How Analytical Solutions in the Alluvial Water Accounting System (AWAS) Compute Depletions and Accretions

Luis A. Garcia, Ph.D.
Professor and Head
Department of Civil and Environmental Engineering

Colorado Aquifer Management Conference
November 28, 2012

AWAS

- Developed over the past 10+ years for augmentation water accounting.
- Multiple analytical solutions (Glover, SDF) as well as URF's.
- Glover solution was based on a program created by the Office of the State Engineer (Dewayne Schroeder, 1987).
- Model supports different time steps. Daily time steps are especially important for wells close to the river.
- Calculates depletion or accretion based on pumping or recharge records.

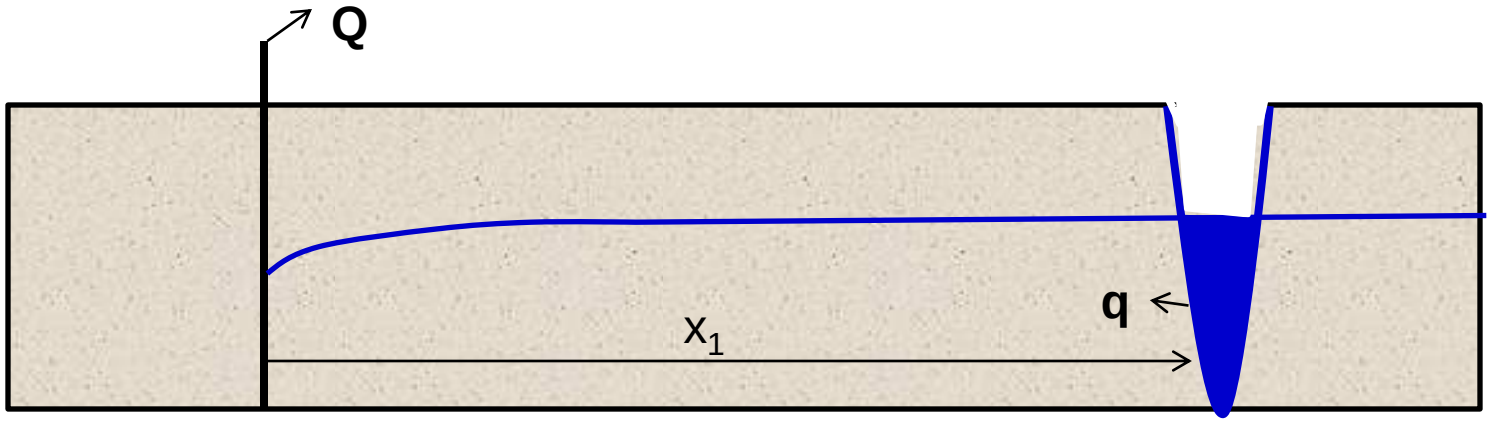
Analytical Solutions

In order to develop a model simplifying assumption must be made since nature is usually too complex to simulate exactly.

Many analytical solutions are developed for homogeneous and isotropic conditions.

To deal with the more realistic situations (e.g., heterogeneous and anisotropic aquifers), numerical techniques (finite difference or finite element) are used.

Review of Glover's Equation



$$\frac{q}{Q} = 1 - \mathrm{erf}\left(\frac{x_1}{\sqrt{4tT/S}}\right)$$

q = depletion rate at stream

Q = pumping rate from well

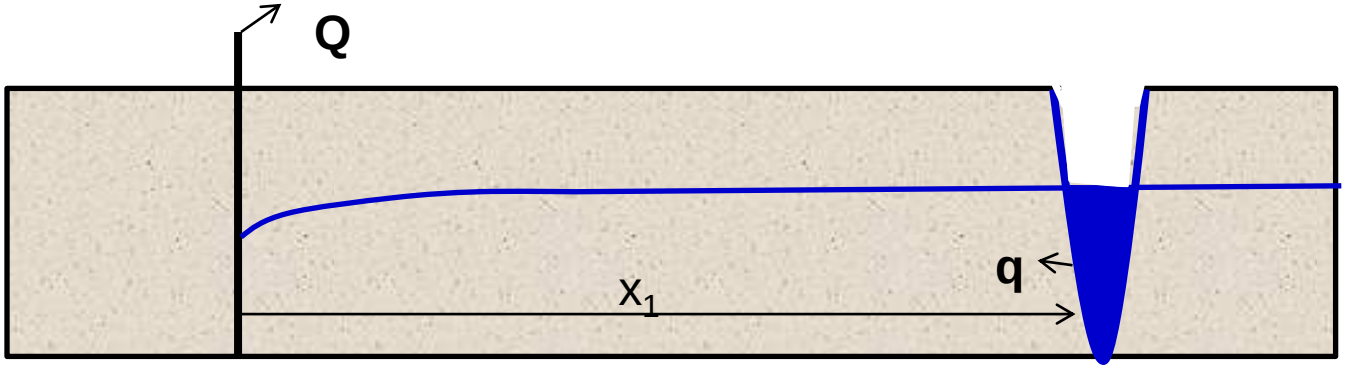
T = trasmissivity

S = specific yield

x_1 = distance from well to stream

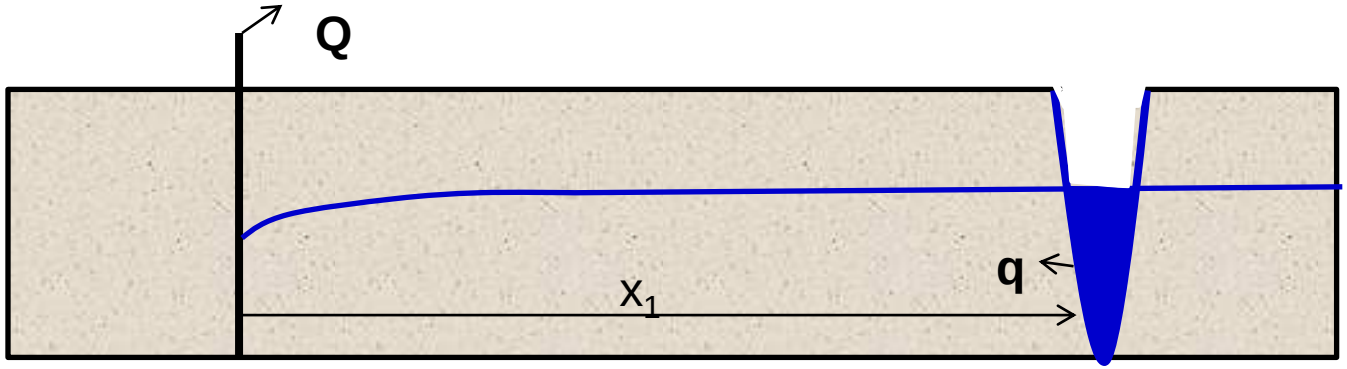
erf = error function

Glover Assumptions



- The aquifer is isotropic, homogenous, of uniform thickness.
- The transmissivity is the same everywhere and does not change with time.
- Drawdown is negligible compared to aquifer thickness.
- The water table is initially flat.
- Water is release instantaneously from storage.

Glover Assumptions



- The stream is straight, infinite in length, and fully penetrates the aquifer.
- The pumping rate is constant for any pumping period.
- The diameter of the well is negligible.

Boundary Conditions

AWAS computes return flows using different boundary conditions:

- Infinite Aquifer
- Alluvial Aquifer
- No Flow Perpendicular to Stream
- Effective SDF $SDF = \frac{a^2 S}{T}$ $\frac{q}{Q} = 1 - erf\left(\sqrt{\frac{SDF}{4t}}\right)$
- URF

Infinite Aquifer

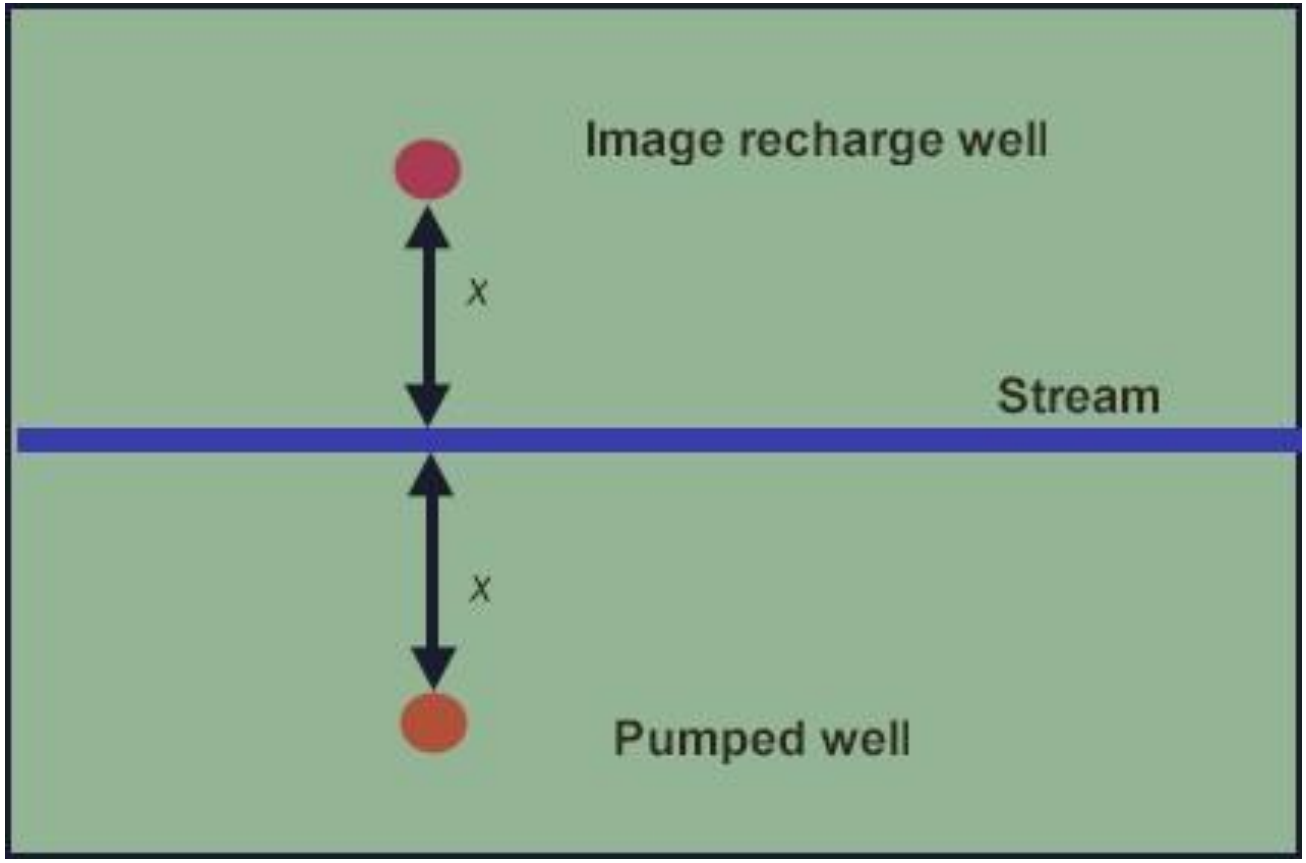
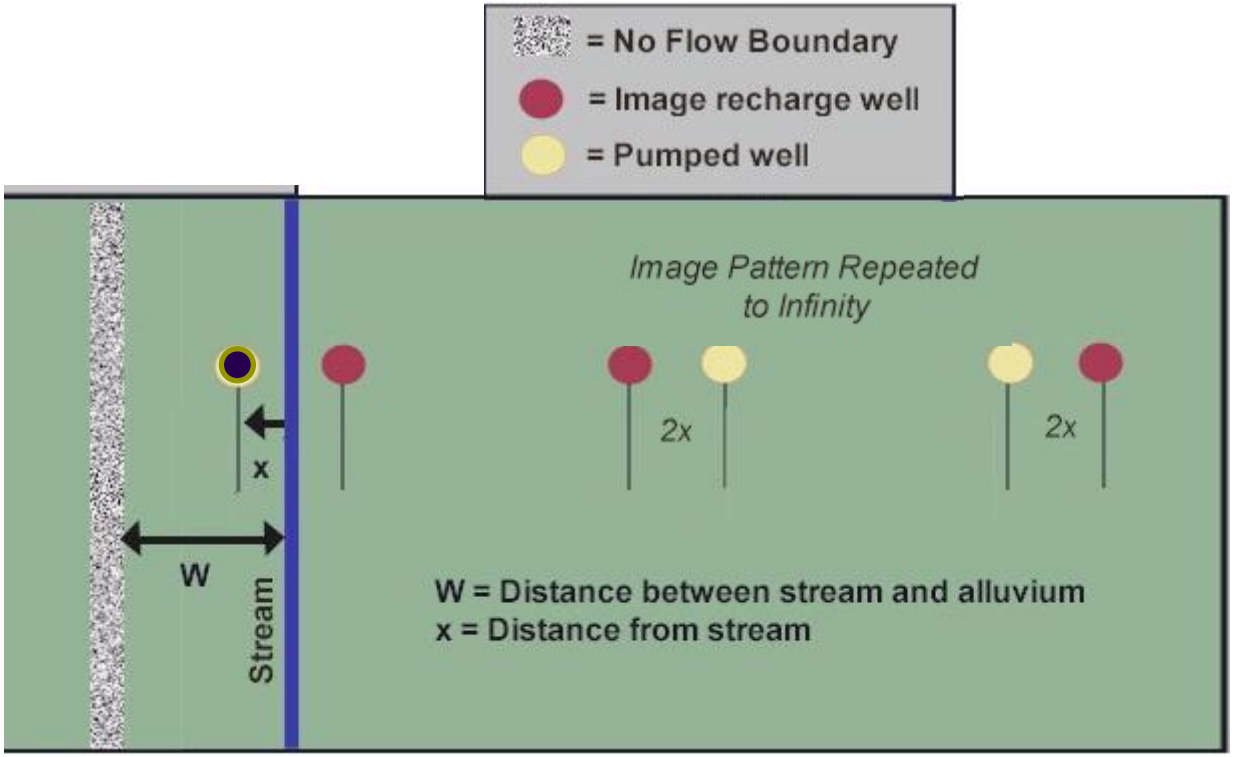


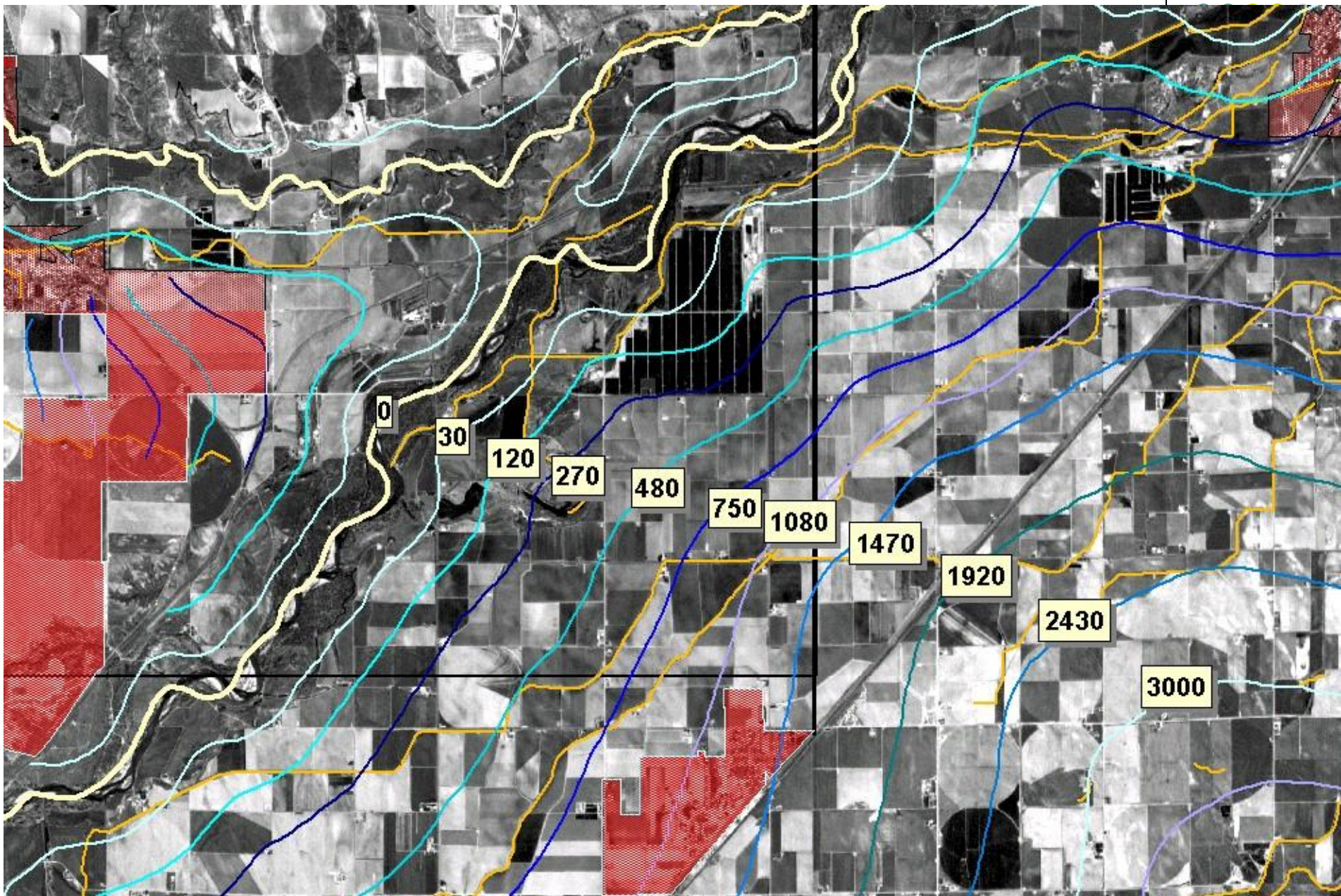
Image recharge well placed across the stream so that zero drawdown occurs at the stream.

Alluvial Aquifer



Boundary condition are met by placing a series of alternating recharge and pumping image wells.

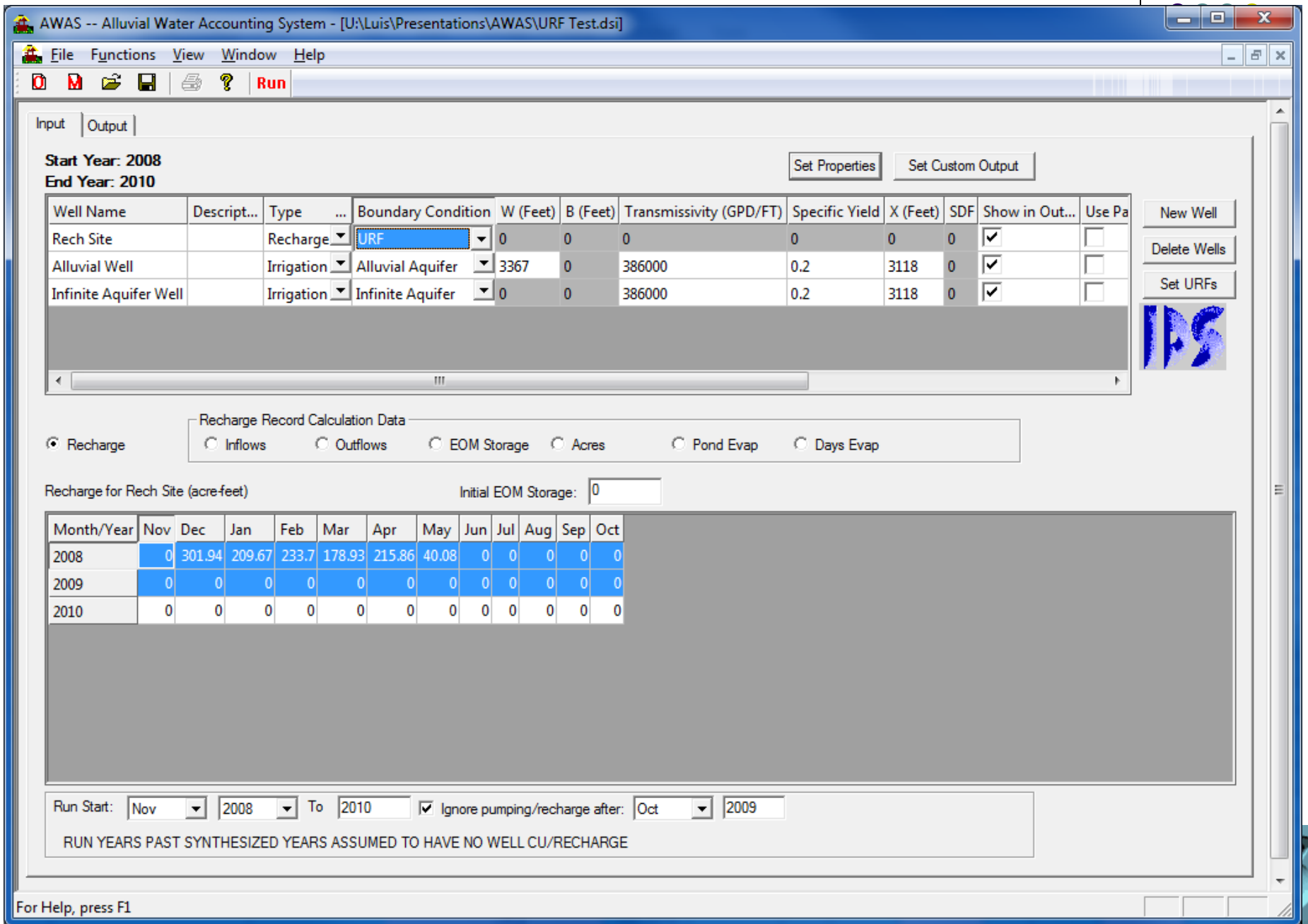
SDF Map Example (SP area)



Boundaries and Heterogeneous Conditions

- Boundaries are calculated by using image wells.
- Averages can be used to deal with heterogeneous aquifer properties.

Main AWAS Window



AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test.dsi]

File Functions View Window Help

Run

Input Output

Scale
- Monthly
- Daily

Output For Well/Recharge Sites:
- Rech Site
- Alluvial Well
- Infinite Aquifer Well
- Total of Show in Output
- Total of Selection
- Recharge Summary
- CU of Ground Water Summary
- Net Impact on Stream

Years
- 2008
- 2009
- 2010

☑ Show CU of Ground Water/Net Recharge Data

☑ Show Depletion/Accretion Data

Display Options

☐ Show Headers ☐ Single Column ☐ Database ☐ Compact ☐ Month Major

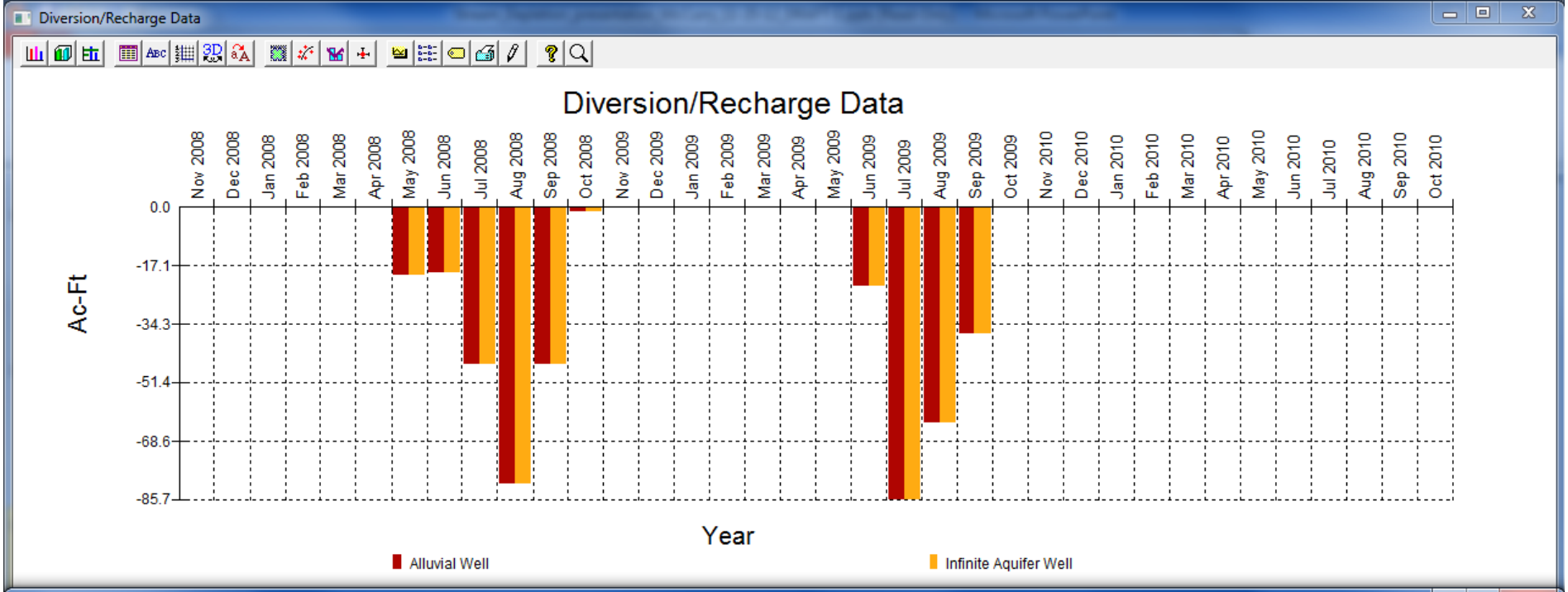
Export ☐ Depletions are Positive ☐ Trim ID to 1st Group ☐ Single Row

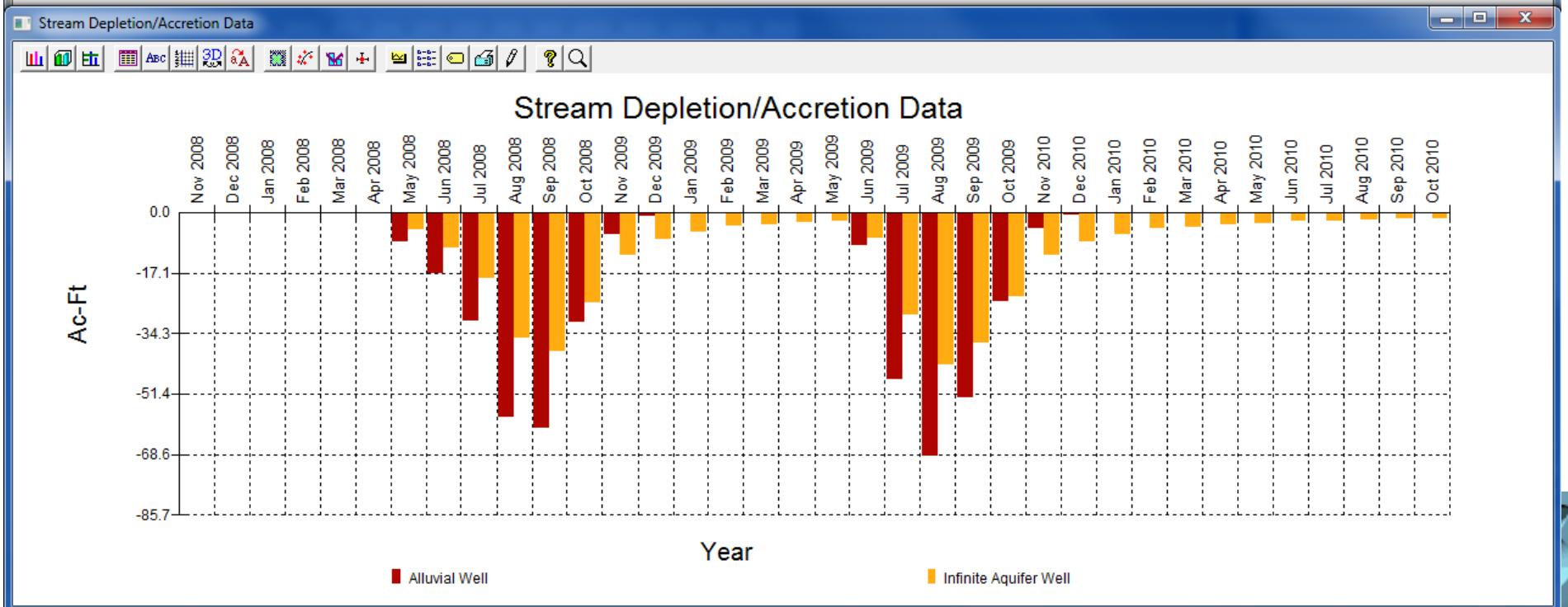
☐ Open In Excel

Number of decimal places: 2 ☐ Display Totals

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Diversions/Recharge (ac-ft)												
Alluvial Well												
2008	0	0	0	0	0	0	-19.9	-19.2	-46.2	-81.1	-46.2	-1.2
2009	0	0	0	0	0	0	0	-22.91	-85.69	-63.19	-36.99	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
Infinite Aquifer Well												
2008	0	0	0	0	0	0	-19.9	-19.2	-46.2	-81.1	-46.2	-1.2
2009	0	0	0	0	0	0	0	-22.91	-85.69	-63.19	-36.99	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
Depletions/Accretions (ac-ft)												
Alluvial Well												
2008	0	0	0	0	0	0	-8.41	-17.17	-30.6	-58.11	-61.1	-31.01
2009	-6.02	-1.14	-0.2	-0.03	-0.01	0	0	-9.41	-47.25	-69.2	-52.35	-25.06
2010	-4.48	-0.84	-0.15	-0.02	-0.01	0	0	0	0	0	0	0
Infinite Aquifer Well												
2008	0	0	0	0	0	0	-4.8	-9.95	-18.63	-35.5	-39.34	-25.6
2009	-11.98	-7.78	-5.52	-3.84	-3.41	-2.71	-2.36	-7.34	-28.91	-42.95	-37	-23.93
2010	-11.95	-8.29	-6.16	-4.43	-4.07	-3.32	-2.96	-2.51	-2.3	-2.06	-1.8	-1.7

Save To File Plot Print


Diversion/Recharge Data
Diversion/Recharge Data
Nov 2008
Dec 2008
Jan 2008
Feb 2008
Mar 2008
Apr 2008
May 2008
Jun 2008
Jul 2008
Aug 2008
Sep 2008
Oct 2008
Nov 2009
Dec 2009
Jan 2009
Feb 2009
Mar 2009
Apr 2009
May 2009
Jun 2009
Jul 2009
Aug 2009
Sep 2009
Oct 2009
Nov 2010
Dec 2010
Jan 2010
Feb 2010
Mar 2010
Apr 2010
May 2010
Jun 2010
Jul 2010
Aug 2010
Sep 2010
Oct 2010
0.0
-17.1
-34.3
-51.4
-68.6
-85.7
Ac-Ft
Year
Alluvial Well
Infinite Aquifer Well


Stream Depletion/Accretion Data
Stream Depletion/Accretion Data
Nov 2008
Dec 2008
Jan 2008
Feb 2008
Mar 2008
Apr 2008
May 2008
Jun 2008
Jul 2008
Aug 2008
Sep 2008
Oct 2008
Nov 2009
Dec 2009
Jan 2009
Feb 2009
Mar 2009
Apr 2009
May 2009
Jun 2009
Jul 2009
Aug 2009
Sep 2009
Oct 2009
Nov 2010
Dec 2010
Jan 2010
Feb 2010
Mar 2010
Apr 2010
May 2010
Jun 2010
Jul 2010
Aug 2010
Sep 2010
Oct 2010
0.0
-17.1
-34.3
-51.4
-68.6
-85.7
Ac-Ft
Year
Alluvial Well
Infinite Aquifer Well

AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test.dsi]

File Functions View Window Help

Run

Input | Output

Scale
- Monthly
- Daily

Output For Well/Recharge Sites:
- Rech Site
- Alluvial Well
- Infinite Aquifer Well
- Total of Show in Output
- Total of Selection
- Recharge Summary
- CU of Ground Water Summary
- Net Impact on Stream

Years
- 2008
- 2009
- 2010

☑ Show CU of Ground Water/Net Recharge Data

☑ Show Depletion/Accretion Data

Display Options

☐ Show Headers ☐ Single Column ☐ Database ☐ Compact ☐ Month Major

Export

☐ Depletions are Positive ☐ Trim ID to 1st Group ☐ Single Row

☐ Open In Excel

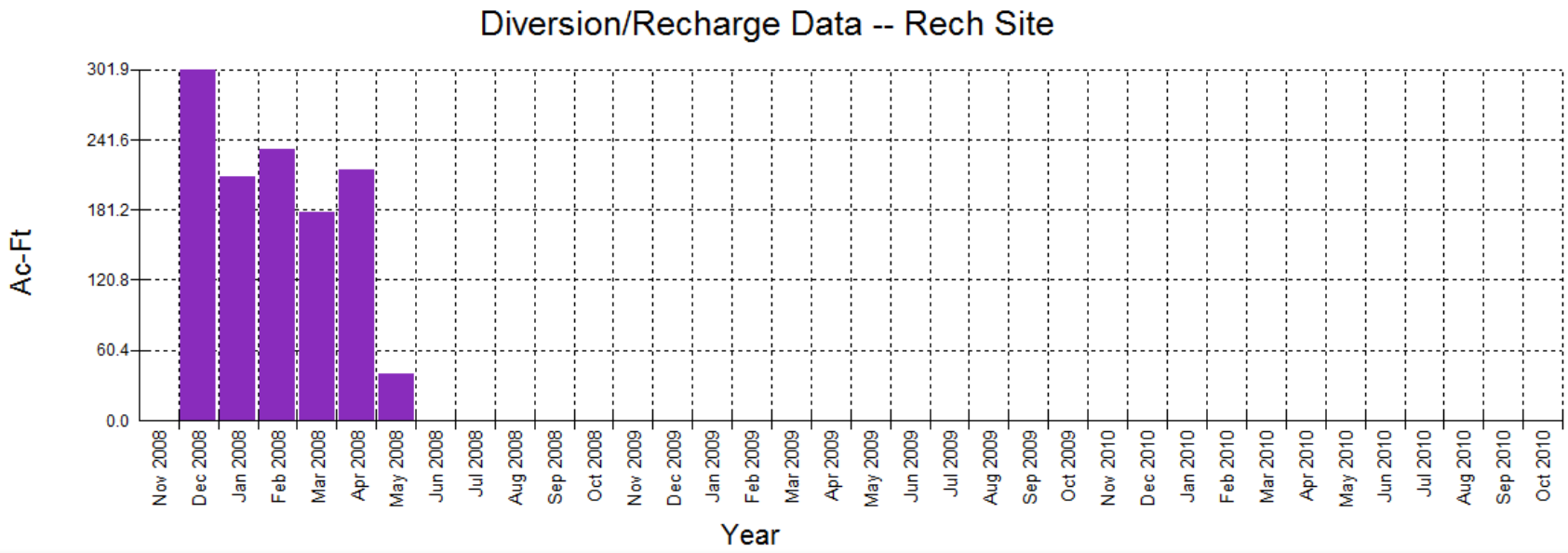
Number of decimal places: 2 ☐ Display Totals

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Diversions/Recharge (ac-ft)												
Rech Site												
2008	0	301.94	209.67	233.7	178.93	215.86	40.08	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
Depletions/Accretions (ac-ft)												
Rech Site												
2008	0	4.29	32.4	55.88	72.26	81.66	88.74	80.69	66.67	55.78	48.39	43.18
2009	39.28	36.17	33.55	31.27	29.22	27.35	25.62	24.03	22.54	21.16	19.86	18.66
2010	17.53	16.48	15.49	14.57	13.71	12.9	12.15	11.45	10.79	10.17	9.6	9.06

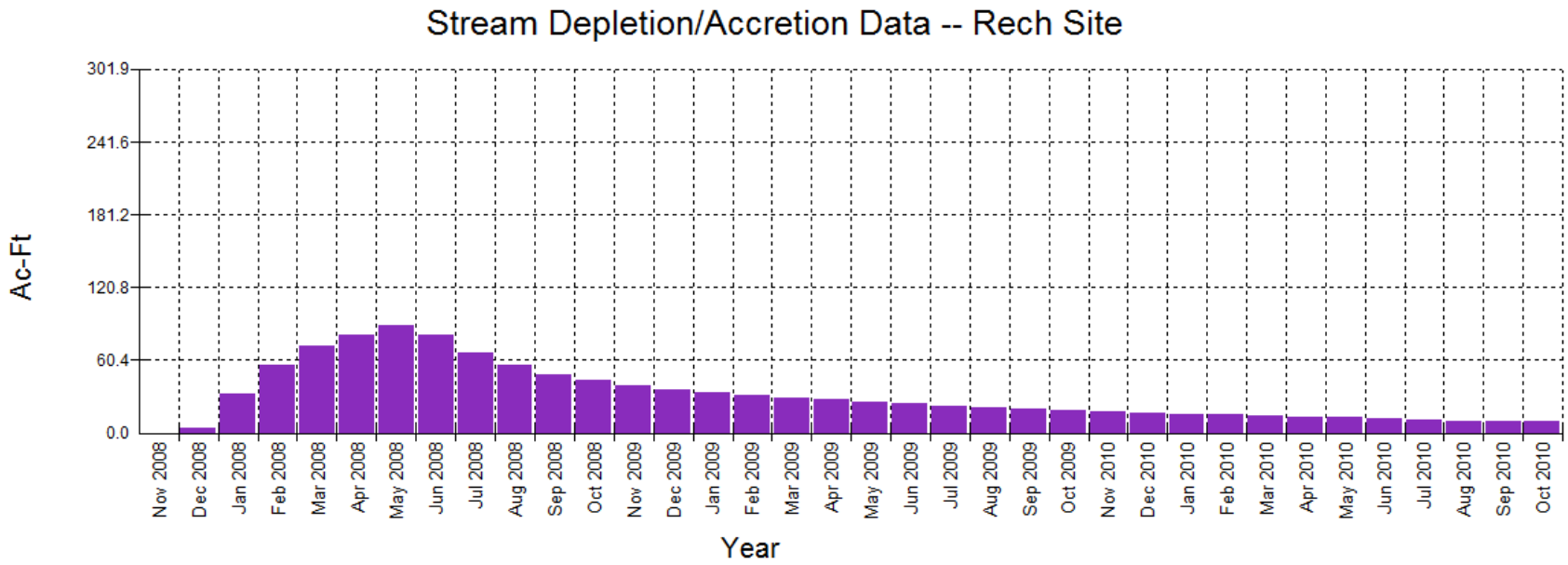
Save To File Plot Print

For Help, press F1

Diversion/Recharge Data



Stream Depletion/Accretion Data



AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test.dsi]

File Functions View Window Help

Run

Input | Output

Scale: Monthly / Daily

Output For Well/Recharge Sites:
- Rech Site
- Alluvial Well
- Infinite Aquifer Well
- Total of Show in Output
- Total of Selection
- Recharge Summary
- CU of Ground Water Summary
- Net Impact on Stream

Years: 2008, 2009, 2010

☑ Show CU of Ground Water/Net Recharge Data

☑ Show Depletion/Accretion Data

Display Options: ☐ Show Headers ☐ Single Column ☐ Database ☐ Compact ☐ Month Major

Export ☐ Depletions are Positive ☐ Trim ID to 1st Group ☐ Single Row

☐ Open In Excel

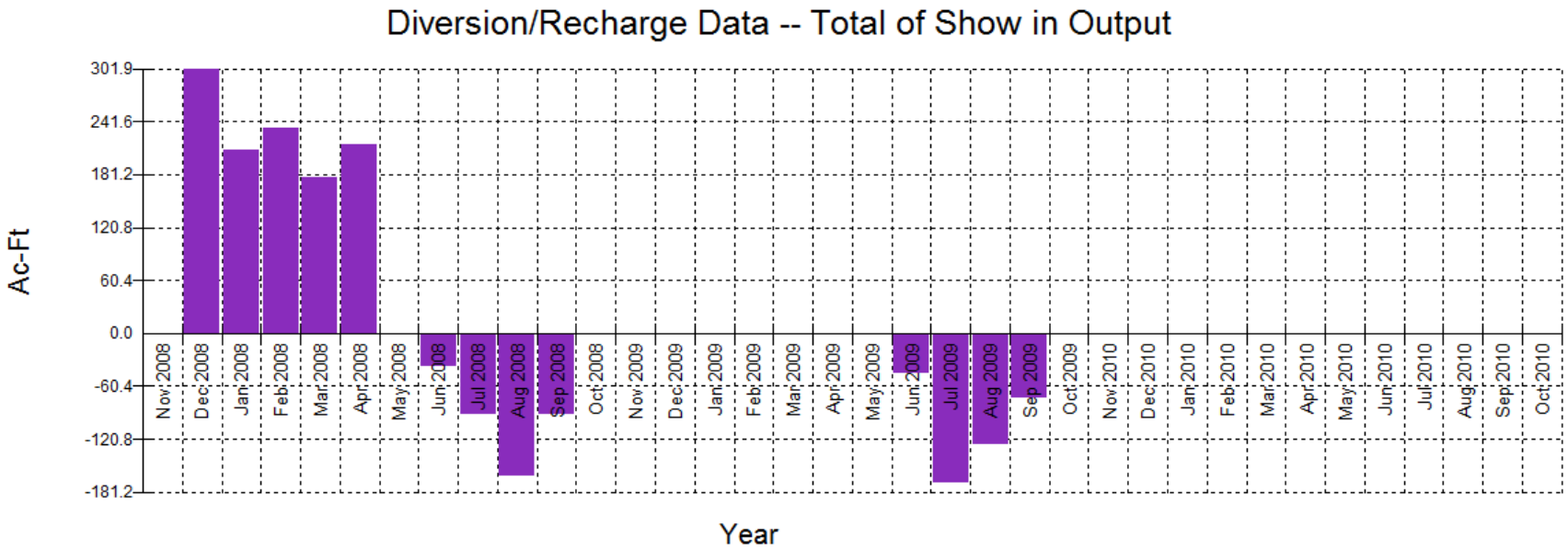
Number of decimal places: 2 ☐ Display Totals

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Diversions/Recharge (ac-ft)												
Total of Show in Output												
2008	0	301.94	209.67	233.7	178.93	215.86	0.28	-38.4	-92.4	-162.2	-92.4	-2.4
2009	0	0	0	0	0	0	0	-45.82	-171.38	-126.38	-73.98	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
Depletions/Accretions (ac-ft)												
Total of Show in Output												
2008	0	4.29	32.4	55.88	72.26	81.66	75.53	53.58	17.44	-37.83	-52.06	-13.42
2009	21.28	27.26	27.84	27.4	25.8	24.63	23.26	7.27	-53.62	-91	-69.49	-30.33
2010	1.09	7.35	9.19	10.11	9.64	9.58	9.19	8.94	8.49	8.11	7.79	7.36

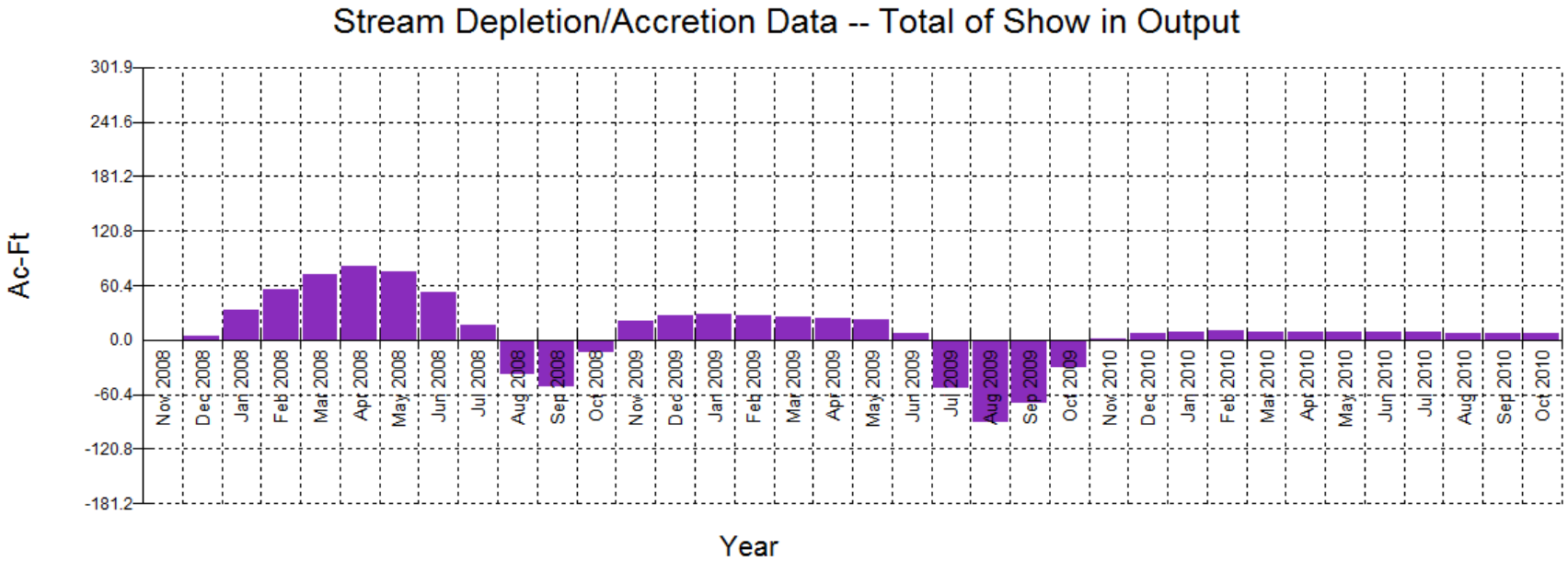
Save To File | Plot | Print

For Help, press F1

Diversion/Recharge Data



Stream Depletion/Accretion Data



AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test.dsi]

File Functions View Window Help

Run

Input | Output

Start Year: 2008
End Year: 2010

Set Properties | Set Custom Output

Well Name	Descript...	Type ...	Boundary Condition	W (Feet)	B (Feet)	Transmissivity (GPD/FT)	Specific Yield	X (Feet)	SDF	Show in Out...	Use P
Rech Site		Recharge	URF	0	0	0	0	0	0	✓	
Alluvial Well		Irrigation	Alluvial Aquifer	3367	0	386000	0.2	3118	0	✓	
Infinite Aquifer Well		Irrigation	Infinite Aquifer	0	0	386000	0.2	3118	0	✓	

New Well | Delete Wells | Set URFs

Recharge

Recharge Record Calculation Data: Inflows | Outflows | EOM Storage | Acres | Pond Evap | Days Evap

Recharge for Rech Site (acre-feet)

Initial EOM Storage: 0

Month/Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2008	0	301.94	209.67	233.7	178.93	215.86	40.08	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0

Run Start: Nov 2008 To 2010 ✓ Ignore pumping/recharge after: Oct 2009

RUN YEARS PAST SYNTHESIZED YEARS ASSUMED TO HAVE NO WELL CU/RECHARGE

AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test.dsi]

File Functions View Window Help

Run

Input | Output

Start Year: 2008
End Year: 2010

Well Name	Descript.
Rech Site	
Alluvial Well	
Infinite Aquifer Well	

Set Custom Output

X (Feet)	SDF	Show in Out...	Use P
0	0	✓	
3118	0	✓	
3118	0	✓	

New Well

Delete Wells

Set URFs

Recharge

Recharge

Inflo

Recharge for Rech Site (acre-feet)

Month/Year	Nov	Dec	Jan
2008	0	301.94	209
2009	0	0	
2010	0	0	

Run Start: Nov 2008

RUN YEARS PAST SYNTHESI

Set Uniform Return Flows For Rech Site

Daily URF

Number of Periods: 0 Set

Time Period	URF

Monthly URF

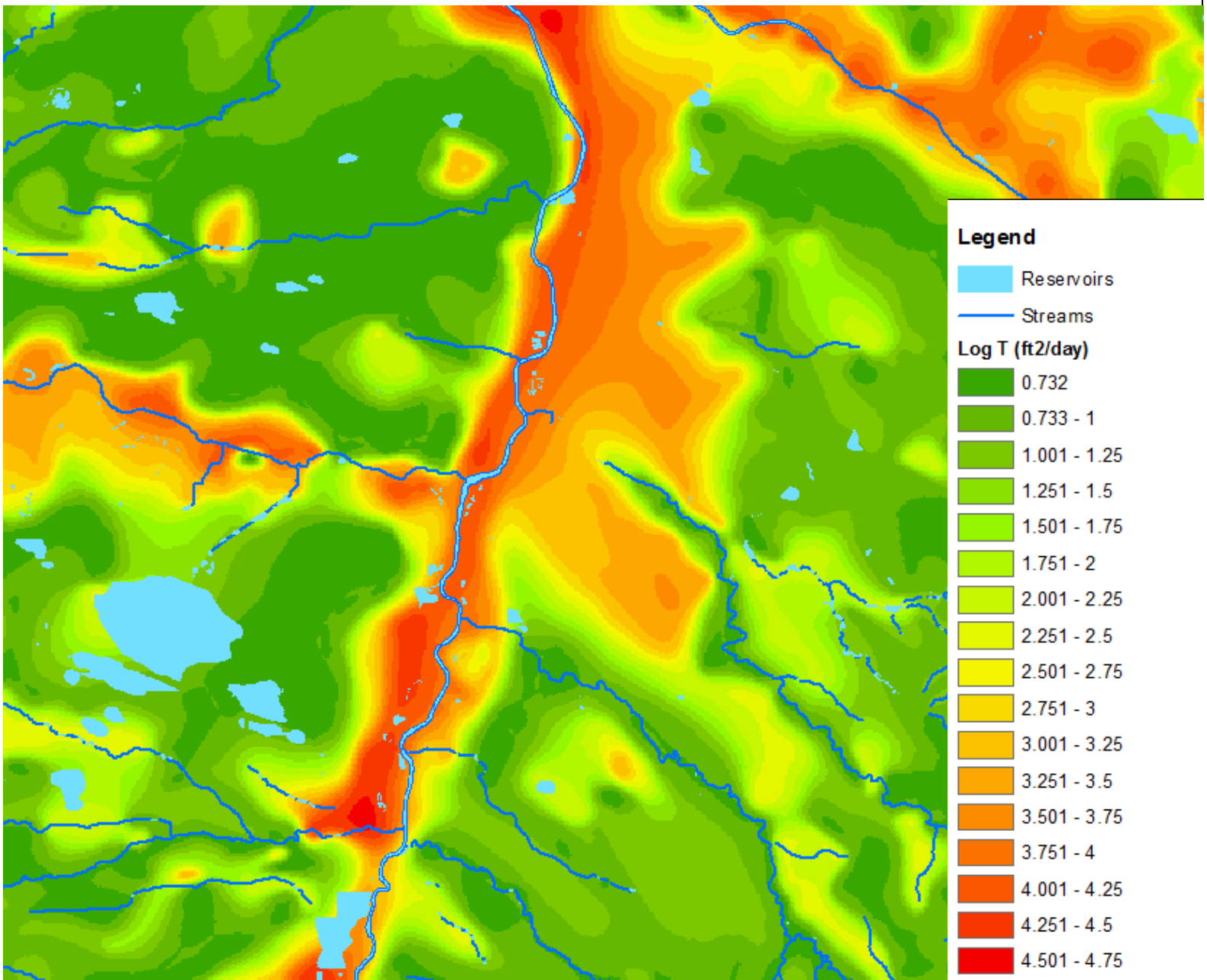
Number of Periods: 43 Set

Time Period	URF
1	0.0141971
2	0.0974503
3	0.106423
4	0.0815782
5	0.0635282
6	0.0520332
7	0.0445852
8	0.0394852
9	0.0357462
10	0.0328152
11	0.0303832
12	0.0282782
13	0.0264022
14	0.0246982
15	0.0231332
16	0.0216842
17	0.0203372
18	0.0190822
19	0.0179132
20	0.0168192
21	0.0157982

OK

Cancel

Heterogeneous Transmissivity



Heterogeneous Transmissivity

- Which Transmissivity Value to Use?
- Harmonic Mean

$$HM = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{a_i}} = \frac{n}{\frac{1}{a_1}+\frac{1}{a_2}+\cdots+\frac{1}{a_n}}.$$

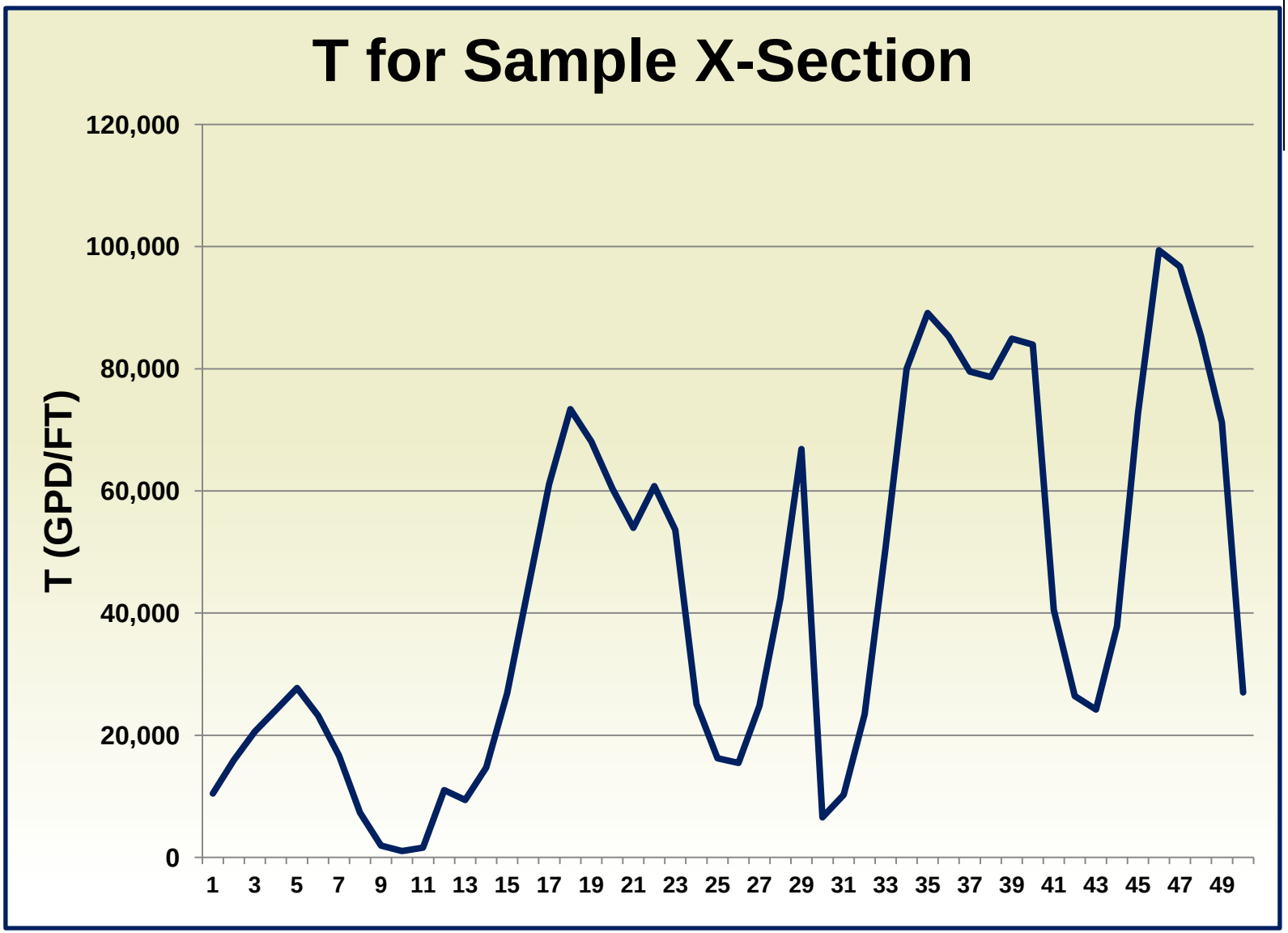
- Arithmetic Mean

$$AM = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{a_1+a_2+\cdots+a_n}{n}.$$

- Geometric Mean

$$\mathrm{GM} = \sqrt[n]{\prod_{i=1}^{n} a_i} = \sqrt[n]{a_1 a_2 \cdots a_n}.$$

Heterogeneous Transmissivity



Heterogeneous Transmissivity

- Which Transmissivity Value to Use?
- Harmonic Mean

$$HM = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{a_i}} = \frac{n}{\frac{1}{a_1}+\frac{1}{a_2}+\cdots+\frac{1}{a_n}}.$$

12,697 GDP/FT

- Arithmetic Mean

$$AM = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{a_1+a_2+\cdots+a_n}{n}.$$

42,655 GDP/FT

- Geometric Mean

$$\mathrm{GM} = \sqrt[n]{\prod_{i=1}^{n} a_i} = \sqrt[n]{a_1 a_2 \cdots a_n}.$$

29,000 GDP/FT

AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test Transmissivity.dsi]

File Functions View Window Help

Run

Input | Output

Start Year: 2008
End Year: 2010

Set Properties | Set Custom Output

Well Name	Description	Type ...	Boundary Condition	W (Feet)	B (Feet)	Transmissivity (GPD/FT)	Specific Yield	X (Feet)	SDF	Show in Out...	Use Partial S
Harmonic T		Irrigation	Infinite Aquifer	0	0	12697	0.2	3118	0	☑	☐
Arithmetic T		Irrigation	Infinite Aquifer	0	0	42655	0.2	3118	0	☑	☐
Geometric T		Irrigation	Infinite Aquifer	0	0	29000	0.2	3118	0	☑	☐

New Well | Delete Wells | Set URFs

Consumptive Use

Pumping Record Calculation Data: Q | App Eff

Consumptive Use for Geometric T (acre-feet)

Month/Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2008	0	0	0	0	0	0	19.9	19.2	46.2	81.1	46.2	1.2
2009	0	0	0	0	0	0	0	22.91	85.69	63.19	36.99	0
2010	0	0	0	0	0	0	0	0	0	0	0	0

Run Start: Nov 2008 To 2010 ☑ Ignore pumping/recharge after: Oct 2009

RUN YEARS PAST SYNTHESIZED YEARS ASSUMED TO HAVE NO WELL CU/RECHARGE

For Help, press F1

AWAS -- Alluvial Water Accounting System - [U:\Luis\Presentations\AWAS\URF Test Transmissivity.dsi]

File Functions View Window Help

Run

Input | Output

Scale
- Monthly
- Daily

Output For Well/Recharge Sites:
- Harmonic T
- Arithmetic T
- Geometric T
- Total of Show in Output
- Total of Selection
- Recharge Summary
- CU of Ground Water Summary
- Net Impact on Stream

Years
- 2008
- 2009
- 2010
- 2011
- 2012

☑ Show CU of Ground Water/Net Recharge Data

☑ Show Depletion/Accretion Data

Display Options

☐ Show Headers ☐ Single Column ☐ Database ☐ Compact ☐ Month Major

Export ☐ Depletions are Positive ☐ Trim ID to 1st Group ☐ Single Row

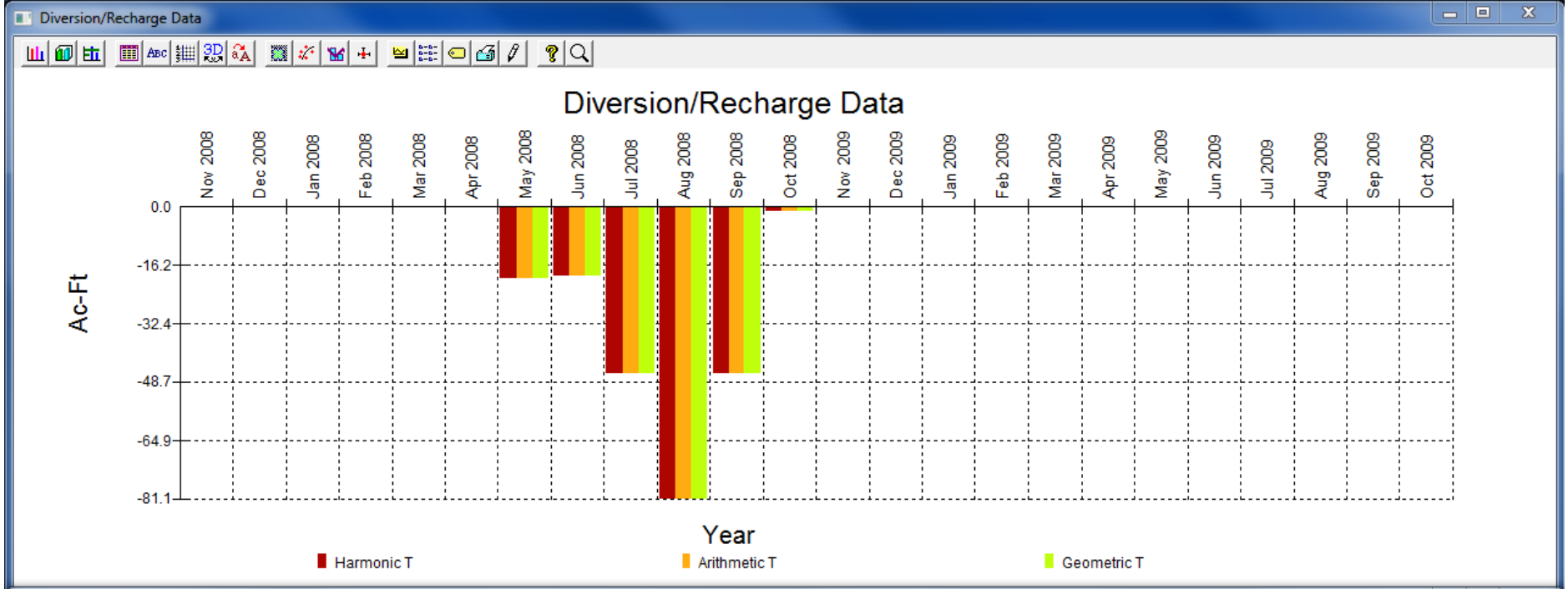
☐ Open In Excel

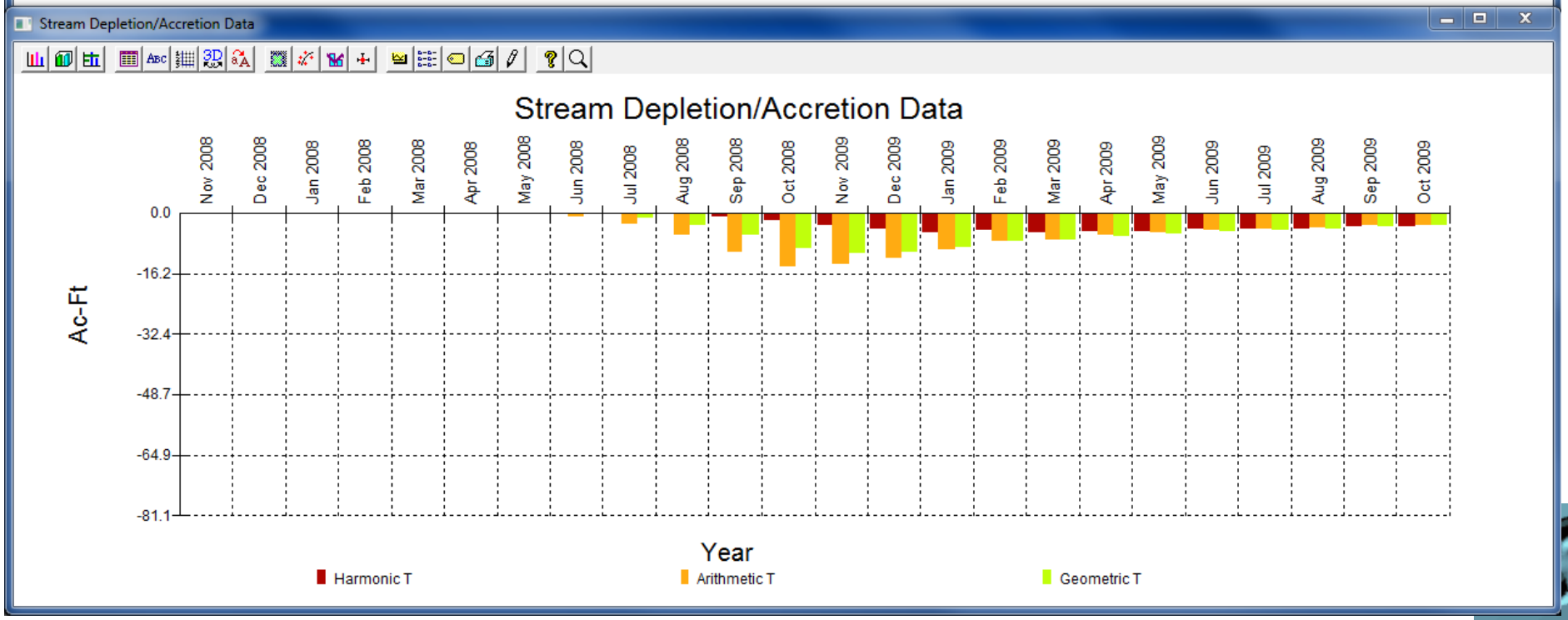
Number of decimal places: 2 ☐ Display Totals

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2008	0	0	0	0	0	0	-19.9	-19.2	-46.2	-81.1	-46.2	-1.2
2009	0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic T												
2008	0	0	0	0	0	0	-19.9	-19.2	-46.2	-81.1	-46.2	-1.2
2009	0	0	0	0	0	0	0	0	0	0	0	0
Geometric T												
2008	0	0	0	0	0	0	-19.9	-19.2	-46.2	-81.1	-46.2	-1.2
2009	0	0	0	0	0	0	0	0	0	0	0	0
Depletions/Accretions (ac-ft)												
Harmonic T												
2008	0	0	0	0	0	0	0	-0.01	-0.13	-0.44	-1	-2.07
2009	-3.26	-4.43	-5.02	-4.7	-5.17	-4.85	-4.79	-4.4	-4.29	-4.04	-3.69	-3.59
Arithmetic T												
2008	0	0	0	0	0	0	-0.08	-1.06	-2.79	-5.74	-10.33	-14.43
2009	-13.76	-12.05	-9.97	-7.58	-7.17	-5.98	-5.39	-4.6	-4.23	-3.79	-3.32	-3.12
Geometric T												
2008	0	0	0	0	0	0	-0.01	-0.4	-1.42	-3.11	-5.91	-9.49
2009	-10.61	-10.43	-9.28	-7.39	-7.21	-6.16	-5.65	-4.9	-4.56	-4.12	-3.64	-3.44

Save To File Plot Print

For Help, press F1


Diversion/Recharge Data
Diversion/Recharge Data
Nov 2008
Dec 2008
Jan 2008
Feb 2008
Mar 2008
Apr 2008
May 2008
Jun 2008
Jul 2008
Aug 2008
Sep 2008
Oct 2008
Nov 2009
Dec 2009
Jan 2009
Feb 2009
Mar 2009
Apr 2009
May 2009
Jun 2009
Jul 2009
Aug 2009
Sep 2009
Oct 2009
0.0
-16.2
-32.4
-48.7
-64.9
-81.1
Ac-Ft
Year
Harmonic T
Arithmetic T
Geometric T


Stream Depletion/Accretion Data
Stream Depletion/Accretion Data
Nov 2008
Dec 2008
Jan 2008
Feb 2008
Mar 2008
Apr 2008
May 2008
Jun 2008
Jul 2008
Aug 2008
Sep 2008
Oct 2008
Nov 2009
Dec 2009
Jan 2009
Feb 2009
Mar 2009
Apr 2009
May 2009
Jun 2009
Jul 2009
Aug 2009
Sep 2009
Oct 2009
0.0
-16.2
-32.4
-48.7
-64.9
-81.1
Ac-Ft
Year
Harmonic T
Arithmetic T
Geometric T

Summary and Conclusions

AWAS is developed as a platform to use several analytical methods and allow users to evaluate a number of different options (boundary conditions and solutions methods).

Analytical models cannot deal with spatial variability but the user can evaluate the impact of different ways to deal with them (T average, boundary types).

AWAS allows for the use of unit response functions developed using numerical models.

Users need to be aware/consider various options and limitations of any model. Any model is only as good as the data and our understanding of the system.

AWAS Distribution

AWAS is distributed via the web:

www.ids.colostate.edu/projects/idsawas

Questions

CSUID Numerical Model