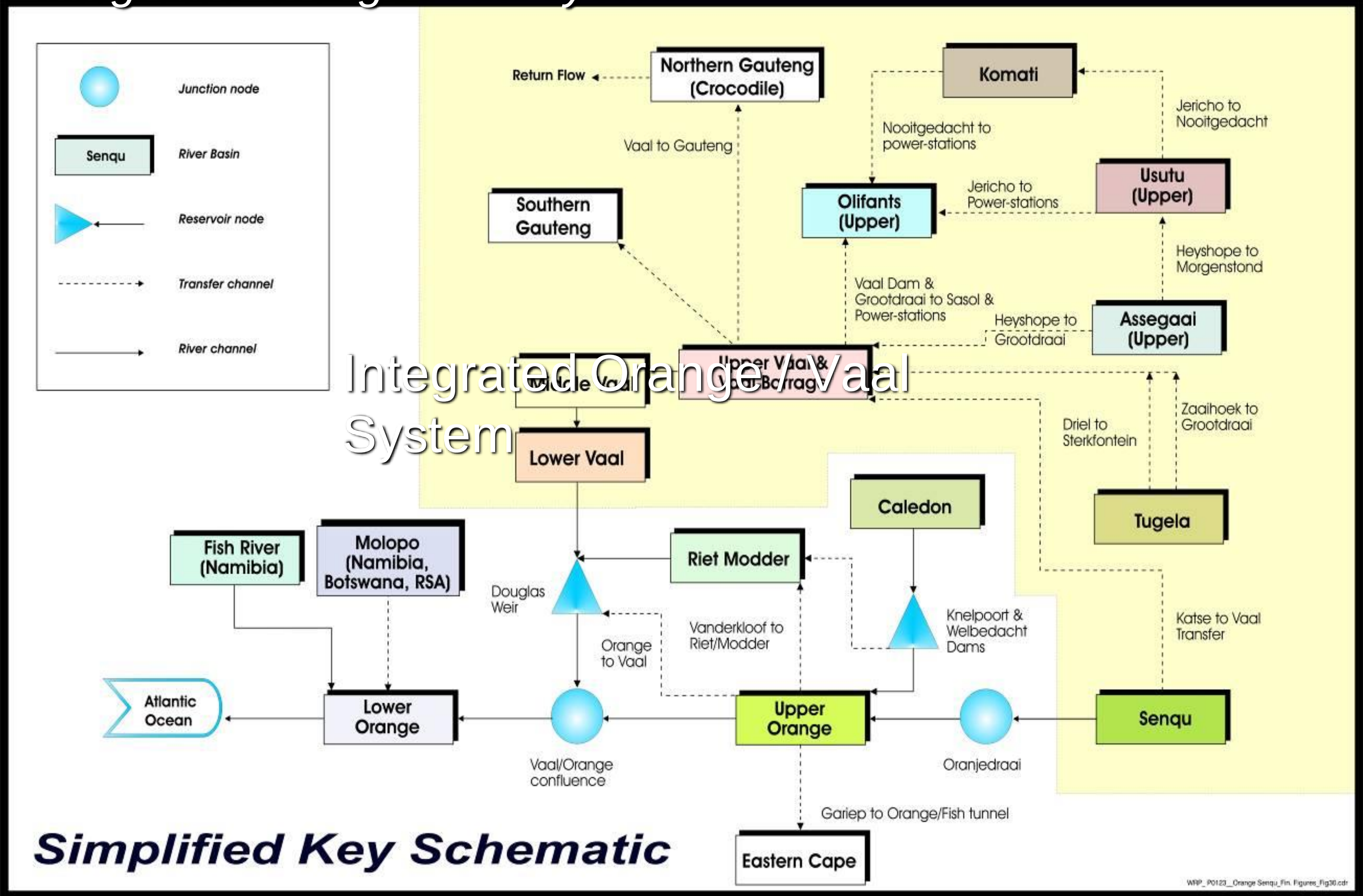
Blending scenario



Short term dilution scenario



Operational Planning Example: Integrated Orange /Vaal system



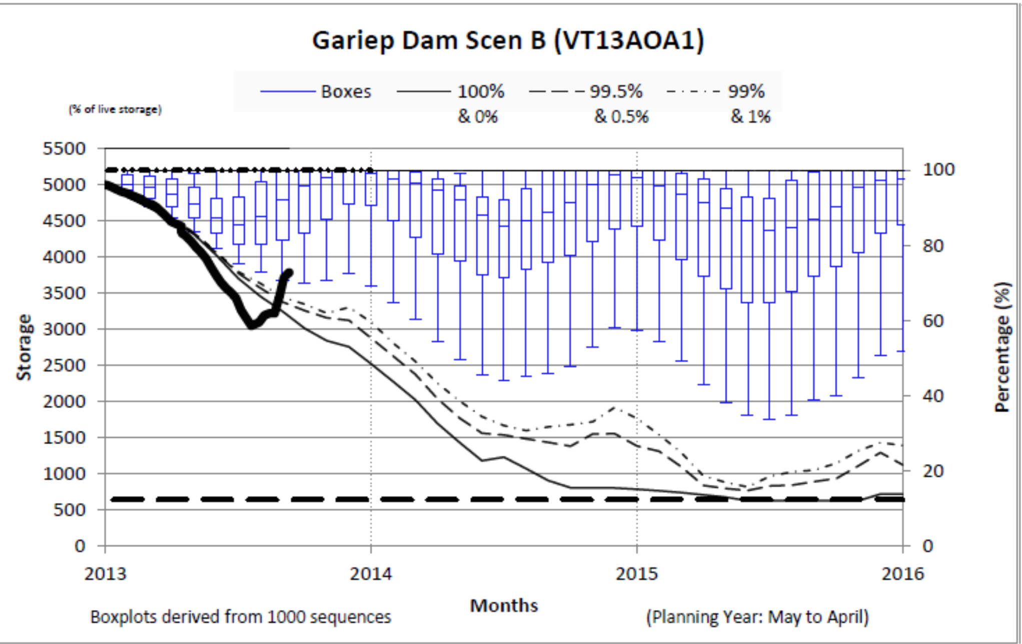
Integrated Orange / Vaal System

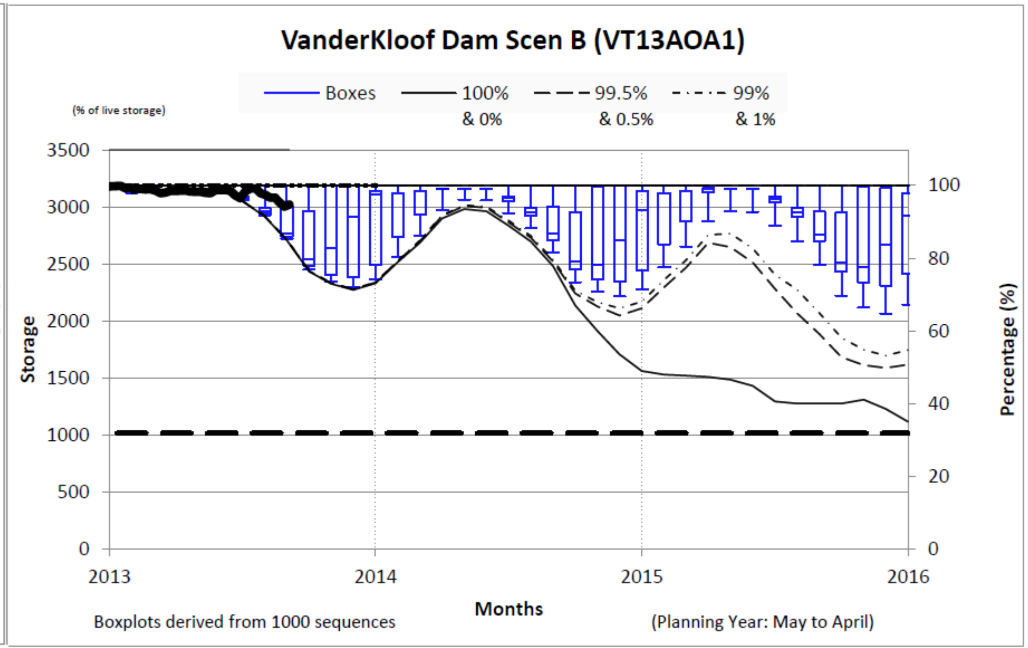
Orange Senqu Basin

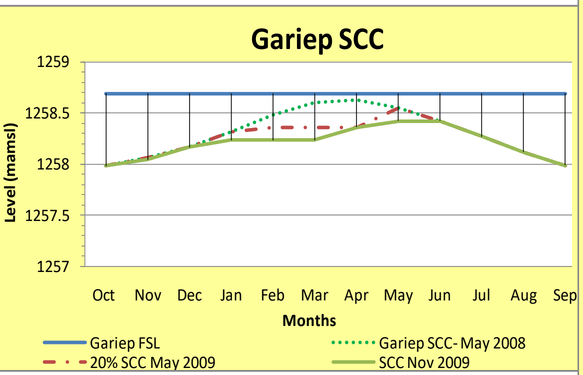
Integrated Orange / Vaal System Statistics

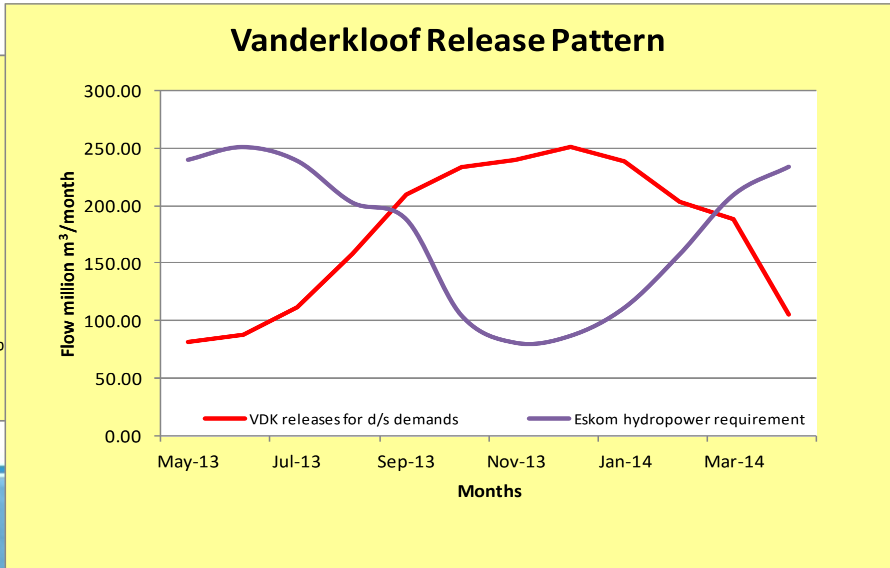
- 87 large and 279 small dams
- 1241 abstraction routes
- Drought Restrictions:
  - Vaal System: 8 Integrated and 5 stand alone subsystems.
  - Orange System: 3 subsystems
- 11 Ecological water requirement structures

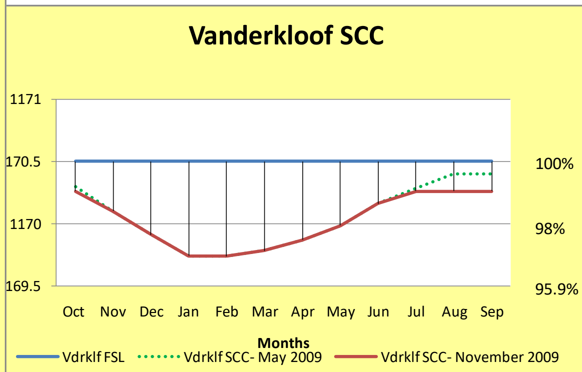
Reservoir operation and monitoring





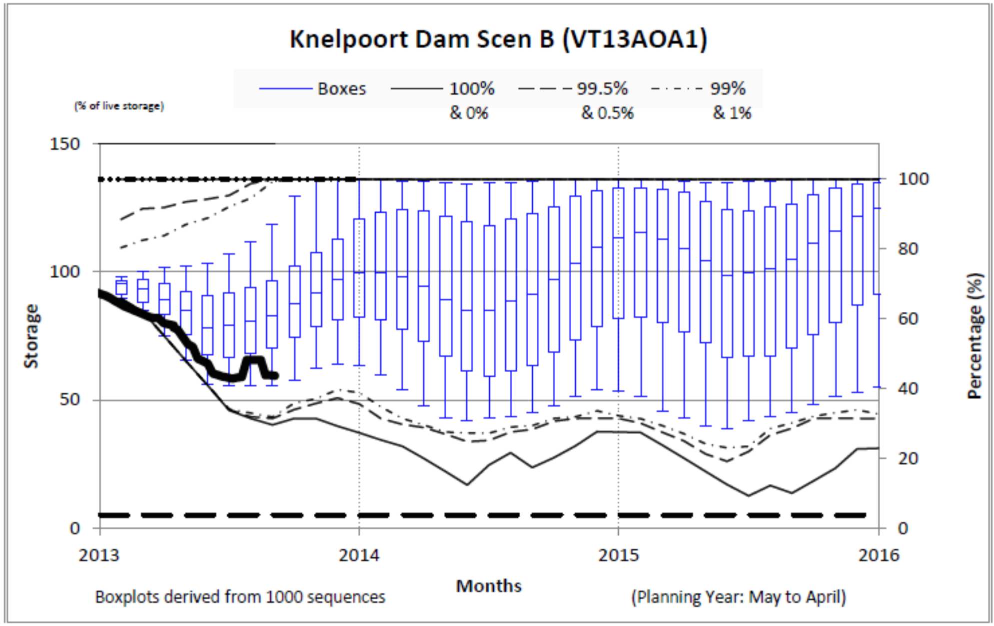


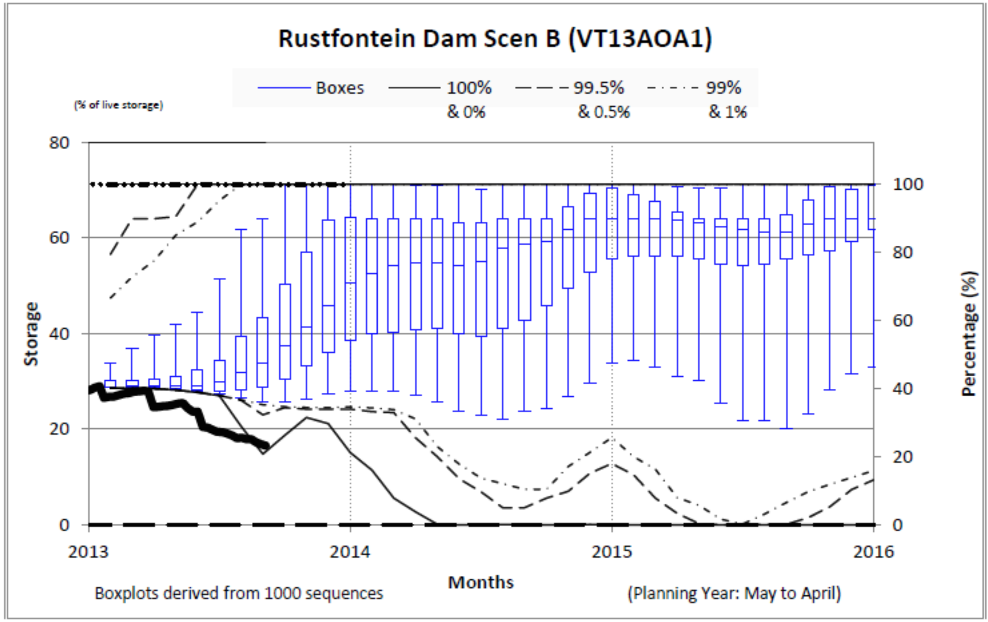


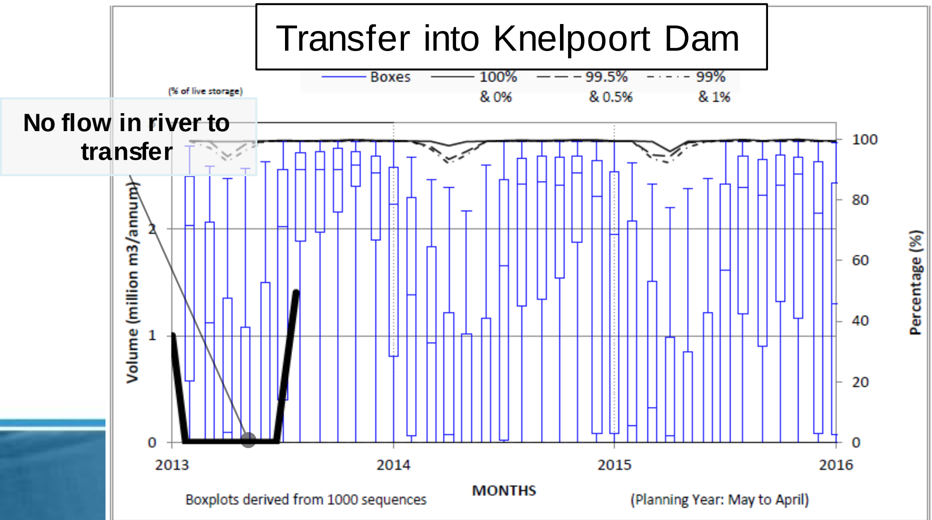


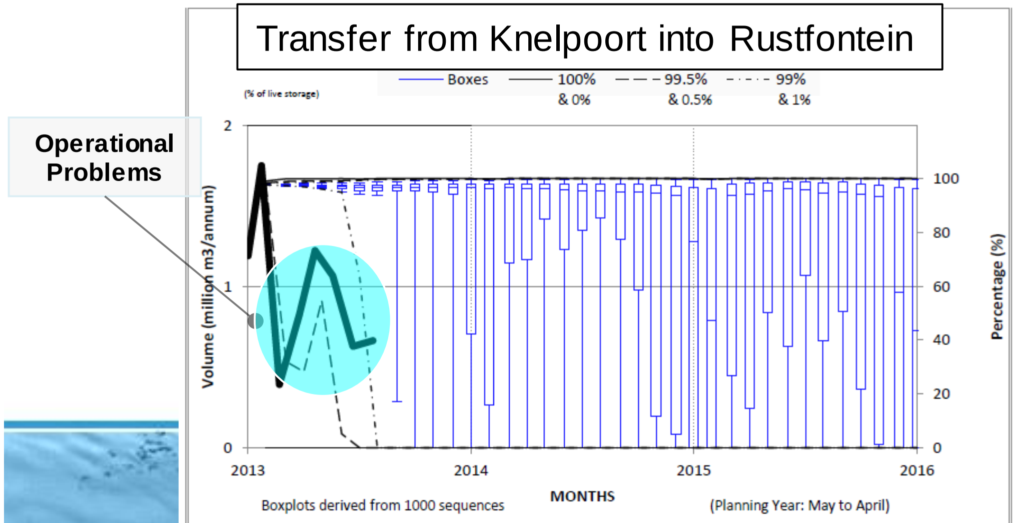
(ToR: 3 & 4)

Reservoir and flow monitoring









Example of cost implication of alternative operating rules

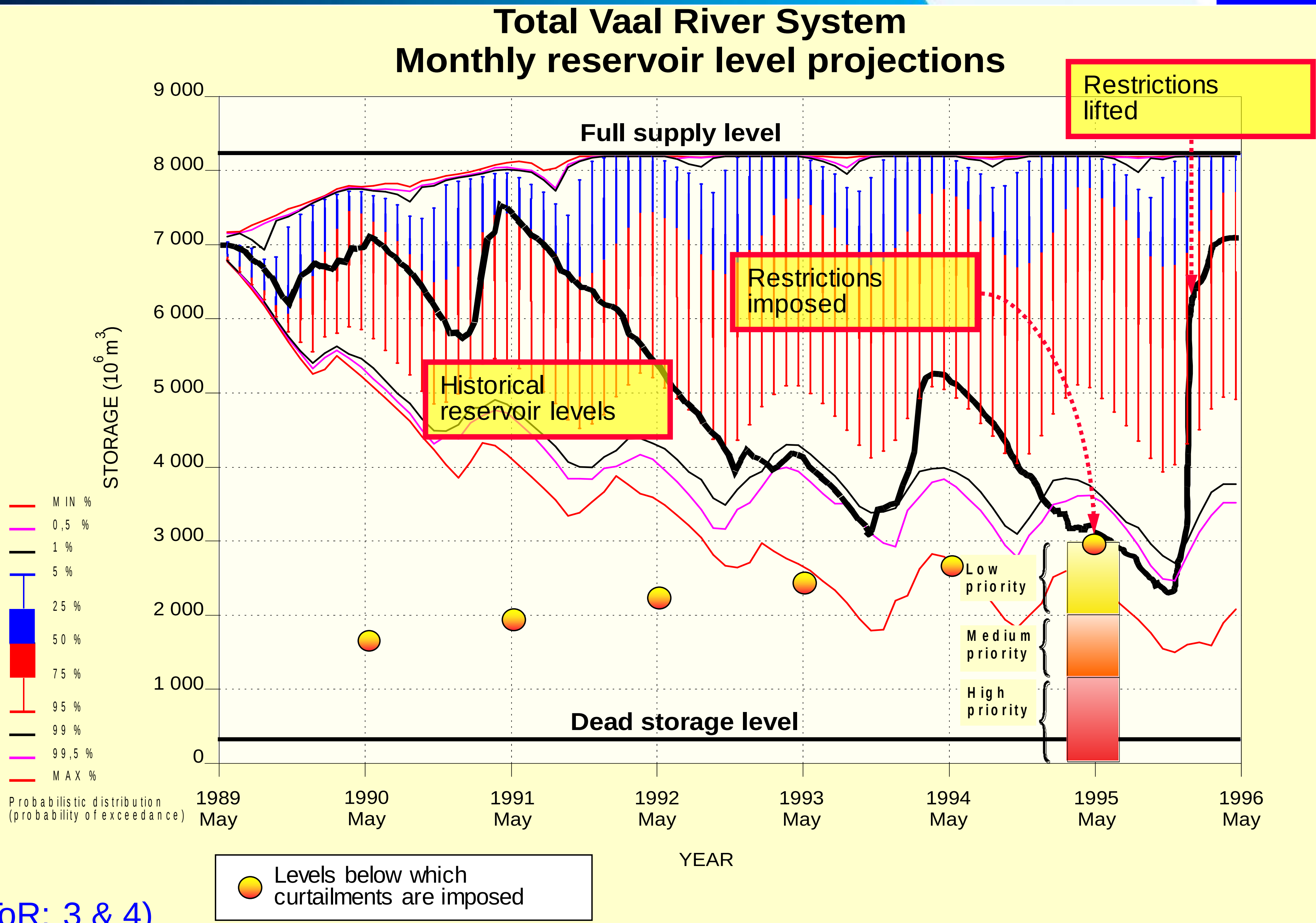
Description of transfer	Saving at indicated exceedance probability (%)[1] (X R1 million)										
	99.5	99	98	95	75	50	25	5	2	1	0.5
Heyshope to Grootdraai	0.6	0.8	1.0	1.7	4.1	5.4	6.9	10.4	11.5	12.5	13.7
Zaaihoek to Grootdraai	(0.5)	(0.4)	(0.1)	0.1	1.0	1.8	2.6	3.8	4.2	4.5	5.3
Total[2]	0.9	1.2	1.8	2.8	5.7	7.3	9.1	13.1	14.7	15.8	17.4

Notes: (1) Values in brackets indicate a cost increase.

(2) Not the sum of columns.

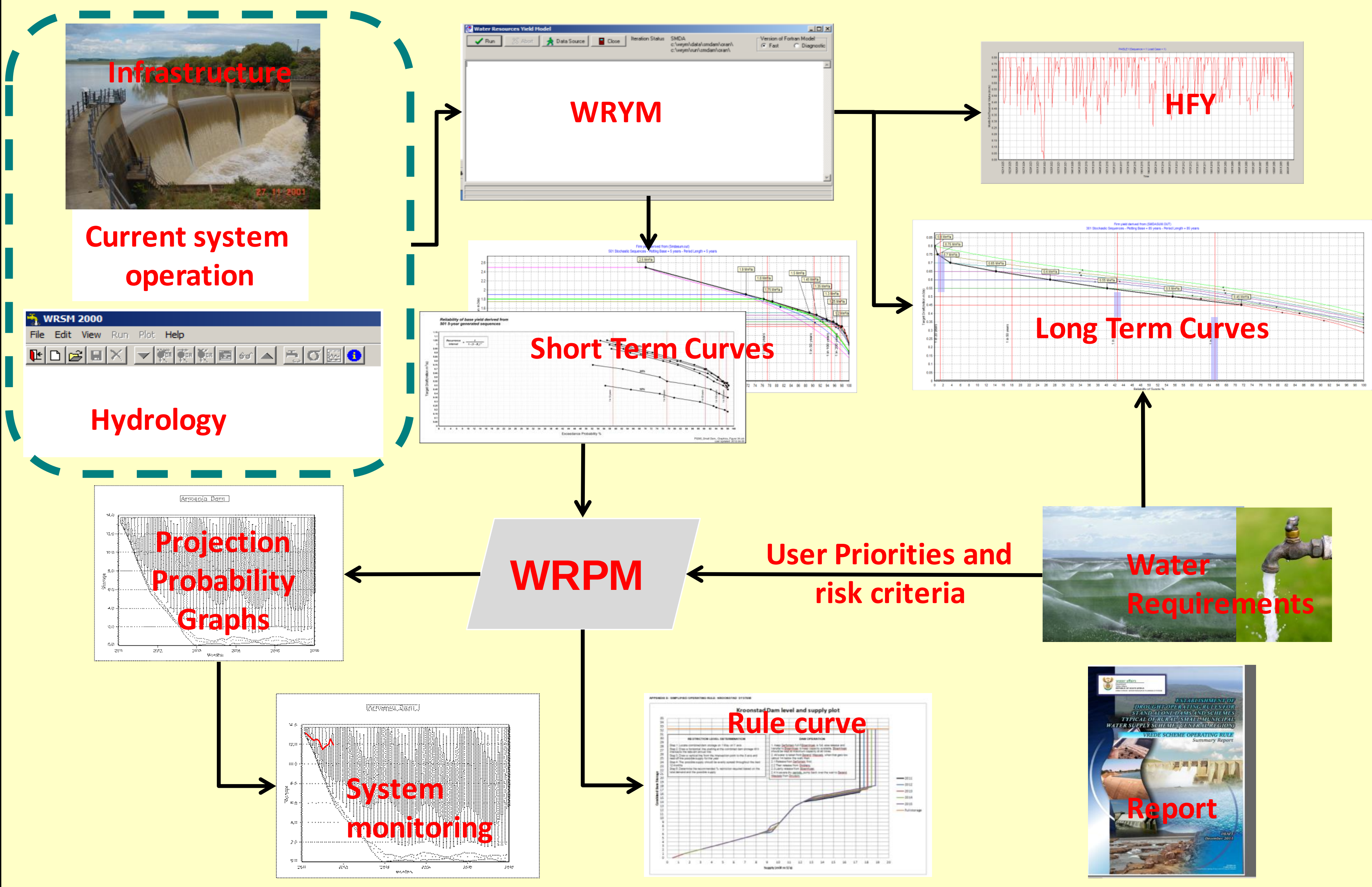
(ToR: 3 & 4)

Drought Management Example



(ToR: 3 & 4)

Operating rule development (overview)

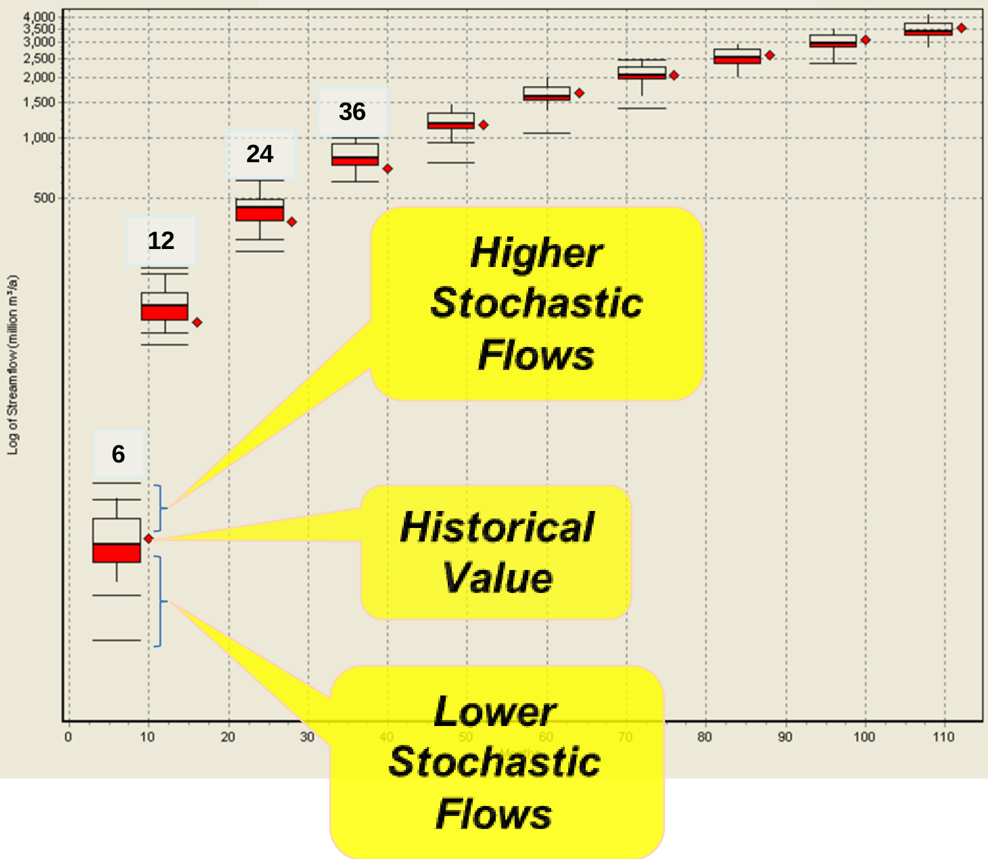


Climate variability and climate change

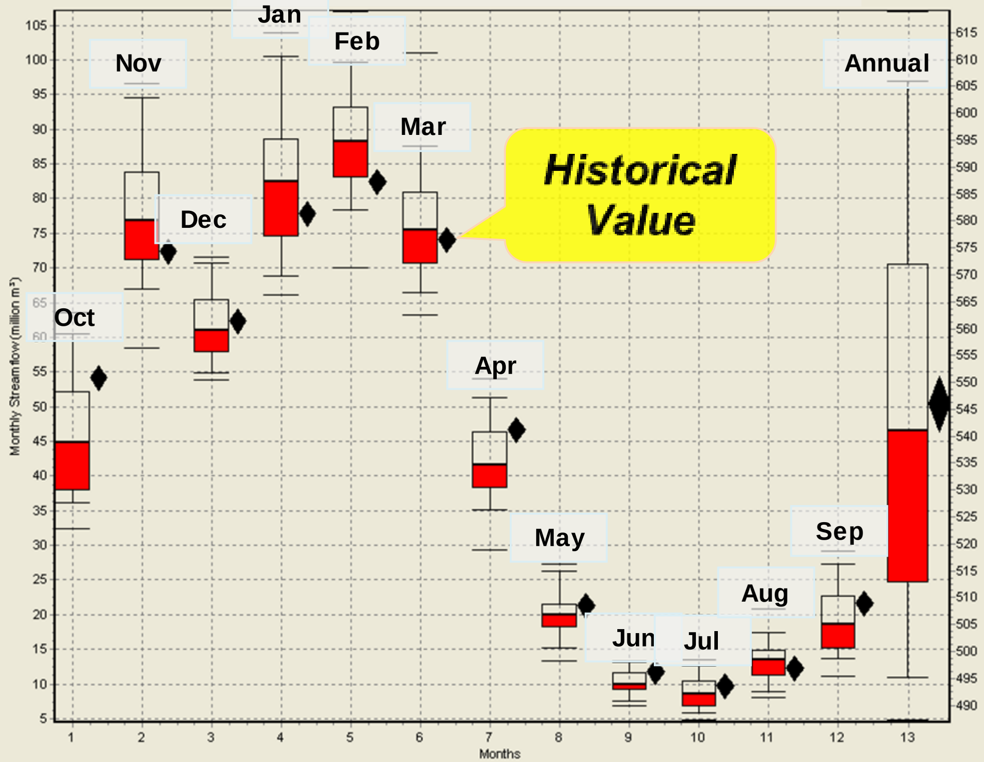
- Stochastic model was designed to account for the variability experiences in Southern Africa.
- Extensively tested and applied in numerous studies.
- Stochastic analysis generate sequences that are wetter and drier than observed historically.
- Option of changing stochastic model parameters to alter flow generation.

Stochastic vs. Historical

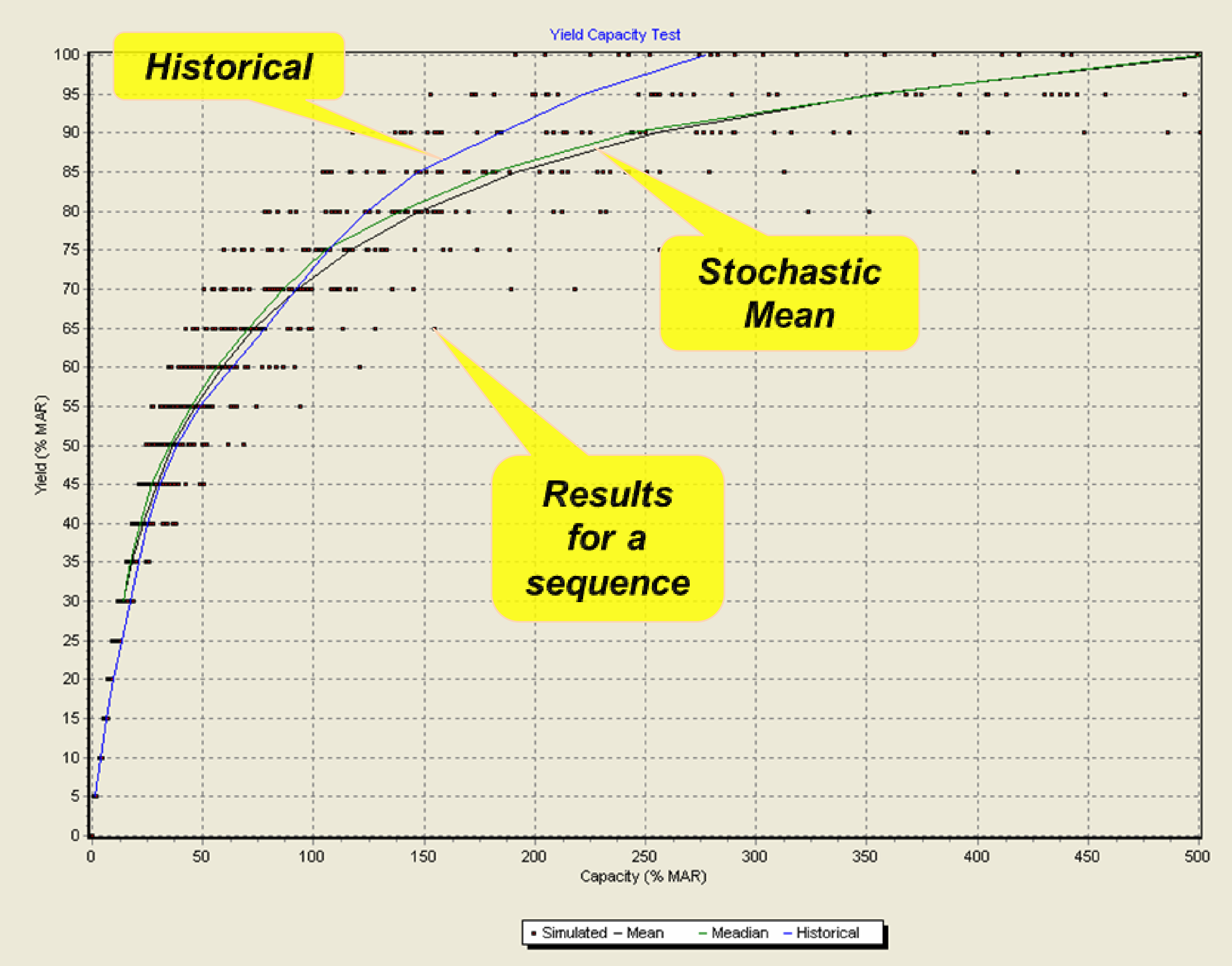
N-month minimum flows



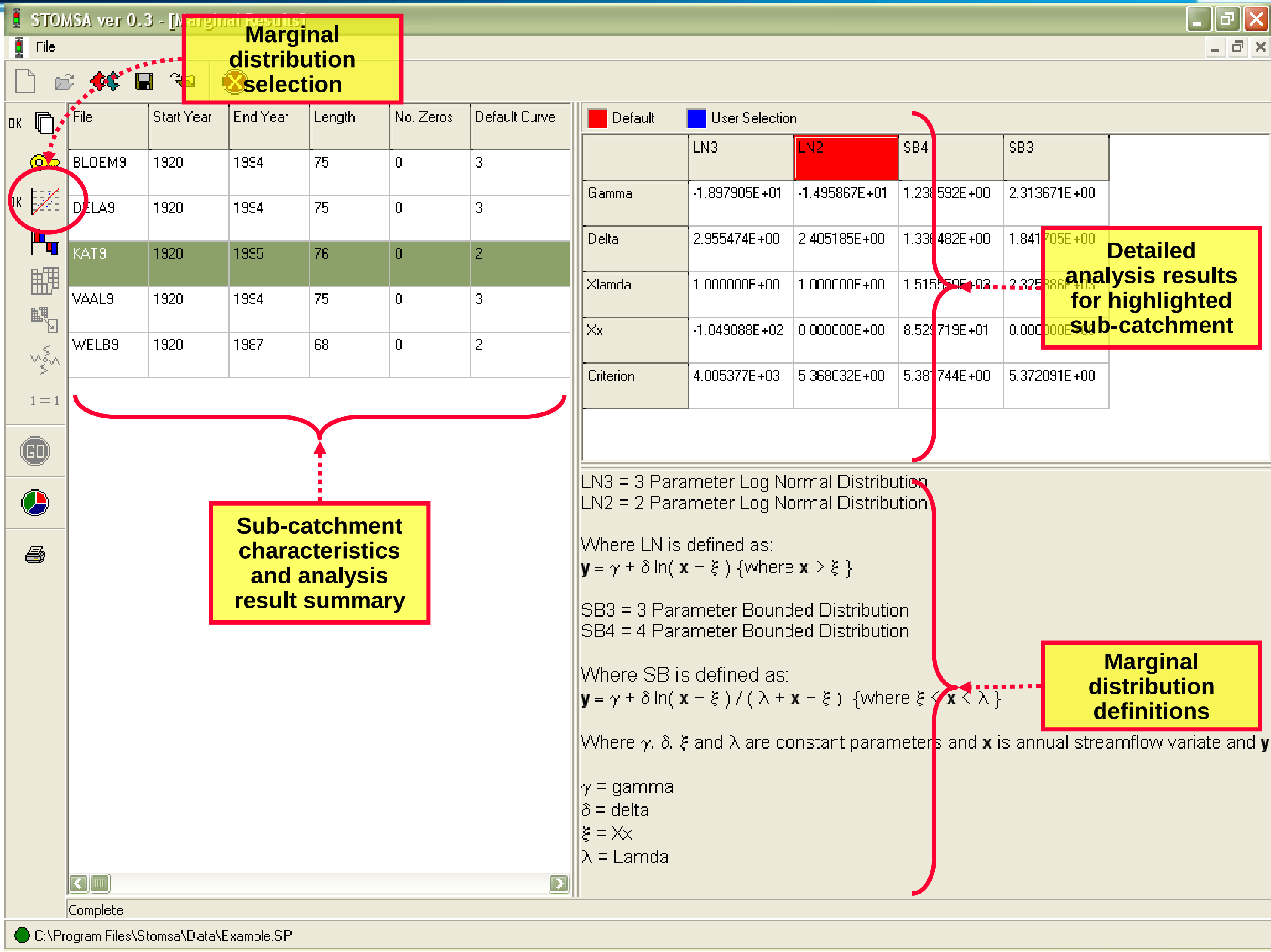
Monthly and Annual Means

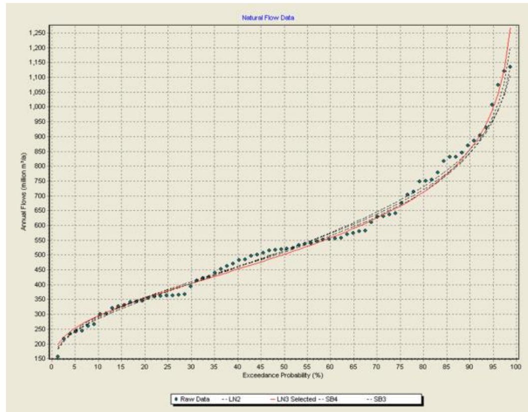


Yield Capacity Diagram



Possible Stochastic Parameters to adjust for climate change





Need for software or application changes for Save

- WRYM already configured, ready to derive short-term yield reliability characteristics.
- WRPM to be configured for projection simulations.
- No need to change model software:
  - Configure priority supply rules through input data (weights).
  - No complex coding needed in primary or rule based languages.
  - Model can be used to evaluate and implement transparent cross boarder flow or ecological release requirement rules.

Licensing fees

- None, SA Government makes models available for use in SADC countries.
- The suit of models is the product of substantial R&D expenditure over many years.
- Continuous enhanced through WRC research and other government funding.
  - Rainfall stochastic generator.
  - Incorporate quantification of uncertainty.

Training courses

- One or two day courses for managers and decision makers.
- Training for model users:
  - Hydrology training – 3 to 4 days.
  - WRYM and WRPM – 5 day course.
- Service provided on a time and cost basis.
- Part of post graduate courses at University of Pretoria and Stellenbosch University.
- SA Department of Water Affairs also provide training courses.

Backup support

- SA Department of Water Affairs has a user support helpdesk and web site - Pretoria.
- Model enhancements funded by SA DWA & WRC.
- WRP provides the following services:
  - Model users that can assist with queries via e-mail.
  - Model development and enhancement services.
  - Application training to officials and consultants as part of water resource studies.

Thank you for the opportunity and your attention

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