

# System Dynamics Modelling for the Simulation of Complex Water Systems



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- **1. SDM Overview**
- 2. Simple example
- **3. SDM in AQUASTRESS**
- 4. Case studies (2)
- 5. Running demo...



System Dynamics Modelling (SDM) or Systems Thinking

- Methodology for analyzing, studying and managing
- Complex Systems
- When formal analytical methods do not exist
- (or are hard to apply)
- By linking feedback mechanisms (loops and iterations)
- Breaking down the problem into sub-systems and submodels
- In a way similar to the conceptual thinking of nonprogrammers (conceptual models)
- No analytical formal simulation model necessary



Based on conceptual/graphical representation of relations among different system components.

- Visualisation using specialised software (interface)
- Models built gradually starting with few components, adding complexity interactively
- Differential equation + Integration simulated in a "friendly" way
- Different time scales for different subsystems

Suitable for developing a model in participatory process Acting as *Decision Support Tools (DST)* for stakeholders (nonengineers) and experts for examining alternatives/scenarios



**History/Applications** 

- Industrial long-term management problems (Forrester 1961)
- Business strategy and policy problems
- Ecology / Complex environmental systems
- Complex water systems
- Participatory process
- Several Specialised software tools for visualisation....
- <u>SIMILE</u> (www.simulistics.com)
- (← Used here)

<u>VENSIM</u> (www.vensim.com)

(← Used here)

- STELLA (www.iseesystems.com)
- **SIMULINK(www.mathworks.com) (MATLAB)**
- POWERSIM (www.powersim.com)
- **MODELMAKER (www.modelmakertools.com) (BORLAND)**



Each SDM model consists of:

- Stocks/Compartments (Levels-State variables)
- Connectors (Arrows)
- Flows/Influences (Rates)
- Converters (Auxiliaries/Parameters)
- Decision processes (Priorities/Allocation/Relations)





Flow diagram

Causal Loop diagram



Flow diagram: For quantitative (numerical) model/simulation Causal Loop diagram: For qualitative (conceptual) model

- For each system, both Flow and Causal Loop diagrams can be drawn
- Causal loop helpful for studying "causality"





Analytical expression (i.e.  $C_t = C_o(1+a)^t$ ) *NOT needed* Data needed:

- Drawing "Capital" as Stock, "Interest" as Flow, "Interest rate" as Parameter, "arrows" as influences
- Initial value for "Capital" (e.g. 10000)
- Interest rate (e.g. 10%)
- Relation: Interest=Capital\*Interest\_rate





## **SDM: Simple example**



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Interest rate



## **SDM: Simple example-Causality**













## **SDM in AQUATRESS**



#### AquaStress

#### (http://www.aquastress.net)

- Mitigation of Water Stress through new Approaches to Integrating Management, Technical, Economic and Institutional Instruments
- EC FP6 IP project (2005-2009)
- € 14 million budget
- 35 partners

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8 (very) different test sites/case studies





## **SDM in AQUATRESS**



Within AQUASTRESS several Technical Options are investigated for mitigating water stress:

From the technical point of view each of these options are separately

- *Examined* (State-of-the-art methodologies, techniques)
- Assessed (Results, quantities, costs)
- Considered for each test site (local feasibility)

They are then combined using Conceptual and System Dynamics Modelling to simulate the water systems for each case study SDM models: low in detail, high in integration



- Identify a problem/system within the case study
- Develop a dynamic hypothesis explaining the cause of the problem (SDM -Conceptual model)
- Build a computer simulation model (SDM Quantitative model)
- Test the model (Validation)
- Use the model to produce and assess alternative policies
- With interactive process

27/02/20 (Experts→stakeholders→experts→stakeholders...)

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## **SDM – AQUASTRESS: Component Types (1/2)**

(1)	(2)	(3)	(4)	(5)
AQUASTRESS terminology	Water Resources	Water Resources	Water losses	Water users
Type of water system model component	Water bodies	Resources	Losses	Water users
SDM Functional type	Stocks	Converters: Inflows	Converters: Outflows	Converters: Outflows
Brief functional description	Storage/ Water sources	Water inputs to the system	Losses	Water users/ Water consumption
Abbreviation	S	I.	L	U
Dimension/Units	Volume - Mass	Volume/time	Volume	Volume/time
Component	Reservoir	Precipitation (Rainfall)	Evapo-transpiration	Agriculture
Abbreviation	RES	Р	ET	AWU
Component	Groundwater- Aquifer	Surface runoff	Groundwater losses	Industry
Abbreviation	GW	SR	GL	IWU
Component	Sea	Groundwater flow		Domestic
Abbreviation	SEA	GF		DWU
Component		Urban Waste water		Environment
Abbreviation		UWW		EWU
Component				Tourism/ Leisure
Abbreviation				TWU





## **SDM – AQUASTRESS: Component types (2/2)**

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(1)	(2)	(3)	(4)	(5)	(6)
AQUASTRESS terminology			Options	Options	Options
Type of water system model component			Quantitativ e manipulato r	Qualitative manipulator	Transfer (mass flow)
SDM Functional type			Converters	Converters	Converters
Brief functional description	AQUASTRES S Option Code	Abbreviati on	Option that alters the volume	Option that alters the quality (e.g. concentratio n)	Option for Re-allocation without altering the volume
Abbreviation			V	Q	Т
Dimension/Units			Volume/tim e	Concentratio n	Volume/time
Waste water re-use	03.1.1	OWWR	~	V	
Desalination	03.1.2	ODES	v	~	
Drainage water re-use	03.1.4	ODWR			*
Water table management	03.2.1	OWTM	×		*
Groundwater remediation	03.2.2	OGRR		~	
Surface water control	03.2.3	OSWC	v		*
Enhanced reservoir management	03.2.4	OERM	v	~	*
Minimising water losses	03.3.1	OMWL	~		
Process optimisation in industry	03.3.2	OPOI	~	~	1
Domestic Water Use and conservation	03.3.3	ODUC	~		
Irrigation water management	03.4.1	OIWM	×	~	1
Tailoring crop patterns	03.4.2	OTCP	×		
Less water intensive processes	03.4.3	OLWI	~		





## **SDM – Conceptual model for technical** options- Example (1)







## <u>SDM – Conceptual model for technical options-</u> Example (2)







## <u>SDM – Conceptual model for technical</u> options- Example (3)







## **AQUASTRESS SDM: Case studies**

- 1. Kremikovtzi plant water system (Bulgaria)
- Industrial (competitive) water use limited water resources
- Improve the rate of water re-use
- Study operational policies for dry and very dry years

#### **2. Merguellil catchment (valley) aquifer management – (Tunisia)**

- Hydrological model (group of small dams+1 large dam)
- Study agricultural water use
- Improve aquifer recharge and management





## Kremikovtzi system: Industrial water re-use

- The industrial plant of Kremikovtzi consist on of the biggest water consumers and water pollutants in the Sofia region.
- Water demands for the plant amound to 550 million m<sup>3</sup> / year, a significant percentage of which is recycled within the plant.
- The plant takes about 50-60 million m3 /year fresh water from two nearby reservoirs



- The SDM model aims at defining operating scenarios, and propose water saving measures, so as to:
- **1.** Reduce the plant fresh water needs
- 2. Improve the rate of water re-use
- 3. Study operational policies for dry and very dry years





## Case study: Kremikovtzi water system







## Kremikovtzi conceptual model initial-July 2006- (1)







## Kremikovtzi conceptual model October 2006- (2)







## **SDM: Initial SDM models**

#### Initial SDM models for water quantities using different software tools (WB3-WB4-JWT-November 2006)



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	n 🖻 🛱 🖬 Kremikovtzi total waste water (red): Uses Tree 📃 📃
	Kremikovtzi total waste water (red)       Flow from KP to sludge pond (red)       (Kremikovtzi total waste water (red))         Sludge pond       Sludge pond         Waste water flow from KP to WWTPI (red)       (Kremikovtzi total waste water (red))
	ー 印 四 面 B Kremikovtzi total waste water (red) : Loops
	Loop Number 1 of length 1 Kremikovtzi total waste water (red)
	Waste water flow from KP to WWTPI (red)

Flow from KP to sludge pond (red)

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## **Causalities with VENSIM**

Kremikovtzi total waste water (red) Waste water % to WWTPI Flow from KP to sludge pond (red)

Delay buffer parameter —— Purple flow from sludge pond to Botunetz —— Sludge pond

(Delay buffer parameter) — Purple inflow from Sludge pond to KP buffer

(Delay buffer parameter) — Wasted water from sludge pond

Evaporation/Losses from Botunetzy

Time — Flow from Pancherevo to Botunetz  $\setminus$ 

Water needs — Purple flow from Botunetz to KP buffer

Delay buffer parameter — Purple flow from sludge pond to Botunetz — Botunetz RES2

WWTPI — Purple flow to Botunetz from WWTPI

River Lesnovska /

River Matitza





## **Causalities with VENSIM**

- WWTPI Flow from WWTPI to KP buffer (purple)
- Water needs Purple flow from Botunetz to KP buffer Buffer Kremikovtzi used water (purple)
- Delay buffer parameter Purple inflow from Sludge pond to KP buffer

(Water needs) — Used water flow to KP

(WWTPI) — Flow from WWTPI to KP buffer (purple)  $\setminus$ 

(WWTPI) — Purple flow to Botunetz from WWTPI

Kremikovtzi total waste water (red) Waste water % to WWTPI Waste water flow from KP to WWTPI (red)

(WWTPI) —— wasted treated water from WWTPI /







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## **SDM: Intermediate SDM Models**

#### (May 2007-July 2007) Separate models for higher and lower quality fresh water





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**Clean industrial water model (2 sub-models)** 

AQUASTRESS









## **Final Model (Causal Loop Diagram)**







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## **Final SDM Model Kremikovtzi**









## KP permanent units

and potable water subsystems







# KP Non permanent units, Ore and Sinter plant units subsystems







## KP Sludge pond subsystem







## **KP Water re-cycling subsystem**







## **KP Domestic Waste Water Subsystem**







## **KP Clean Fresh Water Subsystem**







## **Generating scenarios with SIMILE**

😵 KR-cleanwater-new execution - Simile Eile Edit Add Window Help	
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Clean water inflow to KP     Section water needs     mine water	18000 -
Pancherevo clean water to KP     Pancherevo RES1	
Kremikovtzi total water (blue and purple) →  → inflow →  ● Inflow series	16000
flow to Botunetz drinking water evaporation losses	15000
-	14000-
	13000 10 20 30
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## **Generating scenarios with SIMILE**

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bidger Kremikovtzi used water (purple)         2.0         40511.9668         14112.0000         4736.7549         23024.0000         16261.5700         32000.0000         20160.0000         20255.9834         11840.0000           WVTPI Industrial         3.0         40744.2589         14112.0000         2787.1649         24208.0000         19452.3766         32211.3201         2023.1317         2037.1294         11918.1885           Prople flow to Botunetz from WWTPI         purple flow to Botunetz from WWTPI         5.0         41165.4373         14292.6219         12280.4421         26735.3610         25440.7889         32595.4071         20535.1065         20582.7186         12060.3006           Purple flow to Botunetz from WWTPI         Furple flow to Botunetz         411355.8619         14374.5745         14423.0099         28003.2737         28235.5408         32769.4671         20555.1065         20582.7186         12060.3006           VEX buffer purple from Botunetz         wasted treater from wWTPI         1733.8325         14451.3361         17393.409         2927.27026         30956.8409         32932.2348         2077.5313         12244.9395           VEX buffer purple from Botunetz         9.0         41855.306         14523.1663         19992571         30546.4425         33360.4425         33080.46895         20843.3544
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River Maitza SR purple flow to Botunetz from VWTPI Purple flow to Botunetz from WWTPI Purple flow to KP buffer from sludge pond Inflow for KP buffer from sludge pond Inflow for KP buffer from sludge pond Inflow for MPancherevo to Botunetz Evaporation-Losses from Botunetz Evaporation-Losses from Botunetz Evaporation-Losses from Botunetz I 10.0 42083.0502       14253.1361       12280.4421       26735.3610       25440.7889       32595.4071       20535.1055       20582.7186       12060.3006         9.0       41155.4373       14292.6219       12280.4421       26735.3610       25440.7889       32595.4071       20535.1055       20582.7186       12060.3006         9.0       41153.8352       14451.3310       17393.8409       29273.7026       30905.8409       32292.2393.4585       20643.3544       2050.0302       12241.351         9.0       41855.2306       14590.3481       22613.6537       31821.3051       35871.9955       33227.0660       20933.0516       20927.6153       12294.0144         10.0       42000.0000       14653.1361       25259.49494       33098.1180       3817.9955       33227.0660       20933.0516       20927.6153       12294.0144         10.0       42010.0000       14653.1361       25259.49494       30908.1180       3817.9055       32217.0059       33360.0484       21016.8305       21000.0000       11343.2179         11.0       42134.
Burgle flow to Bottnetz from Studge pond Purple flow to KP buffer from studge pond Inflow for MW/TPI Kremikovtzi total water (folue and purple) purple water to KP         6.0         41355,8619         14374,5745         14823,0099         28003,2737         28236,5408         32769,4581         20644,7586         20677,9309         12124,6395           Wasted water from Studge pond inflow for MowTPI Kremikovtzi total water from Stunge pond inflow from Studge pond inflow from Studge pond inflow from Studge pond inflow from Studge pond inflow from KP red to studge pond inflow from KP red
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Inflow to KP buffer purple from Botunetz       8.0       41700.0605       14523.1663       19991.2571       30546.4425       33084.6895       20843.3544       20850.0302       12241.3351         Wasted treated water from WWTPI       9.0       41855.2306       14590.3481       22613.6537       31821.3051       35871.9955       33227.0660       20933.0516       20927.6153       12294.0144         Wasted treated water from WWTPI       10.0       4200.0000       14653.1361       25259.4994       3008.1180       38172.0509       33360.0484       21016.8305       21000.0000       12343.2179         Purple water to KP       inflow from Pancherevo to Botunetz       10.0       42080.022       14717.7813       27927.3362       34376.7229       40352.0552       33484.1845       21095.0362       21067.4988       12391.4833         Wasted water from sludge pond       11.0       42134.8076       14717.665.5254       30157.791       35656.9750       42413.4048       33600.000       21168.0000       21168.0000       21169.4230.0000       12433.2009       12471.9593         Wasted water from sludge pond       inflow from KP red to sludge pond       14.0       42487.2197       14865.2272       36049.2997       3821.909       46185.0999       33808.6591       21299.4552       21243.6099       12509.2039
Image: Wasted treated water from WWTPI       9.0       41855.2306       14590.3481       22613.6537       31821.3051       35871.9955       33227.0660       20933.0516       20932.6153       12294.0144         Image: Wasted treated water from WWTPI       purple water to KP       10.0       4200.0000       14653.1361       25259.4994       33098.1180       38172.0509       33360.0484       21016.0305       21000.0000       12343.2179         Image: Wasted treated water from Subject to Bolunetz       purple water to KP       11.0       4213.4976       14711.7813       27927.3362       34376.7229       40352.0552       33484.1845       21096.0302       21007.0988       12389.1483         Image: Wasted water from sludge pond       11.0       42378.0502       14817.6000       33323.5148       36938.7116       44357.3499       33700.79891       21236.0388       21189.0251       12471.9593         Image: Wasted water from Sudge pond       14.0       42487.2197       14865.2272       36049.2997       38221.9009       46185.0999       33808.6591       21299.4552       21243.6099       12509.2039         Image: Waste water needs       16.0       42888.476       14909.6186       38791.9587       40731.9607       449456.4292       33999.7758       21431.7106       12576.2170         Image: Waste water
Kremikovtzi total water (blue and purple)         10.0         42000.0000         14553.1361         25259.4994         33098.1180         33172.0509         33360.0484         21016.8305         21000.0000         12343.2179           purple water to KP         purple water to KP         11.0         4213.0976         14711.7813         27927.3362         34376.7229         40352.0552         33484.1845         21095.0362         21067.4988         12389.1483           inflow from Pancherevo to Botunetz         Evaporation-Losses from Botunetz         13.0         42378.0502         14817.6000         33323.5148         36988.7116         44357.3499         33707.9981         21236.0388         21109.0251         12471.9593           wasted water from sludge pond         14.0         42487.2197         14865.2272         36049.2997         3821.9009         46185.0999         33808.6591         21294.4238         12509.2039           inflow from Pancherevo to Bulunetz         15.0         42688.4212         14909.6186         38791.9589         39506.3414         47897.7766         33902.4401         21358.5373         21294.4238         12543.9028           Kremikovtzi total red         16.0         42683.4212         14950.9761         41550.3835         40791.9607         49496.4292         33989.7758         21143.5587 <td< td=""></td<>
11.0       42134.9976       14711.7813       27927.3362       34376.7229       40352.0652       33484.1845       21057.0562       21067.4588       12383.1483         12.0       42260.8238       14766.5254       30615.7791       35656.9750       42413.4048       33600.0000       21168.0000       21130.0119       12320.0000         13.0       42378.0502       148176.000       33323.5148       36938.7416       44357.3499       33707.9981       21296.0388       21189.0251       12471.9533         14.0       42477.1797       14865.2272       36049.2997       38221.9009       4565.0999       33808.6591       21294.4552       21243.6099       12509.2039         15.0       42888.476       14909.6186       38791.9589       39506.3414       47897.7766       33902.4401       21358.5373       21294.4238       12543.9028         16.0       42883.4212       14950.9761       41550.3835       40791.9607       49496.4292       33989.7758       21413.5587       21341.7106       12576.2170         18.0       42883.2219       15025.3454       47110.410       43366.3688       52355.5174       34416.7369       21512.4443       21426.610       12684.2927         waste water to WWTPI       waste water poduced       waste water poduced       19
12.0       42260.8238       14/66.5254       30615.7/91       3565.6.9/50       42413.4048       33500.0000       21188.0000       21130.4119       12432.0000         Evaporation-Losses from Botunetz       13.0       42378.0502       14817.6000       33323.5148       36938.7416       44357.3499       33707.9981       21236.0388       21189.0251       12471.9593         Wasted water from Studge pond       14.0       42487.2197       14865.2272       36049.2997       38221.9009       46185.0999       33302.4401       21388.5373       21294.4238       1259.2039         Minfow from KP red to studge pond       15.0       42588.8476       14909.6186       38791.9589       39506.3414       47897.7766       33302.4401       21388.5373       21294.4238       12543.9028         To KP buffer re-use from WWTPI purple       16.0       42683.4212       14950.9761       41550.3825       40791.9607       49496.4292       33989.7758       21413.5587       21341.7106       12576.2170         Waste water to WWTPI       18.0       42853.2219       15025.3454       47110.4100       43365.5888       52355.5174       34141.67369       21512.4443       21466.610       2660.3347         waste water poduced       19.0       42292.2931       1508.7110       4991.01038       44654.9324
13.0       423/8.0502       1487/5000       33323.5148       35938/7416       44357.3499       33707.9981       21236.0388       21189.0251       12471.9593         13.0       423/8.0502       14817.5000       33323.5148       35938.7416       44357.3499       33707.9981       21236.0388       21189.0251       12471.9593         14.0       42487.2197       14865.2272       36049.2997       38221.9009       46185.0999       33302.4401       21358.5373       21294.4238       1259.2039         15.0       42588.8476       14999.6186       38791.9589       39506.3414       47897.7766       333902.4401       21358.5373       21294.4238       12543.9028         16.0       42683.4212       14950.9761       41550.3835       40791.9607       49496.4292       33398.7758       21413.5587       21341.7106       12576.2170         17.0       42771.4011       14989.4911       44323.5284       42078.6652       50982.0377       34071.0781       21464.7792       21385.7005       12606.2899         waste water to WWTPI       18.0       42853.2219       15025.3454       47110.4100       43365.3688       52355.5174       3414.67369       21512.4443       21466.610       12660.23897         waste water poduced       19.0       42929.2931
Inflow from KP red to sludge pond       14.0       42487.2197       14865.2272       36049.3997       38221.9009       46185.0999       33808.6591       21299.4552       21243.6099       12509.2039         Kremikovtzi water needs       15.0       42588.8476       14909.6186       38791.9589       39506.3414       47897.7766       33902.4401       21358.5373       21294.4238       12543.9028         To KP buffer re-use from WWTPI purple       16.0       42683.4212       14950.9761       41550.3835       40791.9607       49496.4292       33989.7758       21413.5587       21341.7106       12576.2170         Waste water to WWTPI       18.0       42853.2219       15025.3454       47110.4100       43365.3688       52355.5174       3416.7369       21512.4443       21466.610       12634.2929         Waste water produced       19.0       42929.2931       15083.7503       52721.7415       45944.4638       54769.4496       34282.5775       21598.0239       21606.02897         Waste delan water 20       20.0       43000.0000       15089.7503       52721.7415       45944.4638       54769.4496       34282.5775       21598.0239       21500.0000       12684.5537
Kremikovtzi water needs         15.0         42988.8476         14309.6186         3873.5983         33506.3414         47837.7766         33302.4401         21398.5373         21294.4238         12943.3028           To KP buffer re-use from WWTPI purple         16.0         42683.4212         14950.9761         41550.3835         40791.9607         49496.4292         33398.7758         21413.5587         21341.7106         12576.2170           Waste water to WWTPI purple         17.0         42771.4011         14989.4911         44323.5284         42078.6652         50982.0377         34071.0781         21464.7792         21385.7005         12666.2389           Waste water to WWTPI         18.0         42853.2219         15025.3454         47110.4100         43366.3688         52355.5174         34146.7369         21512.4443         21466.610         12664.2929           Waste water produced         19.0         42929.2931         15085.7110         49910.1038         44654.9924         53617.7225         34217.71209         21556.7861         21466.610         12600.0347           Wasted clean water 20         20.0         43000.0000         15089.7503         52721.7415         4594.4638         54769.4496         34282.5775         21598.0239         21500.0000         12684.5537
To KP buffer re-use from WWTPI purple         15.0         42683.4212         14300.3761         41500.3833         40/31.5007         43936.4232         33353.7736         21413.3387         21413.0387         2141.7105         12376.2170           Kremikovtzi total red         17.0         42771.4011         14989.4911         44323.5284         42078.6652         50982.0377         34071.0781         21463.7005         12606.2989           waste water to WWTPI         18.0         42853.2219         15025.3454         47110.4100         43366.3688         52355.5174         34146.7369         21512.4443         21426.6110         12634.2927           Waste water produced         19.0         42929.2931         15058.7110         49910.1038         44654.9924         53617.7225         34217.1209         21556.7861         21464.6466         12604.2937           Waste delan water 20         20.0         43000.0000         15089.7503         52721.7415         45944.4638         54769.4496         34282.5775         21598.0239         21500.0000         12684.5537
Kremikoviz total red         17.0         4277.3-011         14363.4-311         44325.3264         42076.6632         3366.0577         3407.0781         21464.732         21366.7003         12506.2363           waste water to WWTPI         18.0         42853.2219         15025.3454         47110.4100         43366.3688         52355.174         34146.7369         21454.413         21426.6110         12684.2397           waste water produced         19.0         42929.2331         15058.7110         49910.1038         44654.9324         53617.7225         34217.71209         21556.7861         21464.6466         12606.23637           waste dclean water 20         20.0         43000.0000         15089.7503         52721.7415         45944.4638         54769.4496         34282.5775         21598.0239         21500.0000         12684.5537
A wase water low with         100         4203-2213         1023-3414         4710-100         4300-3065         3233-3174         34146-786         2142-6416         1203-237           A waste delan water 20         10.0         4203-231         1508.7110         49910.1038         44654.924         53617.7225         34217.1209         21426.6466         1260-3247           A waste delan water 20         20.0         43000.0000         15089.7503         52721.7415         45944.4638         54763.4496         34282.5775         21598.0239         21500.0000         12684.5537
→ wasted clean water 20 20.0 43000.0000 15089.7503 52721.7415 45944.4638 54769.4496 34282.5775 21598.0239 21500.0000 12684.5537
Kremikovizi water needs time series 21.0 43065 7046 15118 6167 55544 5085 47234 7162 55811 4414 34343 4345 21636 3637 21532 8523 12707 0708
<b>22.0</b> 43126,7467 15145,4546 58377,6415 48525,6887 56744,3899 34400,0000 21672,0000 21573,3734 12728,0000
<b>23.0 43183.4452 15170.4000 61220.4257 49817.3250 57568.3395 34452.5636 21705.1151 21591.7226 12747.4485</b>
24.0 43236.0988 15193.5806 64072.1921 51109.5735 58285.6905 34501.3974 21735.8803 21618.0494 12765.5170
25.0 43284.9870 15215.1162 66932.3155 52402.3868 58895.2012 34546.7562 21764.4564 21642.4935 12782.2998
26.0 43330.3713 15235.1195 69800.2115 53695.7213 59397.9913 34588.8790 21790.9938 21665.1857 12797.8852
<b>27.0 43372.4962 15253.6957 72675.3346 54989.5367 59794.5440 34627.9896 21815.6334 21686.2481 12812.3561</b>
28.0 43411.5901 15270.9434 75557.1756 56283.7962 60085.3085 34664.2970 21838.5071 21705.7951 12825.7899
<b>29.0 43447.8661 15286.9550 78445.2598 57578.4655 60270.7027 34697.9970 21859.7381 21723.9330 12838.2589</b>
30.0 43481.5230 15301.8167 81339.1444 58873.5135 60351.1144 34729.2721 21879.4414 21740.7615 12849.8307 📷





## **KP Results-Alternatives**

#### Ognjanovo reservoir volume-Very dry scenarios - SP gradually reduced







## KP Results-System total recycling rate

Very dry	All on								0.6276
95%	OP sto	ops							0.6230
	OP sto	ops+ O	ther wa	ter use	ers (Pri	ority 0)			0.6374
	OP sto	ops+ N	on pern	nanent	units (	Priority	1)		0.6298
	OP sto	ops+ N	on pern	nanent	units (	Priority	2)		0.6299
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)		0.6010
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)+ SI	P 5/6	0.5906
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)+ SI	P 4/6	0.5793
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)+ SI	P 3/6	0.5671
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)+ SI	P 5/6+Lesnovska releas	e 0.5661
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)+ SI	P 4/6+Lesnovska releas	e 0.5539
	OP sto	ops+ N	on pern	nanent	units (	Priority	3)+ SI	P 3/6+Lesnovska releas	e 0.5405
Dry	Recyc	le 90%	+ Retu	rn WQ	3				0.6224
	Recyc	le 90%	)						0.5785
Normal	Recyc	le 75%	)						0.5330
	Recyc	le 70%	)						0.5045
	Recyc	le 65%	)						0.4759
	Recyc	le 60%	)						0.4474





## **AQUASTRESS SDM: Case studies**

- 1. Kremikovtzi plant water system (Bulgaria)
- Industrial (competitive) water use limited water resources
- Improve the rate of water re-use
- Study operational policies for dry and very dry years

#### **2. Merguellil catchment (valley) aquifer management – (Tunisia)**

- Hydrological model (group of small dams+1 large dam)
- Study agricultural water use
- Improve aquifer recharge and management





## Merguellil conceptual model (Tunisia)







## **Merguellil SDM (Tunisia) Initial model**







## Merguellil SDM (Tunisia) final model







## Merguellil SDM (Tunisia) final model







## Merguellil SDM (Tunisia) final model



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## Merguellil SDM (Tunisia) detail





## **SDM: Advantages/Disadvantages**

#### **Advantages**

- Easy to build models for complex, "non-specific" systems
- Good graphics environment
- Easy to make others understand and get involved
- Easy to run and compare scenarios
- SDM: Modelling by "afterthought"
- Especially useful for "time series" runs

### **Disadvantages**

- Iterative procedures within the same time step to be avoided
- Need for special "simulation schemes"/logic (e.g. continuity)
- Multiple variables for the same component need to be separated



## Time for demo display...