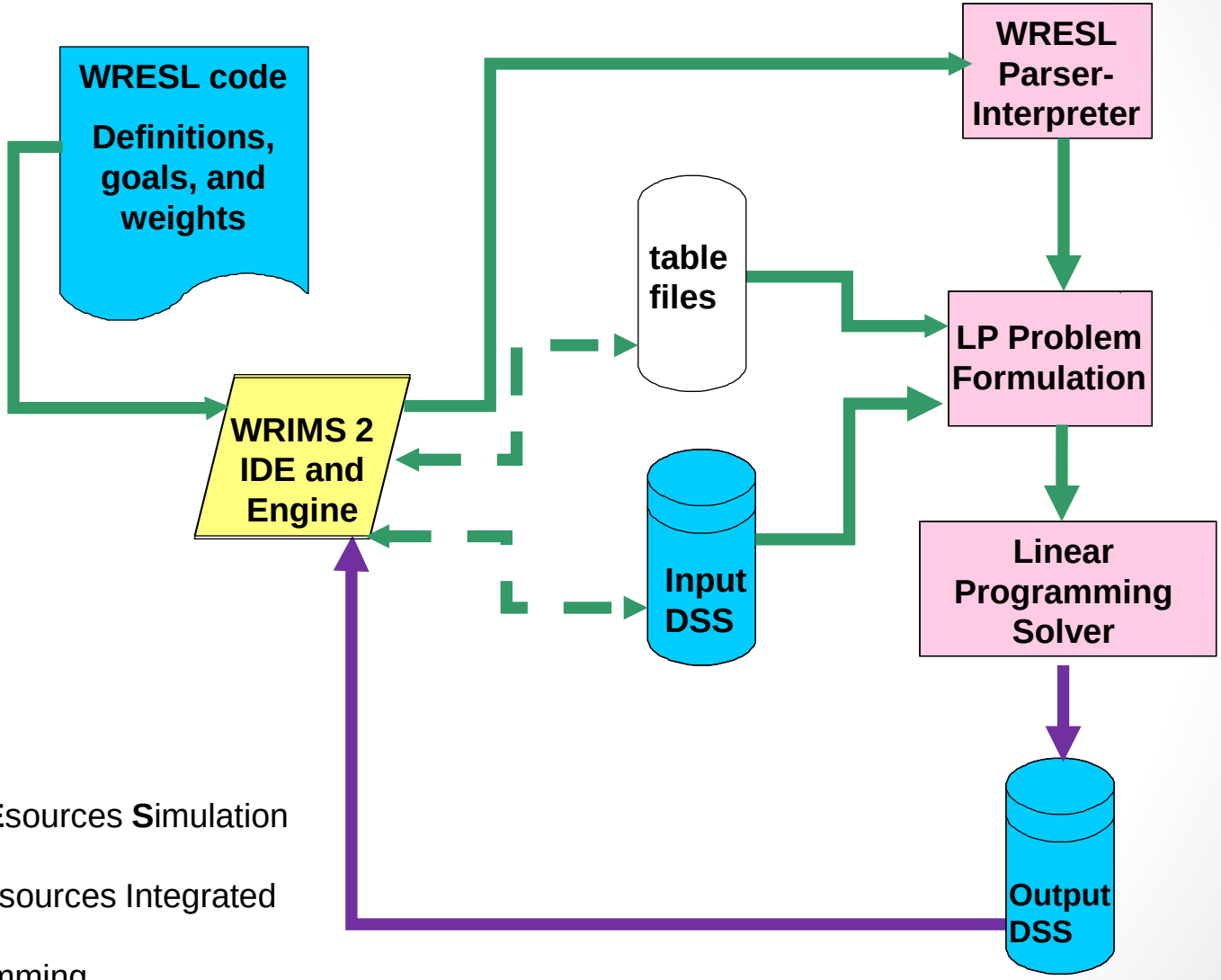
WRIMS and Introduction to Linear Programming

California Department of Water Resources
United States Bureau of Reclamation

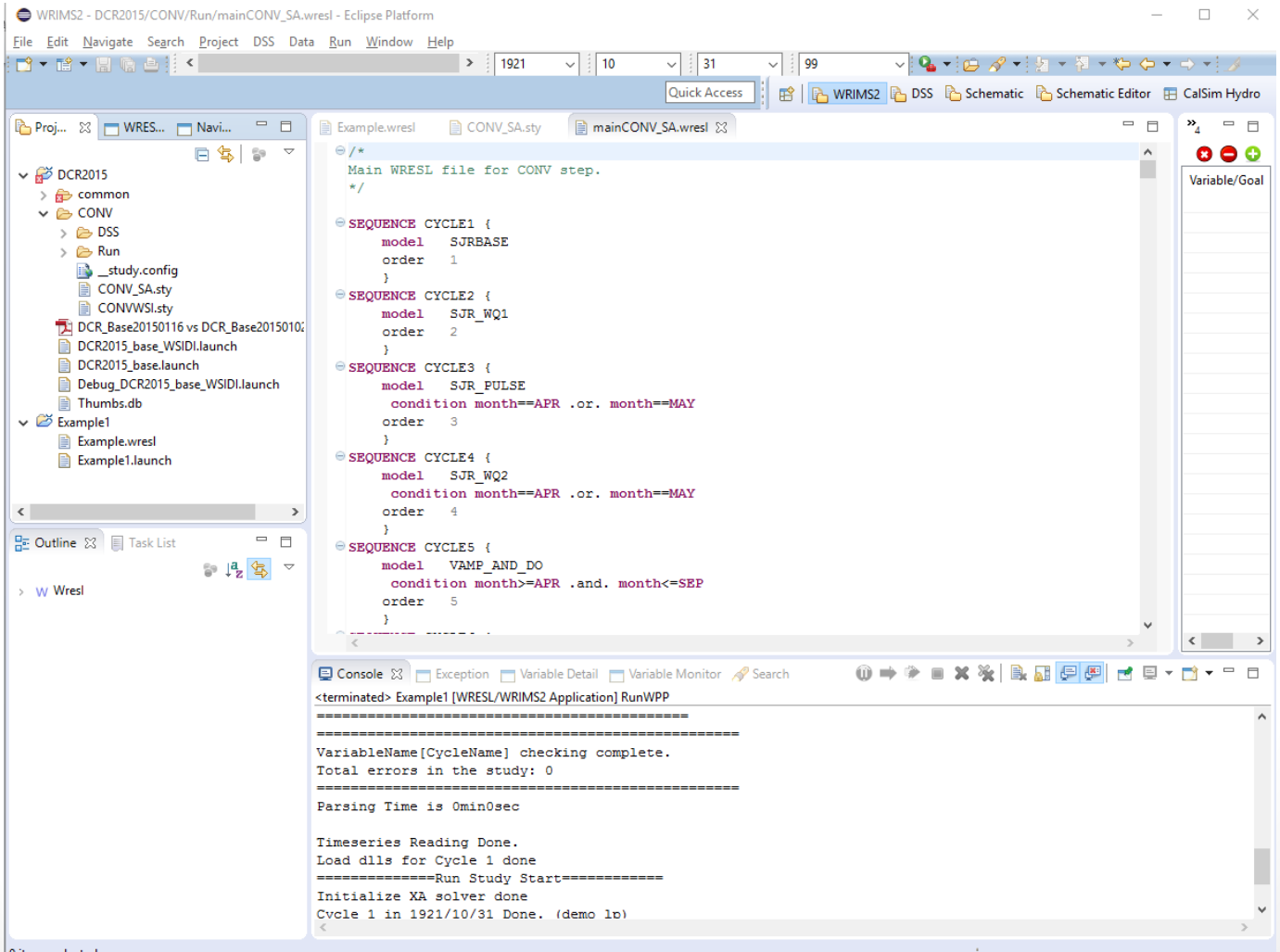
Overview



WRESL = **W**ater **RE**sources **S**imulation **L**anguage
WRIMS = **W**ater **R**esources Integrated **M**odeling **S**ystem
LP = **L**inear **P**rogramming
DSS = **D**ata **S**torage **S**ystem
IDE = **I**ntegrated **d**evelopment **E**nvironment

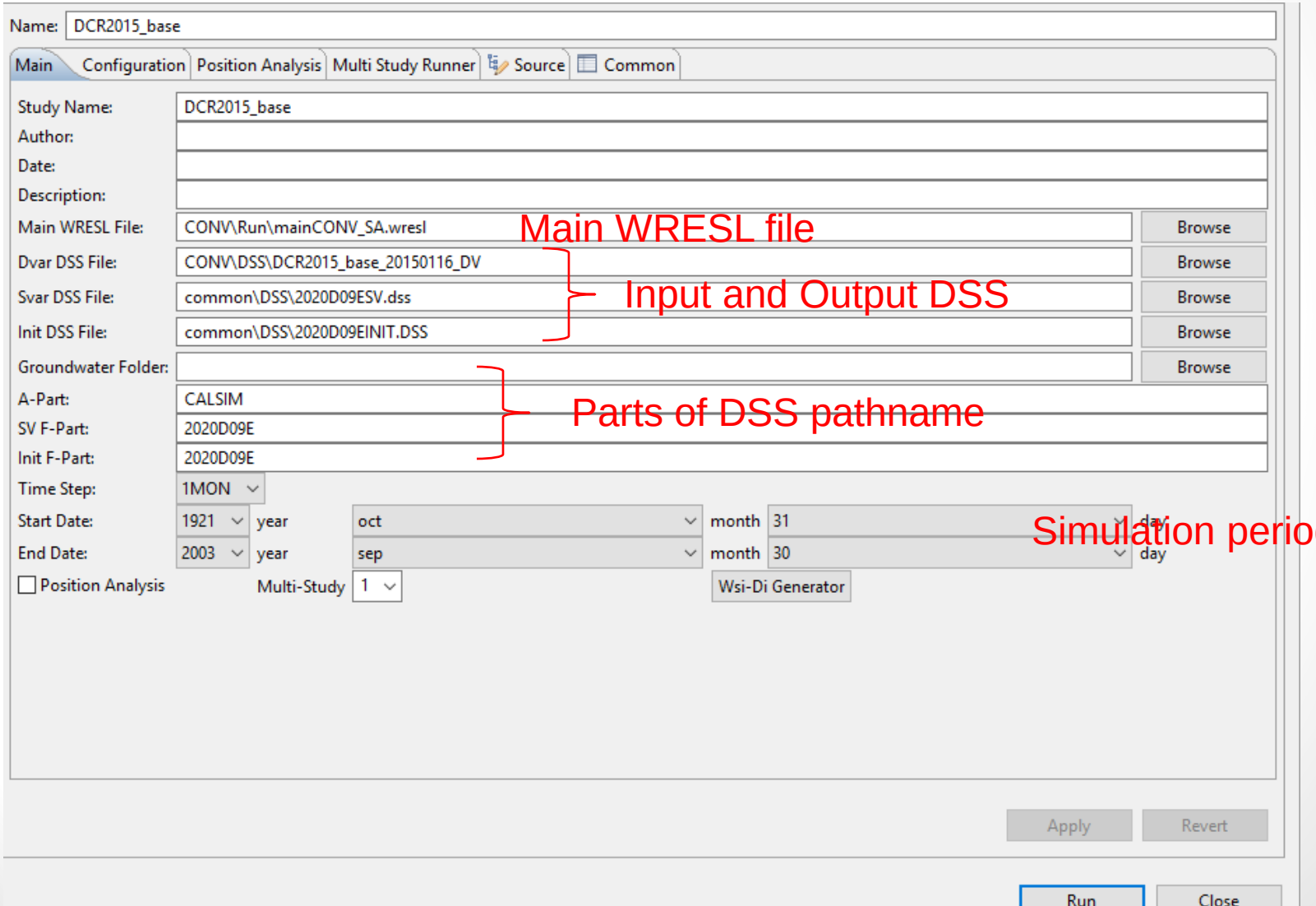
WRIMS 2 Software (Water Resources Integrated Modeling System)

- developed and maintained by DWR and Reclamation



WRIMS 2

DCR2015_base.launch



WRESL
Water REsources Simulation Language

- High-level language for describing
  - Variables – Svars (State) and Dvars (Decision)
  - Constraints – physical and regulatory
- Concise – very short users manual
- Syntax based on Java and SQL
- ascii text format
  - syntax highlighting available

WRESL

CALSIM

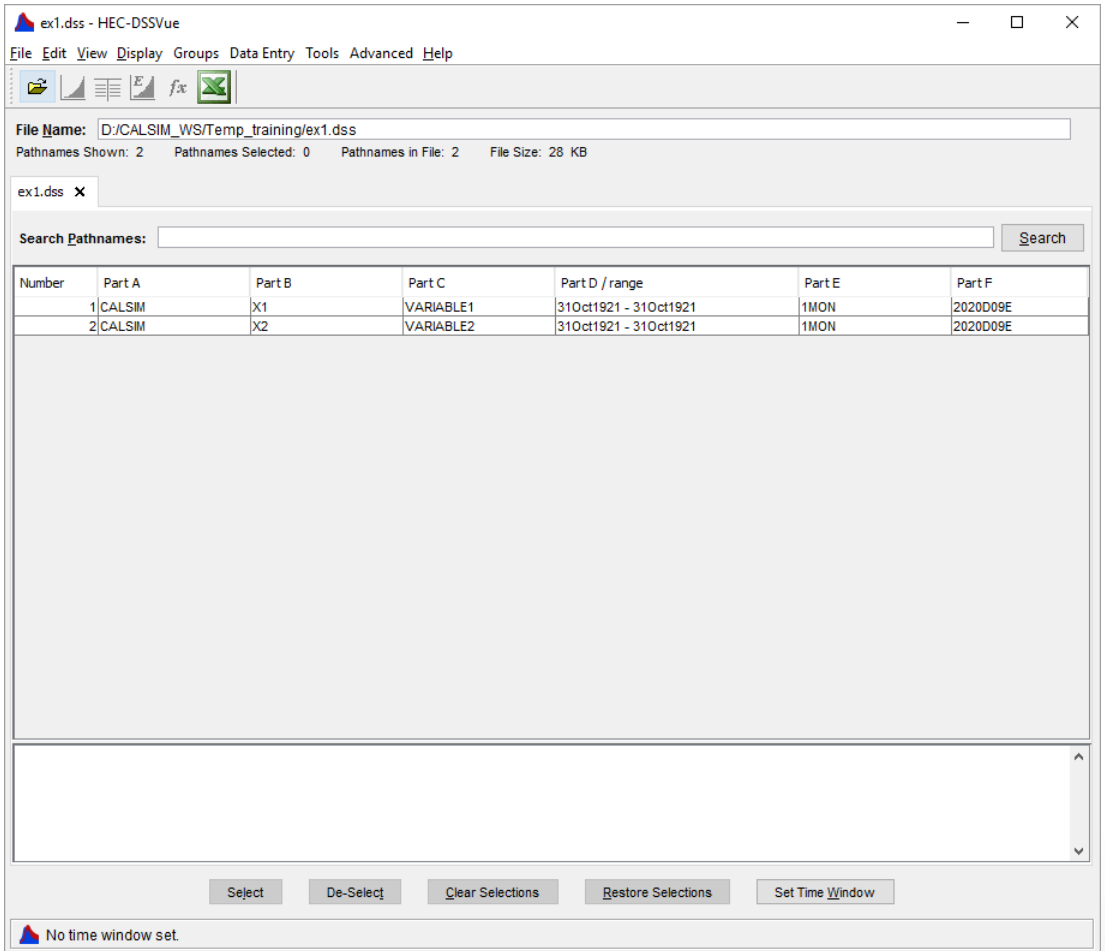
Water Resources Simulation Model

WRESL Language Reference

Draft Documentation

DSS - Data Storage System

- Designed to efficiently store scientific data in time series.



DSS - Data Storage System

- Each time series has unique path name

Number	Part A	Part B	Part C	Part D / range	Part E	Part F
1	CALSIM	X1	VARIABLE1	31Oct1921 - 31Oct1921	1MON	2020D09E
2	CALSIM	X2	VARIABLE2	31Oct1921 - 31Oct1921	1MON	2020D09E

CalSim II specific:

Part	Description
A	CalSim
B	Unique name (S1, C1, etc.)
C	Data Type (flow-channel, flow-delivery, storage, etc.)
D	Starting date of block, in a 9 character military format
E	Time interval
F	User-defined descriptive information (Hydrology, Version, etc.)

Introduction to Linear Programming (LP)

- Linear Programming (LP) is the most powerful method of **constrained optimization problem**.
- Easily handles problems involving **tens of thousands** of variables and constraints.
- LP solver **finds values for decision variables** to maximize (or minimize) the objective function while satisfying all constraints

Introduction to LP

Example of a LP problem

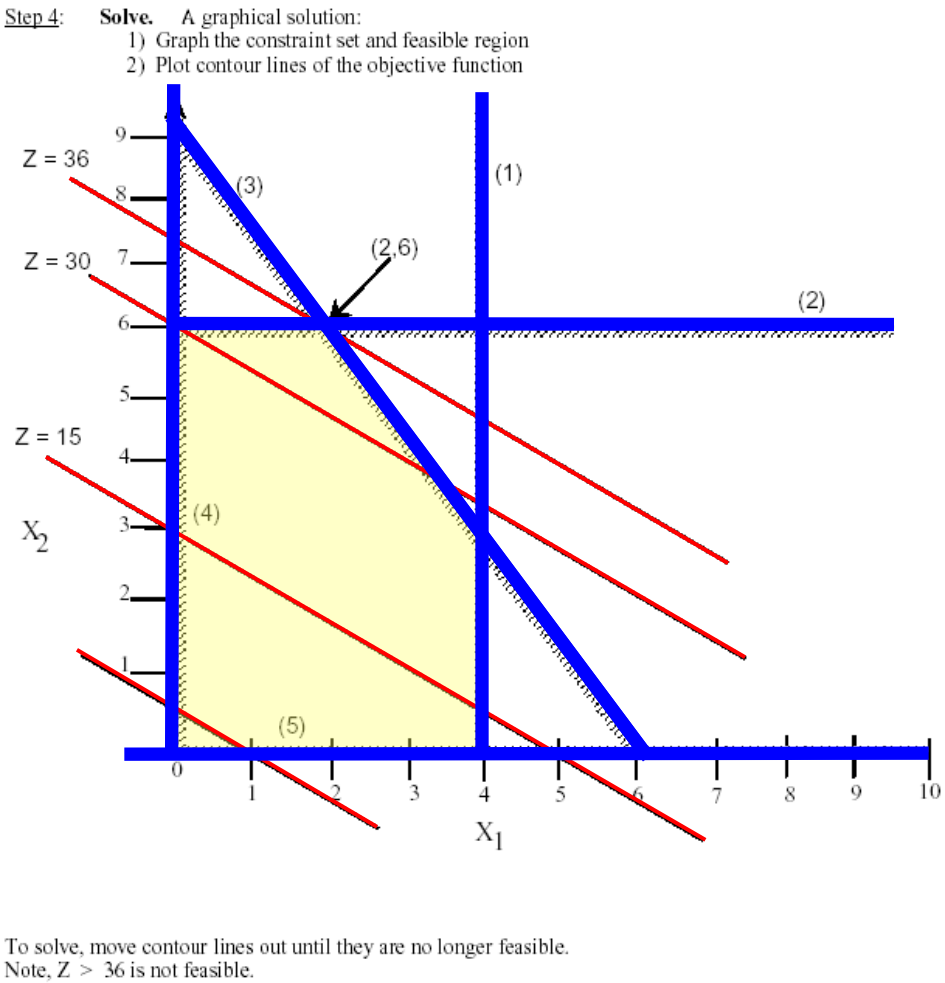
Max Z = 3X1 + 5X2 ← Objective function

Subject to:

$$
\left.
\begin{array}{lllll}
1X_1 & & & & < 4 \\
 & & 2X_2 & & <12 \\
3X_1 & + & 2X_2 & & <18 \\
1X_1 & & & & > 0 \\
 & & 1X_2 & & > 0
\end{array}
\right\}
$$

← Constraints

Introduction to LP – Simplex method



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Introduction to LP – WRIMS 2

Max Z = 3X1 + 5X2

Subject to:

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1X_1 & & & & > 0 \\
 & & 1X_2 & & > 0
\end{array}
$$

```
/* A simple linear problem with two variables
Max Z = 3X1 + 5X2
Subject To:
(1) 1X1                 <  4
(2)             2X2     < 12
(3) 3X1 + 2X2     < 18
(4) 1X1                 >  0
(5)             1X2     >  0    */

/**syntax required for the WRESL and WRIMS to run the PROBLEM**/
SEQUENCE CYCLE1 {
    model   Demo_LP
    order   1
    }

/**Construct the problem**/
MODEL Demo_LP {
define X1 {lower 0. upper 4 kind 'variable1' units 'CFS'}
define X2 {lower 0. upper 6 kind 'variable2' units 'CFS'}
goal simpleLPconstraint {3.0*X1 + 2.0* X2 < 18 }

Objective obj = {[X1,3],[X2,5]}

}
```

Introduction to LP – WRIMS 2

```
/* A simple linear problem with two variables
Max Z = 3X1 + 5X2
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```

Definition and Constraints

Constraints

Priorities

$$\max Z = \sum_{i=1}^{n} (w_i \cdot X_i)$$

Introduction to LP – WRIMS 2

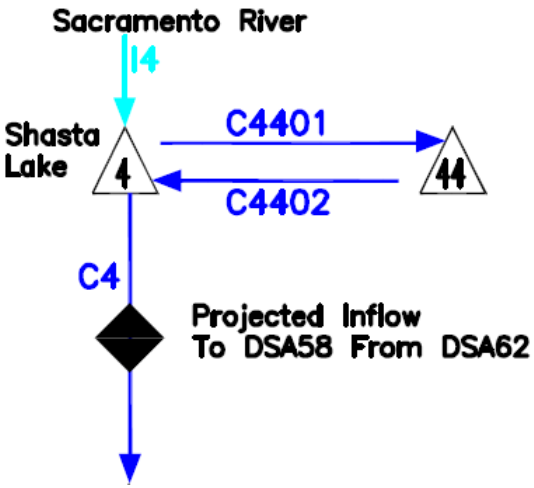
```
Maximize   Solve Number 1      V16.65       Thu Oct 13 10:52:45 2016
OBJ: + 5 X2 + 3 X1

Constraints
SIMPLELPCONSTRAINT: + 2 X2 + 3 X1  <= 18

X1 <= 4 | X2 <= 6 |

STATISTICS - d:\calsim_ws\temp_training\ Thu Oct 13 10:52:45 2016 SN: 25
  XA VERSION 16.65.WRIMS DLL (32bit)    USABLE MEMORY 24.0 MBYTE
  SOLVE NUMBER 1
  VARIABLES 2
     0 LOWER, 0 FIXED, 2 UPPER, 0 FREE
  CONSTRAINTS 2
     0 GE, 0 EQ, 1 LE, 0 NULL/FREE, 0 RANGED
     4 NON-ZEROS WORK 714,955
  MAXIMIZATION.
  California Department of Water Resources - 2403500
  WRIMS Edition

L P   O P T I M A L   S O L U T I O N ---> OBJ: 36.00000
SOLVE 1 TIME 00:00:00  ITER 4

File: d:\calsim_ws\temp_training\                                  Thu Oct 13 10:52:45 2016 Page 1
SOLUTION REPORT - COLUMN ACTIVITY SOLVE NUMBER 1
NUMBER  .COLUMNS  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
     1  X1       BS        2.00000        3.00000          .            4.00000          .
     0  X2       UL        6.00000        5.00000          .            6.00000        3.00000

File: d:\calsim_ws\temp_training\                                    Thu Oct 13 10:52:45 2016 Page 2
CONSTRAINT REPORT - ROW ACTIVITY SOLVE NUMBER 1
NUMBER  ...ROW............  AT  ...ACTIVITY...  SLACK ACTIVITY  ..LOWER LIMIT.  ..UPPER LIMIT.  .DUAL ACTIVITY
     0  OBJ                 BS       36.00000      -36.00000          NONE            NONE          1.00000
     1  SIMPLELPCONSTRAINT  UL       18.00000          .              NONE         18.00000         1.00000
```

LP for CalSim II

- Decision Variables
  - **Flows** through system during a particular time step
  - **Storage** at end of the time step
- Constraint Set
  - **Mass balance** at system nodes
  - Upper and lower bound constraints for **physical limits**
  - Constraints reflect **operating criteria, contractual and regulatory requirements**
- Objective function
  - Priorities (weights) based on cost coefficient

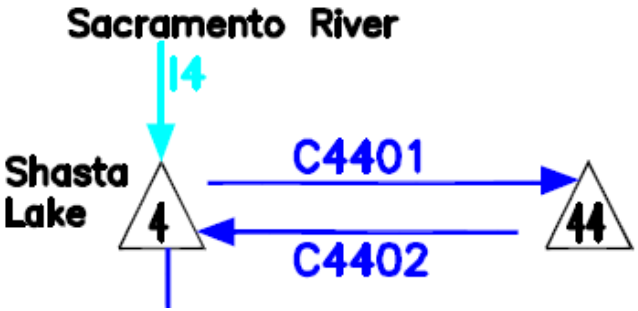
LP for CalSim II – Decision variables

Decision Variable	Description	Example
S_i	end of period storage in node i	S1
S_{ij}	end of period storage in node i, zone j	S1_2
C_i	period average flow in channel arc i	C1
C_{ij}	period average flow in channel arc i, zone j	C1_MIF, C1_EXC
D_i	period average flow in delivery arc i	D6
D_{ij}	period average flow in delivery arc i, zone j	D6_MI, D6_AG
R_i	period average flow in return flow arc i	R7
E_i	period average flow in evaporation arc i	E1
F_i	period average flow in non-recoverable spill arc i	F1
A_i	end of period reservoir surface water area in node i	A1



LP for CalSim II – State variables

State Variable	Description	Example
I_i	period average unregulated flow in inflow arc i	I1
$S_i level_j$	storage in node i at level j	S1level4
$relcap_i$	maximum release capacity of reservoir i, applied at channel arc i	relcapC1
$C_i min$	absolute minimum flow in channel arc i	C5min
$C_i max$	maximum flow in channel arc i	C5max
$minflow_i$	minimum instream flow requirement for channel arc i	minflow_C4
$demand_{ij}$	demand for delivery arc i of type j	demand_D2_ag
$rfactor_i$	return flow fraction for return flow arc i resulting from a specified delivery arc	rfactor_R3
ev_i	period cummulative unit evaporation for node i	evap_S1
eff_i	recharge efficiency for a ground water node i resulting from a specified delivery arc	eff_D3
X^{t-1}	value of any decision variable X at any time previous to the current time period t	S1(-1), C5(-3)



LP for CalSim II - Constraints

- User-specified constraints which may be **violated at a cost** (penalty)
- Goal minimizing the deviation between a constraint's **Left-hand-side (LHS) and Right-hand-side (RHS)**
- Reformulated from **"hard" to "soft"** constraint by introducing auxiliary variables
  - Auxiliary variables penalized in objective function

LP for CalSim II - Constraints

- Original “hard” constraint

$$S_A - S_B = 0$$

```
goal continuity100 {I100+C1-D100-C100=0} !LEWISTON LAKE
```

- Reformulated “soft” constraint

$$S_A - S_B + x^- - x^+ = 0$$

  - Slack (x^-) and surplus (x^+) variables added

```
goal set_HandSminpump {
    lhs     D418_TD + D419_TD
    rhs     HandS_minpump
     lhs>rhs penalty 0
     lhs<rhs penalty 90000}
```

LP for CalSim II – Objective function

$$max\ Z = \sum_{i=1}^{nwt} (w_i \cdot X_i) + \sum_{j=1}^{npen} (-p_j \cdot x_j^+ \mid x_j^-)$$

- Objective function is Maximized
- Weights (w) on variables based upon priority
- Negative penalties (p) multiply slack and surplus variables from “soft” constraints

Introduction to LP – Mixed integer linear programming (MIP)

- Mixed Integer Programming Solver
  - Decision variables can be restricted to binary solutions (**0 or 1**)
  - Use of **integer** variables greatly expands the scope of useful optimization problems
  - Branch-and-Bound method

```
! The following variables are 0 or 1

define int_SAC_below  {INTEGER std kind 'INTEGER' units 'NONE'}
 !0: high flow; 1:  low flow
```

Solver

- XA solver
  - Commercial
  - Free with CalLite
- CBC
  - Developed and Maintained by DWR and Reclamation

Quiz

#1. Fill in the blanks below:

WRIMS	
WRESL	
CalSim	
DSS	
WRIMS IDE	

1. Programming Language
2. Engine to run the Code
3. Data storage system
4. CA Water resources system planning model
5. Facilities code edits, set up scenarios, and run