OPTIMIZING CONJUNCTIVE USE FOR SUSTAINABLE PRODUCTION: TOOLS FOR THE MANAGEMENT SPECTRUM

Richard C. Peralta
Shengjun Wu
Fernando Chanduvi
H. J. Morel-Seytoux

S/O Model Has

- Variables
- Objective Function
- Bounds
- Constraints

SIMULATION/OPTIMIZATION (S/O) MODELS

- CONJUS...for small relatively simple physical systems, field engineers/scientists
- REMAX...for complex physical systems, groundwater modelers

REMAX SIMULATION/OPTIMIZATION MODEL

- Analytical, Numerical, & Neural Simulation Expressions
- Superposition Equations
- Optimization Algorithms

REMAX Optimization Options

- Linear Optimization
- Nonlinear Optimization
- Mixed Integer Nonlinear Optimization
- Evolutionary Optimization

REMAX Can Develop Optimal

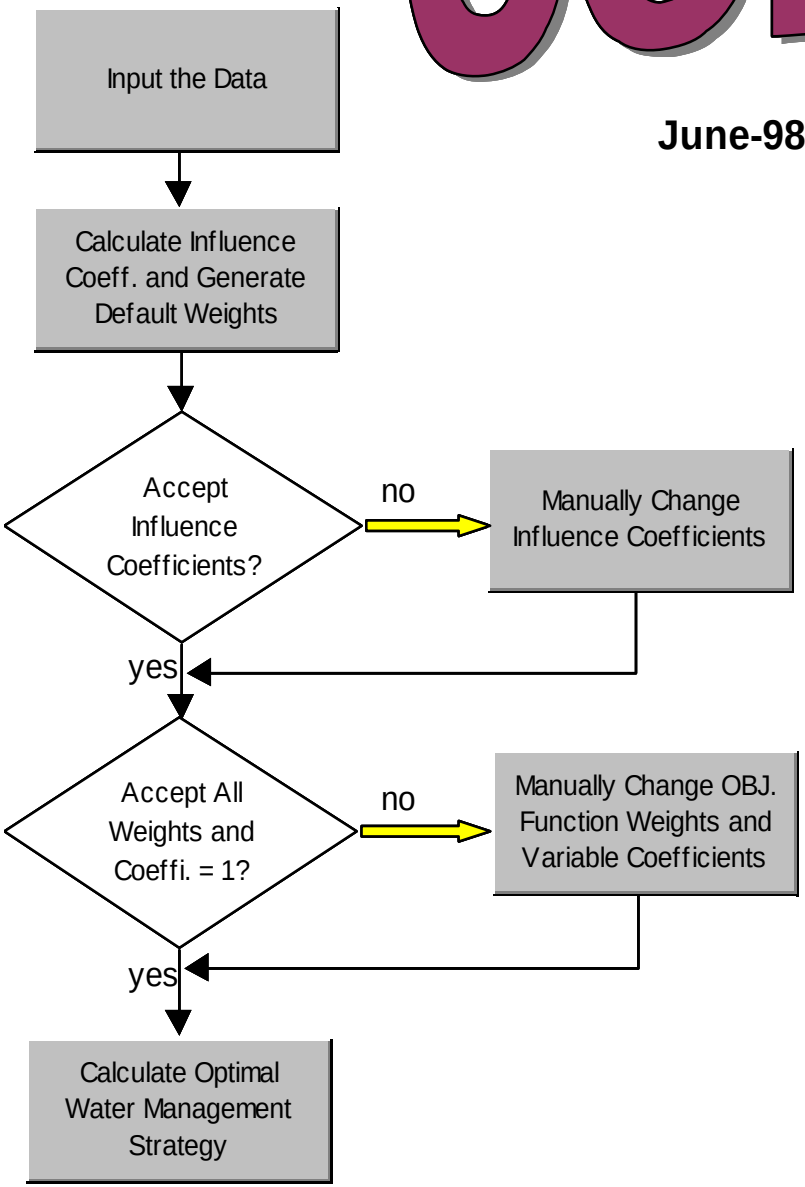
- Regional sustained yield groundwater management strategies
- Conjunctive water management strategies (quantity & quality goals)
- Groundwater contaminant plume management strategies (containment & cleanup goals)

CONJUS SIMULATION/OPTIMIZATION MODEL

- Analytical Simulation Equations
- Superposition Equations
- Optimization Algorithms

CONJUS

June-98 Alpha Version 1.0



CONJunctive Water Management Utility Software and Simulation/Optimization Tool

Richard C. Peralta **and** Shengjun Wu

Software Engineering Division
Systems Simulation/Optimization Laboratory
Dept. of Biological and Irrigation Engineering
Utah State University
Logan, UT 84322-2105

Phone: (435) 797-2785/6
Fax: (435) 797-1248

CONJUS Simulation Abilities

- Stream depletion due to gw pumping
- Gw head response to gw pumping (extraction or injection)
- Gw head response to stream stage changes
- Gw head response to line source
- Gw head response to field/basin recharge

Transient Variables

- groundwater pumping rate
- groundwater head & gradient
- cumulative pumping volume
- stream depletion rate & volume
- stream stage change
- line source seepage rate
- field or pond recharge rate

CONJUS Attributes

- User-friendly interface (VBA & Excel 97-based spreadsheet model)
- Automated input array sizing
- Option for manually changing influence coefficients
- Optimization options (linear, quadratic, nonlinear, goal programming, MiniMax, MaxiMin)

CONJUS Attributes

- Ability to use two nonuniform stress periods as well as many uniform stress periods
- Ability to constrain the ratio (total injection / total pumping)

Example Problem

- One extraction well having 15 cm radius, 2500 m from stream
- One observation well between the extraction well and the stream
- Aquifer: 10 m thick, 0.1 storativity, 100 m/day conductivity
- Pump for 12 weeks; stop for 4 weeks

- WANTED: Determine maximum steady pumping during first 12 weeks which will not cause stream depletion by the end of 12 weeks to exceed 0.002 m^3/sec (172.8 m^3/day)

General CONJUS Input

- Number of stress (time) periods
- Number of extraction, injection, & observation wells
- Number of gradient control pairs
- Aquifer storativity
- Aquifer hydraulic conductivity
- Bounds on (injection / total pumping)
- Stress period duration

General Management Problem Information

No. of periods	No. of extraction wells	No. of Injection wells	No. of observation wells	No. of gradient control pairs of observation wells	Simulate stream depletion response to pumping and use image well(s) to compute aquifer head (yes / no)	Simulate aquifer head response to stream stage change without image well(s) considered (yes / no)	Simulate aquifer head response to line source without image well(s) considered (yes / no)	Rectanglular recharge areas, generally only one recharge area considered (yes / no)
2	**1**	**0**	**1**	**0**	**yes**	**no**	**no**	**no**

Additional Problem Information

Storativity	Average hydraulic conductivity [L / T]	Minimum ratio of injection to total pumping for every period	Maximum ratio of injection to total pumping for every period	Unit period 1 [T]	Unit period 2 [T]
0.1	**100**	**n/a**	**n/a**	**84**	**28**

Input Concerning Wells & Pumping

- Location
- Aquifer thickness
- Ground surface elevation
- Radius
- Unit pumping rate
- Transient unmanaged groundwater head
- Transient bounds on optimal managed head, pumping, & cumulative pumping

Extraction Well Information

Well #.	X coordinate [L]	Y coordinate [L]	Aquifer thickness [L]	Well radius [L]	Ground surface elevation [L]	Unit pumping [[L^3 /T]	Initial Head [L]
1	2500	0	10	0.1524	100	2592	100

Injection Well Information

Well #.	X coordinate [L]	Y coordinate [L]	Aquifer thickness [L]	Well radius [L]	Ground surface elevation [L]	Unit pumping [L^3 /T]	Initial Head [L]

Observation Well Information

Well #.	X coordinate [L]	Y coordinate [L]	Aquifer thickness [L]	Well radius [L]	Initial Head [L]
1	1250	0	10	0.5	100

Gradient Control Pairs of Observation Wells

Nonoptimal head at the end of period 1 [L]	Head lower bound for period 1 [L]	Head upper bound for period 1 [L]	Extraction rate lower bound for period 1 [L^3 / T]	Extraction rate upper bound for period 1 [L^3 /T]	Nonoptimal head at the end of period 2 [L]	Head lower bound for period 2 [L]	Head upper bound for period 2 [L]	Extraction rate lower bound for period 2 [L^3 / T]	Extraction rate upper bound for period 2 [L^3 /T]
100	**0**	**n/a**	**0**	**n/a**	**100**	**0**	**n/a**	**0**	**0**

Nonoptimal head at the end of period 1 [L]	Head lower bound for period 1 [L]	Head upper bound for period 1 [L]	Injection rate lower bound for period 1 [L^3 /T]	Injection rate upper bound for period 1 [L^3 /T]	Nonoptimal head at the end of period 2 [L]	Head lower bound for period 2 [L]	Head upper bound for period 2 [L]	Injection rate lower bound for period 2 [L^3 /T]	Injection rate upper bound for period 2 [L^3 /T]

Nonoptimal head at the end of period 1 [L]	Head lower bound for period 1 [L]	Head upper bound for period 1 [L]
100	**0**	**200**

Nonoptimal head at the end of period 2 [L]	Head lower bound for period 2 [L]	Head upper bound for period 2 [L]
100	**0**	**200**

Input for Stream Stage Change Problem

- Location
- Surface elevation (stage)
- Unit surface elevation change
- Bounds on surface elevation change

Input for Line Source Problem

- Location and orientation
- Unit seepage rate
- Bounds on seepage rate for each period

General Stream and Stream Stage Change Information

X1 coordinate [L]	Y1 coordinate [L]	X2 coordinate [L]	Y2 coordinate [L]	Stream surface elevation [L]	Unit stream stage change [L]	Minimum Stream stage change during period 1 [L]	Maximum Stream stage change during period 1 [L]	Minimum Stream stage change during period 2 [L]	Maximum Stream stage change during period 2 [L]
0	0	0	1						

Line Source Information

Line source #	X1 coordinate [L]	Y1 coordinate [L]	X2 coordinate [L]	Y2 coordinate [L]	Unit line source seepage rate [L^2 / T]	Minimum Line source seepage rate during period 1 [L^2 / T]	Maximum Line source seepage rate during period 1 [L^2 / T]	Minimum Line source seepage rate during period 2 [L^2 / T]	Maximum Line source seepage rate during period 2 [L^2 / T]

Rectangular Recharge Area Information

Input for Rectangular Recharge Problem

- Location
- Orientation
- Size
- Unit seepage rate
- Bounds on seepage in each time period

Input for Stream Depletion Problem

- Well information
- Pumping information
- Aquifer information
- Stream location
- Stream orientation

Rectangular Recharge Area Information

Rectangular recharge #	Center of X coordinate of the rectangular recharge area [L]	Center of Y coordinate of the rectangular recharge area [L]	Rotation of shorter side of rectangular recharge area (anticlockwise) [Radians]	Length of rectangular recharge area [L]	Width of rectangular recharge area [L]	Unit rectangular field seepage rate [L^2 / T]	Minimum recharge seepage rate during period 1 [L^2 / T]	Maximum recharge seepage rate during period 1 [L^2 / T]	Minimum recharge seepage rate during period 2 [L^2 / T]	Maximum recharge seepage rate during period 2 [L^2 / T]

Stream Depletion Constraints

Minimum allowed river depletion rate during period 1 [L^3 /T]	Maximum allowed river depletion rate during period 1 [L^3 /T]	Minimum allowed river depletion volume during period 1 [L^3]	Maximum allowed river depletion volume during period 1 [L^3]	Minimum allowed river depletion rate during period 2 [L^3 /T]	Maximum allowed river depletion rate during period 2 [L^3 /T]	Minimum allowed river depletion volume during period 2 [L^3]	Maximum allowed river depletion volume during period 2 [L^3]
0	**172.8**	**0**	**n/a**	**0**	**n/a**	**0**	**n/a**

Constraints on Cumulative Pumping Volume

Constraints on Cumulative Pumping Volume

Minimum allowed cumulative pumping thru period 1 [L^3]	Maximum allowed cumulative pumping thru period 1 [L^3]	Minimum allowed cumulative pumping thru period 2 [L^3]	Maximum allowed cumulative pumping thru period 2 [L^3]
n/a	**n/a**	**n/a**	**n/a**

End of Input Data

Return to 'main' sheet

Influence coefficients

Unless you have changed them, the below coefficients were created by CONJUS using your input data. CONJUS will use these coefficients to calculate the optimal water management strategy.

Influence coefficients describing drawdown for two nonuniform periods:

Unitperiod(1)= 8.40000E+01 unitperiod(2)= 2.80000E+01

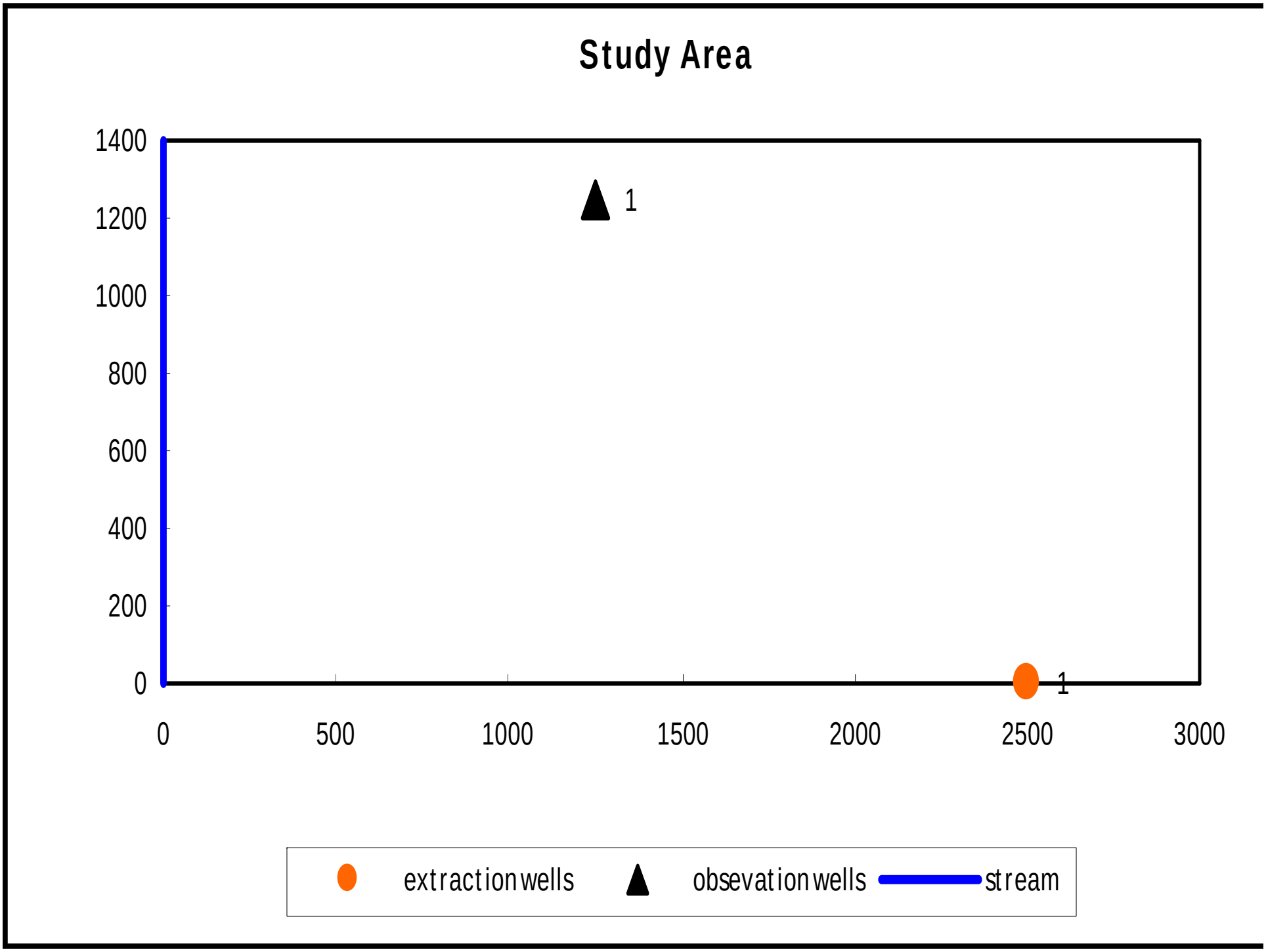
Observation location	Excitation location	pumping during Period 1; observe at the end of period 1	pumping during Period 1; observe at the end of period 2	pumping during Period 2; observe at the end of period 2	Unit pumping
extraction well #1	extraction well #1	3.75663E+00	2.85823E-01	3.53004E+00	2.59200E+03
observation well #1	extraction well #1	1.24681E-01	1.40059E-01	2.41506E-02	2.59200E+03

Depletion rate influence coefficients for two nonuniform periods:

Excitation location	pumping during Period 1; observe at the end of period 1	pumping during Period 1; observe at the end of period 2	pumping during Period 2; observe at the end of period 2	Unit pumping
extraction well #1	1.39338E+02	2.43669E+02	2.16558E+00	2.59200E+03

Depletion coefficients describing volume of river depletion for nonuniform period:

Excitation location	pumping during Period 1; observe at the end of period 1	pumping during Period 1; observe at the end of period 2	pumping during Period 2; observe at the end of period 2	Unit pumping
extraction well #1	3.09183E+03	8.46879E+03	7.82103E+00	2.59200E+03


Study Area
1400
1200
1000
800
600
400
200
0
1
1
0
500
1000
1500
2000
2500
3000
extraction wells
obsevation wells
stream

Optimization option: *Linear*

Maximize *precision: 0.001* *convergance: 0.002* *tolerance: 5%*

Use linear model to perform optimization

Objective solution:

3.21447830E+03

Period 1

Optimal pumping and injection rate(s) [L^3 / T]:

pumping of extraction well #1 **3.21447830E+03**

Optimal head at extraction and injection well(s) [L]:

head at extraction well #1 **9.53412009E+01**

Optimal head at observation well(s) [L]:

head at observation well #1 **9.98453770E+01**

Optimal stream depletion rate [L^3 / T]: **1.72800000E+02**

Optimal stream depletion volume [L^3]: **3.83434145E+03**

Cumulative pumping volume [L^3]: **2.70016177E+05**

Ratio of injection to extraction: **n/a**

Period 2

Optimal pumping and injection rate(s) [L^3 / T]:

pumping of extraction well #1	0.00000000E+00

Optimal head at extraction and injection well(s) [L]:

head at extraction well #1	9.96455352E+01

Optimal head at observation well(s) [L]:

head at observation well #1	9.98263057E+01

Optimal stream depletion rate [L^3 / T]:	3.02187473E+02
Optimal stream depletion volume [L^3]:	1.05026053E+04
Cumulative pumping volume [L^3]:	2.70016177E+05
Ratio of injection to extraction:	n/a

SUMMARY

- Powerful stream-aquifer S/O models
- Suitable for physical systems of a range of complexities
- User-friendly for range of users
- Adaptable to nonlinear systems
- Compute optimal strategies

A model is a representation of a system for a particular purpose.

You must be able to simulate system response to management before you can develop optimal management strategies.

CONJUS Variables

- gw pumping rate
- cumulative gw pumping volume
- gw head
- gw gradient
- goal programming variables
- stream depletion rate
- stream depletion volume
- stream stage change
- line source
- field recharge

CONJUS Optimization Options

- Linear Optimization
- Nonlinear Optimization

CONJUS Simulation Schemes

- Analytical Expressions
- Discretized Convolution Equations
- Superposition
- Influence Coefficients