CALIFORNIA DEPARTMENT OF WATER RESOURCES

The CalSim Solvers

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Outline

- Introduction on Linear Programming (LP) and Mixed Integer Linear Programming (MILP) models

- Objective: why Solvers in CalSim3
    - Generic Form of LP problems
    - LP applications within CalSim 3

- Motivation for Investigating Gurobi, XA, and CBC Solvers in CalSim Studies
- Results and Summary

Introduction to Linear Programming

- Solves optimization problems with linear constraints and objectives
- Used in engineering, operations research, and Water Resources Planning
- Efficient for large-scale problems with thousands of variables
- Applications: resource allocation, scheduling, system optimization

Objective: why Solvers in CalSim3

- WRIMS supports multiple Mixed-Integer Programming (MIP) solvers.
- This expansion is critical for accuracy performance while enhancing the computational performance, and flexibility of CalSim planning scenarios.
- Adding more solvers boost transparency and providing better insight into model results.

Example:

Max Z = 2 X_1 **+ 3** X_2 ← *Objective function*

Subject to:

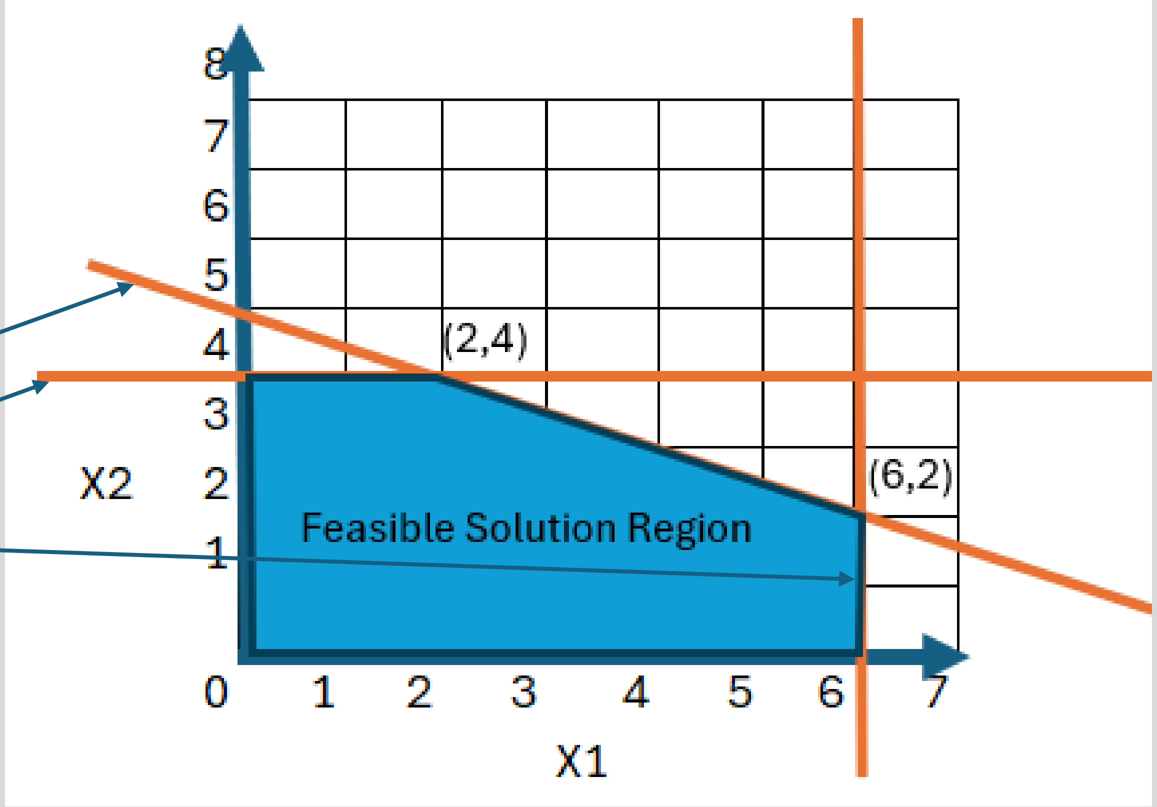
$X_1 + 2\,X_2 \leq 10$

$X_1 \leq 6$

$X_2 \leq 4$

$X_1 \geq 0$

$X_2 \geq 0$



Optimal Solution:

- $X_1 = 6$, $X_2 = 2$
- **Maximum Z = 18**

Point	X_1	X_2	$Z = 2X_1 + 3X_2$
A	0	0	0
B	6	0	12
C	6	2	12 + 6 = 18
D	2	4	4 + 12 = 16
E	0	4	0 + 12 = 12

LP application within CalSim 3

- **Decision Variables**

Flows through system during a particular time step

Storage at end of the time step

- **Constraint Set**

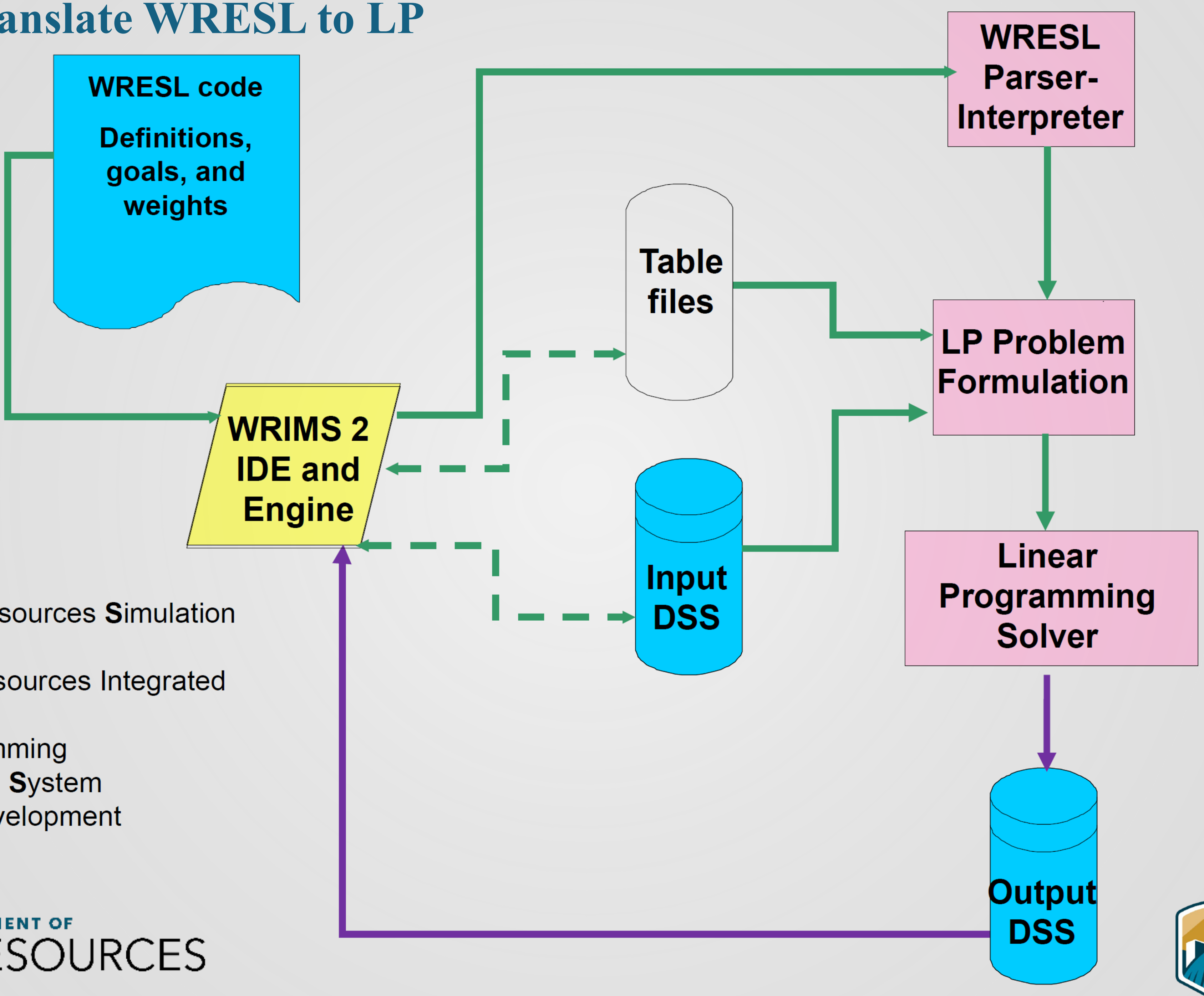
Mass balance at system nodes

Upper and lower bound constraints and regulatory requirements

- **Objective function**

Priorities (weights) based on cost coefficient

How do we translate WRESL to LP



WRESL = **W**ater **RE**sources **S**imulation **L**anguage

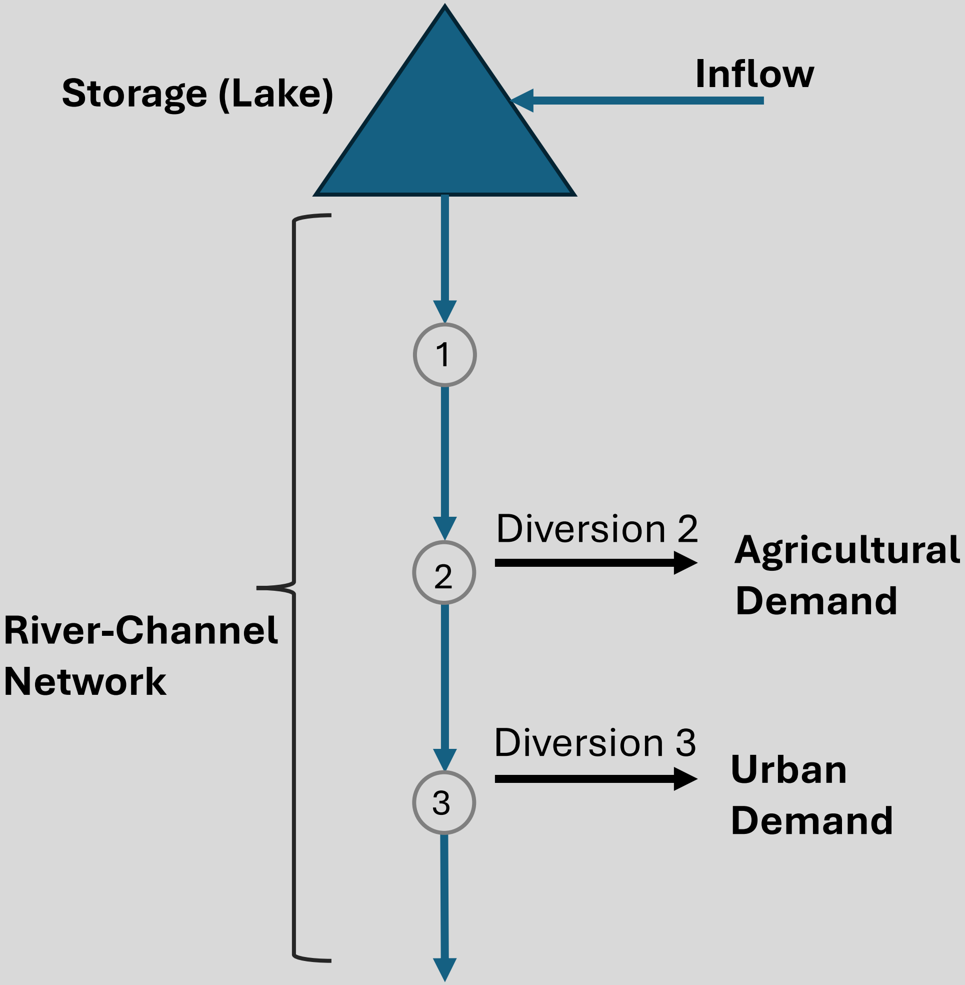
WRIMS = **W**ater **R**esources Integrated **M**odeling **S**ystem

LP = **L**inear **P**rogramming

DSS = **D**ata **S**torage **S**ystem

IDE = **I**ntegrated **d**evelopment **E**nvironment

A Simple Network within CalSim for LP Formulation



Maximize:

$Objective\ Function =$
$F(Diversions, \ldots)$

Subject to constraints:

$Regulatory\ Constraints$

$\vdots$

$Mass\ Balance\ Hard\ Constraints$

$(\Delta S = \sum I_i - \sum O_i)$

$x_1, x_2 \cdots, x_n \geq 0$

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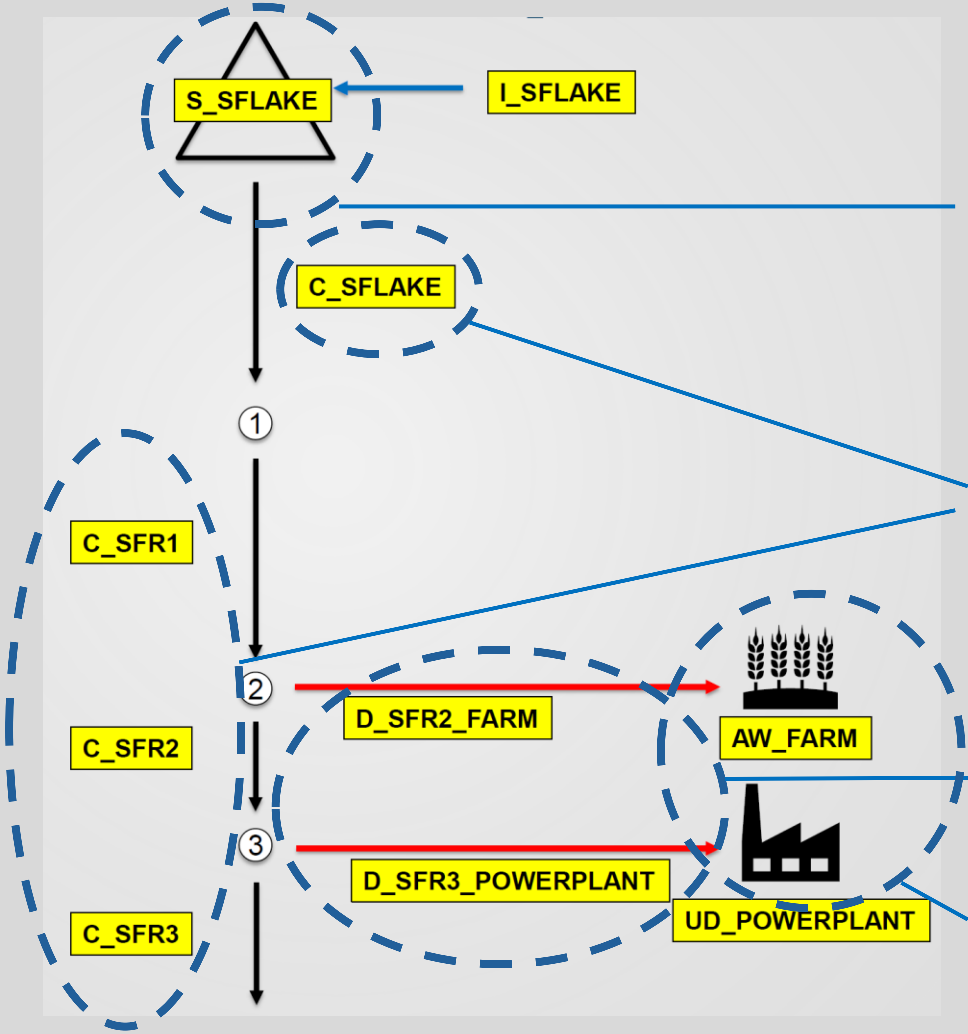
LP for CalSim 3 – Decision and State Variables, Constraints, and Objective Function Formulation



Defining a 390 TAF reservoir with Deadpool at 10 TAF:

```
define S_SFLAKE      {std kind 'STORAGE' units 'TAF’}

define      S_SFLAKE_level1 {value 10}
define      S_SFLAKE_level2 {value 390.0}

define     S_SFLAKE_1  {std kind 'STORAGE-ZONE’ units 'TAF’}
define     S_SFLAKE_2  {std kind ’STORAGE-ZONE’ units 'TAF'}
```

Defining channel segments with the capacity of 1000 cfs:

```
define      C_SFLAKE  {upper 1000 kind 'CHANNEL’ units 'CFS’}
define      C_SFR1    {upper 1000 kind 'CHANNEL’ units 'CFS’}
define      C_SFR2    {upper 1000 kind 'CHANNEL’ units 'CFS’}
define      C_SFR3    {upper 1000 kind 'CHANNEL’ units 'CFS’}
```

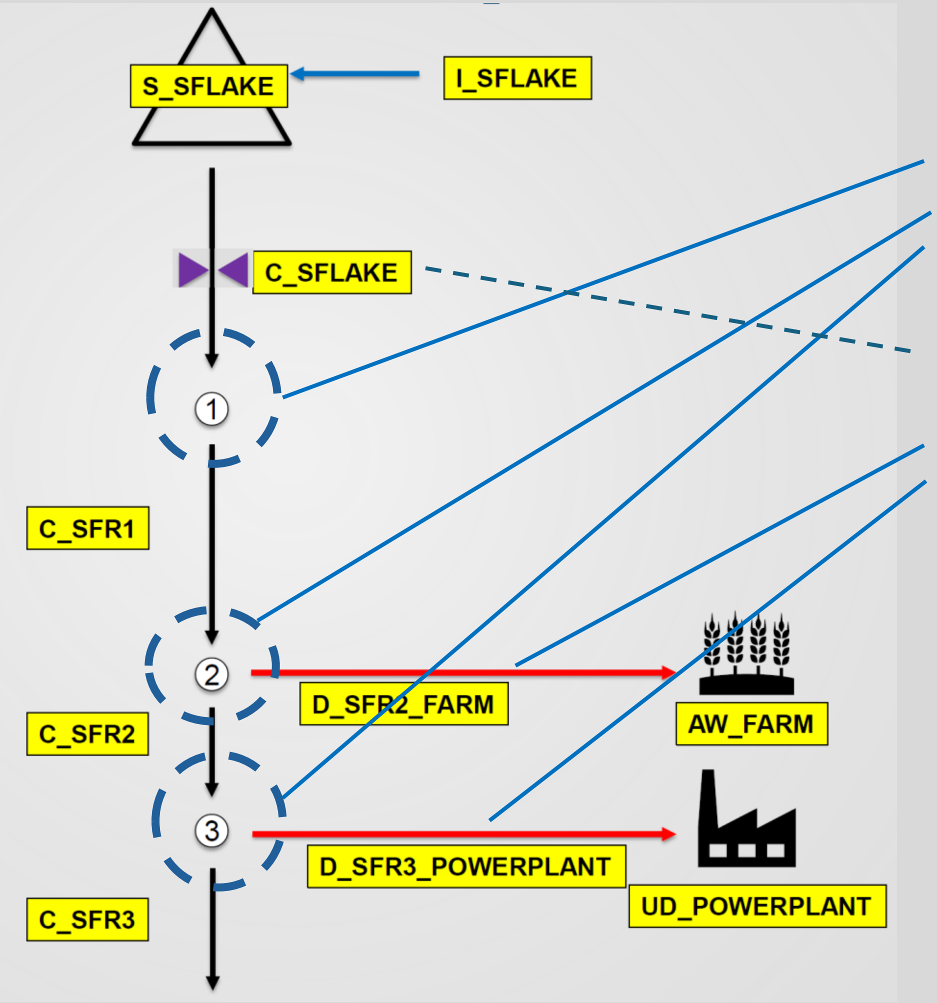
Define two Diversions off the Springfield River:

```
define      D_SFR2_FARM          {std kind ‘DIVERSION’ units 'CFS’}
define      D_SFR3_POWERPLANT    {std kind ‘DIVERSION’ units 'CFS’}
```

Define two demands whose values are input timeseries. The demands are in Thousand Acre-Feet, so convert them to CFS.

```
define AW_FARM       {timeseries kind 'APPLIED-WATER’ units 'TAF' convert 'CFS’}
define UD_POWERPLANT {timeseries kind ‘URBAN-DEMAND’  units 'TAF' convert 'CFS’}
```

LP for CalSim 3 – Decision and State Variables, Constraints, and Objective Function Formulation



Constraints: Mass Balance and Diversion Limitations

```
goal continuity_SFLAKE {I_SFLAKE - C_SFLAKE = S_SFLAKE * taf_cfs - S_SFLAKE(-1) * taf_cfs}
goal continuity_SFR2   {C_SFR1 - C_SFR2 - D_SFR2_FARM = 0}
goal continuity_SFR1   {C_SFLAKE - C_SFR1 = 0}
```

Note: Some other regulatory constraints also would be applied.

```
goal continuity_SFR2   {C_SFLAKE = C_SFLAKE_MIF + C_SFLAKE_ADD}
goal constrain_for_MIF {C_SFLAKE_MIF < MIF_FROM_LOOKUP_TABLE}

goal constrain_D_SFR2_FARM        {D_SFR2_FARM < AW_FARM}
goal constrain_D_SFR3_POWERPLANT  {D_SFR3_POWERPLANT < UD_POWERPLANT}
```

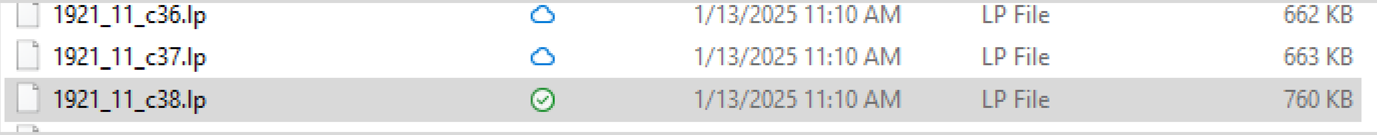
Objective Function:
Note: 1000 and 2000 are the weights of the decision variables within the Objective Function

```
Objective obj_SYS = {…
[D_SFR2_FARM,  1000],
[D_SFR3_POWERPLANT,  2000],
[C_SFLAKE_MIF,  1500]
…}
```

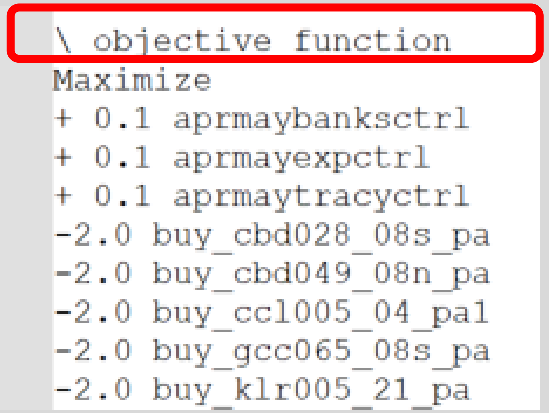
Simulated LP Model for the Example within the CalSim

```
\ Date: 2021.09\ Cycle: 01\ Solver: CBC\ objective function
Maximize
+ 1500.0 c_sflake_mif
+ 1000.0 d_sfr2_farm
+ 2000.0 d_sfr3_powerplant
+ 3361111.111333334 s_sflake_1
+ 5041.666667 s_sflake_2
\ constraint
Subject To
constrain_c_sflake_mif:  + c_sflake_mif <= 0
constrain_d_sfr2_farm:  + d_sfr2_farm <= 10.786869120979885
constrain_d_sfr3_powerplant:  + d_sfr3_powerplant <= 16.80555555666667
continuity_sflake:  - c_sflake -16.80555555666667 s_sflake = -5435.042064741771
continuity_sfr1:  + c_sflake - c_sfr1 = 0
continuity_sfr2:  + c_sfr1 - c_sfr2 - d_sfr2_farm = 0
continuity_sfr3:  + c_sfr2 - c_sfr3 - d_sfr3_powerplant = 0
s_sflake_zone1:  + s_sflake_1 <= 10.0
s_sflake_zone2:  + s_sflake_2 <= 390.0
split_c_sflake:  + c_sflake - c_sflake_add - c_sflake_mif = 0
storage_sflake:  + s_sflake - s_sflake_1 - s_sflake_2 = 0
\dvar
Bounds
c_sflake <= 1000.0
c_sfr1 <= 1000.0
c_sfr2 <= 1000.0
c_sfr3 <= 1000.0 End
\ objective value:   3.522732731891689E7
```

LP sample model within CalSim CalSim 3



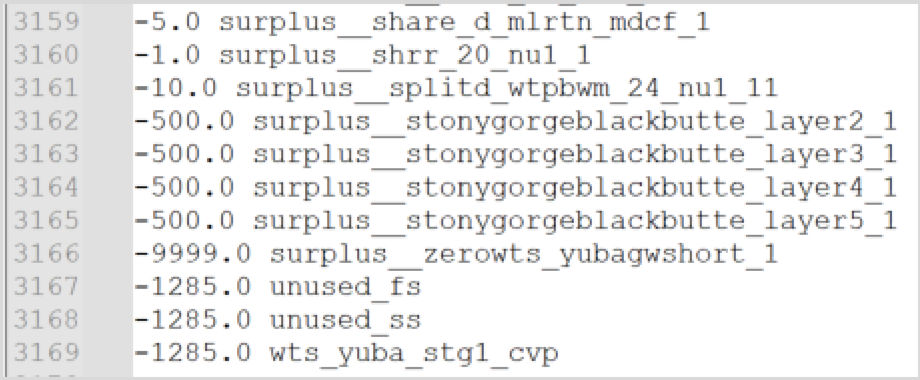
1921_11_c36.lp	1/13/2025 11:10 AM	LP File	662 KB
1921_11_c37.lp	1/13/2025 11:10 AM	LP File	663 KB
1921_11_c38.lp	1/13/2025 11:10 AM	LP File	760 KB



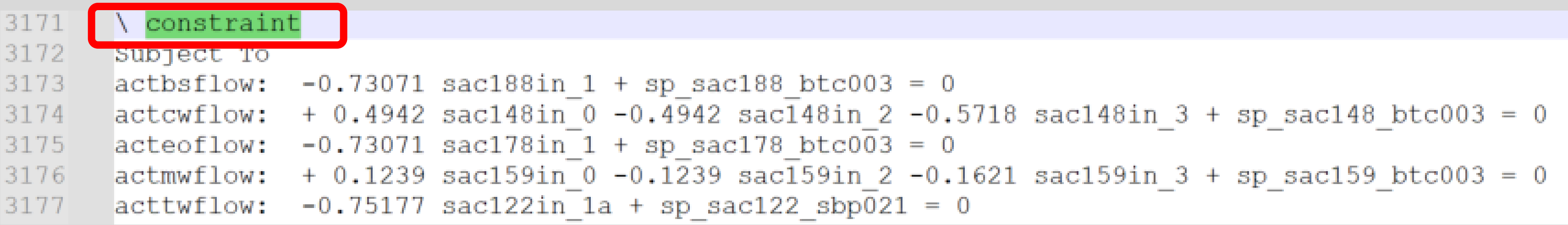
```
\ objective function
Maximize
+ 0.1 aprmaybanksctrl
+ 0.1 aprmayexpctrl
+ 0.1 aprmaytracyctrl
-2.0 buy_cbd028_08s_pa
-2.0 buy_cbd049_08n_pa
-2.0 buy_ccl005_04_pa1
-2.0 buy_gcc065_08s_pa
-2.0 buy_klr005_21_pa
```

…

…



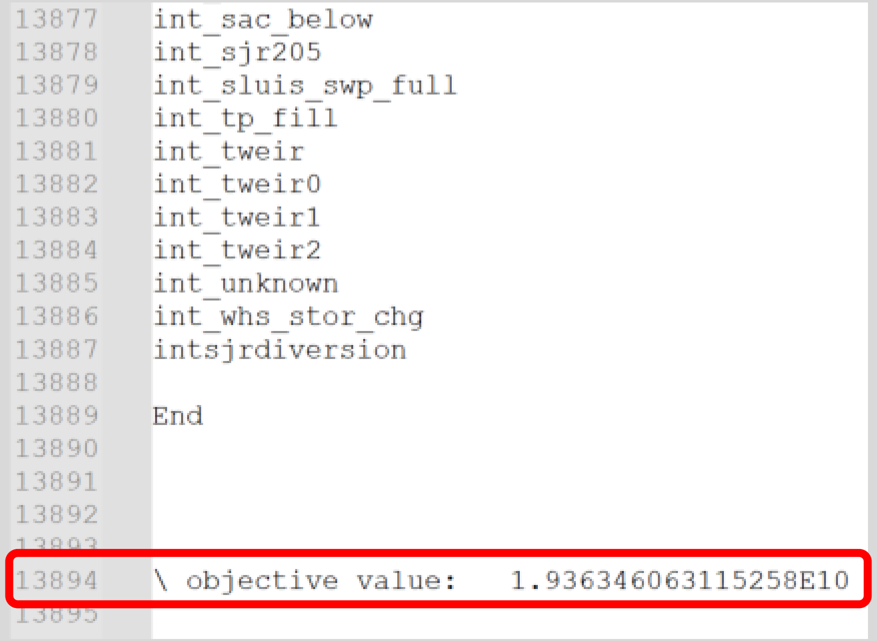
```
-5.0 surplus__share_d_mlrtn_mdcf_1
-1.0 surplus__shrr_20_nu1_1
-10.0 surplus__splitd_wtpbwm_24_nu1_11
-500.0 surplus__stonygorgeblackbutte_layer2_1
-500.0 surplus__stonygorgeblackbutte_layer3_1
-500.0 surplus__stonygorgeblackbutte_layer4_1
-500.0 surplus__stonygorgeblackbutte_layer5_1
-9999.0 surplus__zerowts_yubagwshort_1
-1285.0 unused_fs
-1285.0 unused_ss
-1285.0 wts_yuba_stg1_cvp
```



```
\ constraint
Subject To
actbsflow:  -0.73071 sac188in_1 + sp_sac188_btc003 = 0
actcwflow:  + 0.4942 sac148in_0 -0.4942 sac148in_2 -0.5718 sac148in_3 + sp_sac148_btc003 = 0
acteoflow:  -0.73071 sac178in_1 + sp_sac178_btc003 = 0
actmwflow:  + 0.1239 sac159in_0 -0.1239 sac159in_2 -0.1621 sac159in_3 + sp_sac159_btc003 = 0
acttwflow:  -0.75177 sac122in_1a + sp_sac122_sbp021 = 0
```

…

…



```
int_sac_below
int_sjr205
int_sluis_swp_full
int_tp_fill
int_tweir
int_tweir0
int_tweir1
int_tweir2
int_unknown
int_whs_stor_chg
intsjrdiversion

End




\ objective value:   1.936346063115258E10
```

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Motivation for Investigating Gurobi, XA, and CBC Solvers in CalSim Studies

- Computational Performance, Accuracy Performance
- Cost vs. Capability
- Solver Features
- CBC Enhancement
- WRIMS Compatibility and Transparency
- Scenario Robustness
- Licensing & Deployment

CBC Solver (Open-source MILP solver, part of the COIN-OR project)

Advantages:

- Robustness
- License free and open-source
- Often used in CalSim for cost-effective deployment
- Can utilize the Pre-solve approach to foster the solving strategy

Limitations:

- Slower on large models
- Needs efficient handling of unstable or degenerate problems.

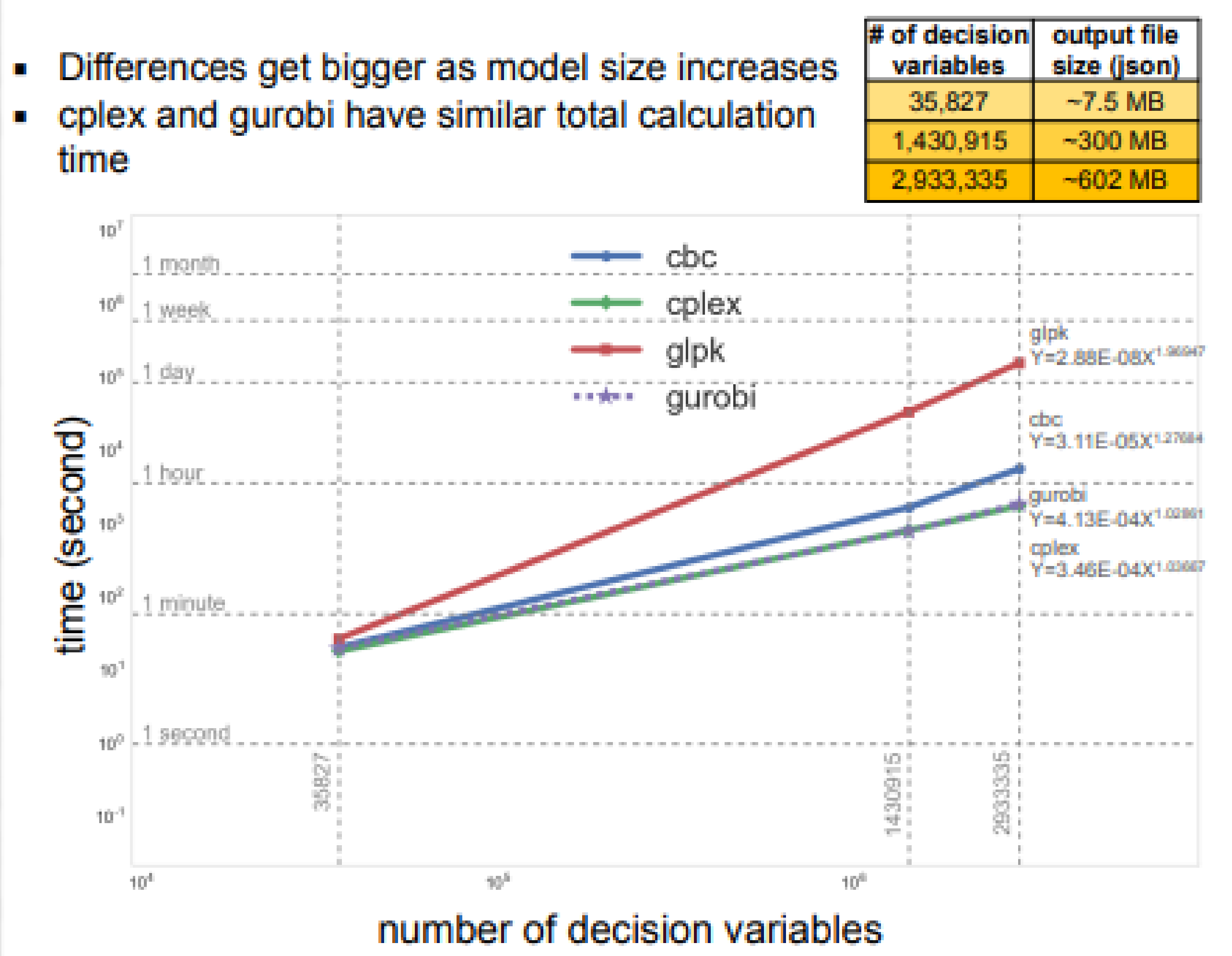
XA Solver

- Uses Simplex as core algorithm
- Long-used in WRIMS/CalSim by some state agencies
- Limited community support and licensing cost

Gurobi Solver

- Uses Primal/Dual Simplex; optimized for LPs & MILPs
- Fast, robust, and ideal for large or sparse CalSim models
- Integrates with WRIMS via Java (e.g., jGurobi)
- License required (free for academics)

Computational Time Performance Comparison (applied to Calvin model)



- Differences get bigger as model size increases
- cplex and gurobi have similar total calculation time

# of decision variables	output file size (json)
35,827	~7.5 MB
1,430,915	~300 MB
2,933,335	~602 MB

https://msdogan.github.io/other/Poster_AGU2016.pdf

- ➢ Independent of CalSim; compares Gurobi, CPLEX, GLPK, and CBC.
- ➢ Gurobi outperforms CBC and others in computational time.
- ➢ Gurobi and CPLEX show similar speed and performance.
- ➢ Full-period Gurobi simulation is in progress.

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Some advantage of Pre-solve approach within the Gurobi leads to:

- Removes redundant constraints and empty rows/columns
- Fix variable values based on bounds
- Simplifies constraints and tightens bounds
- Detect infeasibility early

Why It Helps with Computational Time

- Reduces variables, constraints, and problem size
- Shrinks branch-and-bound tree (for MILPs)
- Speeds up solving, lowers memory use, and improves stability

Summary - Advantage and Disadvantage of Solvers and recommendations

Solver	License	Community Support	Typical Use Case in CalSim
CBC	License Free	Active - Open Source (COIN-OR), Online Forums	Default (DWR/USBR setups)
Gurobi	Commercial /Free Academic	Commercial Support	In Testing Phase
XA	Commercial	Commercial Support	In Use- DWR/USBR setups

Summary - Advantage and Disadvantage of Solvers and recommendations

- CBC can continue as a license free Solver (distributable within WRIMS) option and continue its improvement.

- Gurobi is already being investigated as a potential option of Solver for WRIMS along with the CBC and XA.

- Continue to investigate the Gurobi's applicability and its performance for CalSim studies

- Continue to create configuration setting platform for Gurobi to use within WRIMS for CalSim studies

References

- https://msdogan.github.io/other/Poster_AGU2016.pdf
- CalSim Workshop: Session 1: Introduction and Overview, Jan 2025
- CalSim Workshop: Session 1: Simple WRIMS Application, Jan 2025

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