CE EN 547 – BRIGHAM YOUNG UNIVERSITY

Model Calibration

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Lecture Objectives

- Understand the role that calibration plays in the modeling process
- Be familiar with both manual and automated approaches to model calibration
- Understand the various error norms used to to quantify calibration
- Understand the concept of model uniqueness

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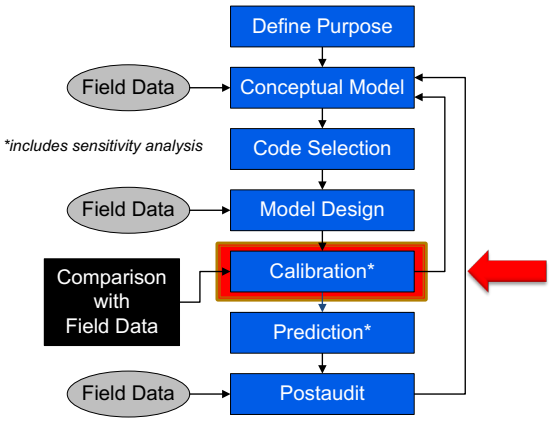
Calibration

- Solution is computed by model
- Simulated heads and flows are compared to field observed values
- Input parameters (K, recharge, etc.) Are adjusted until model outputs match field observations



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Types of Calibration

- Trial and error
  - Manually tweak inputs and re-run model
- Automated parameter estimation
  - Optimization utility is used to adjust input parameters in a systematic fashion
  - PEST, UCODE

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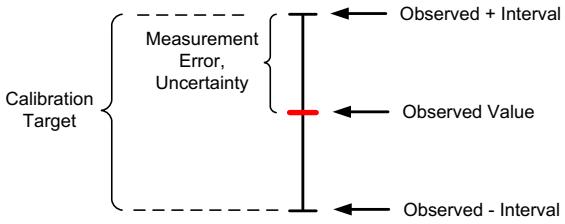
When is a model "calibrated"?

- We should not expect a perfect fit between simulated and observed values due to:
  - Measurement error
  - Simplifying assumptions
  - Uncertainty in inputs (river stages, estimated pumping rates, etc.
- We generally try to get the simulated values within a certain "window" of the field observations:



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Calibration Error Norms

- Mean Error

$$ME=\frac{1}{n}\sum_{i=1}^{n}(h_o - h_c)_i$$

- Mean Absolute Error

$$MAE=\frac{1}{n}\sum_{i=1}^{n}\left|(h_o - h_c)\right|_i$$

- Root Mean Squared Error

$$RMS=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(h_o - h_c)_i^2}$$

Each error norm provides a numerical measure of how well the model is calibrated

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Error Norms, cont.

Weighted errors:

$$ME=\frac{1}{n}\sum_{i=1}^{n} w_i(h_o - h_c)_i$$

$$RMS=\sqrt{\frac{1}{n}\sum_{i=1}^{n} w_i(h_o - h_c)^2_i}$$

$$MAE=\frac{1}{n}\sum_{i=1}^{n} \left|w_i(h_o - h_c)\right|_i$$

where:

w_i = observation weight $= \frac{1}{\sigma_i^2}$

σ_i = standard deviation

Standard deviation can be derived from interval and confidence

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Error Norms, cont.

Sum of Squared Weighted Residuals:

$$Error=\sum_{i=1}^{n_h} w_i(h_o - h_c)_i^2 + \sum_{j=1}^{n_f} w_j(f_o - f_c)_j^2$$

where:

n_h = number of head observations

n_f = number of flow observations

f_c = computed flow

f_o = observed flow

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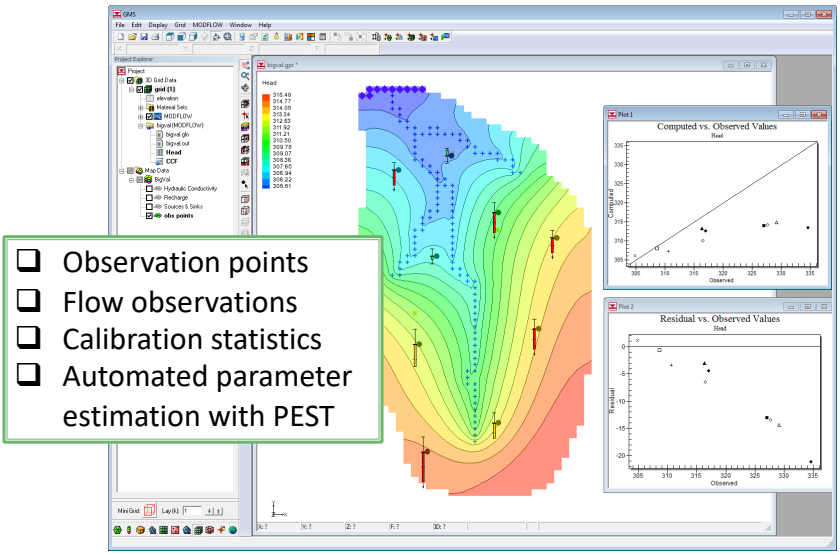
Calibration in GMS



- ❑ Observation points
- ❑ Flow observations
- ❑ Calibration statistics
- ❑ Automated parameter estimation with PEST

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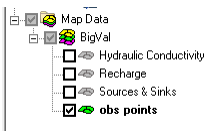
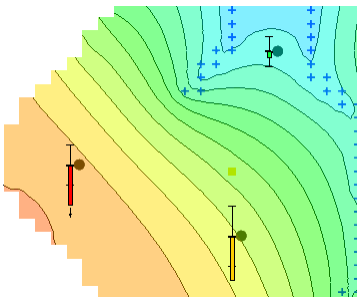
Observation Points

- Primarily used for head values observed in monitoring wells
- Points are contained in an "Observation Coverage" in the Map module





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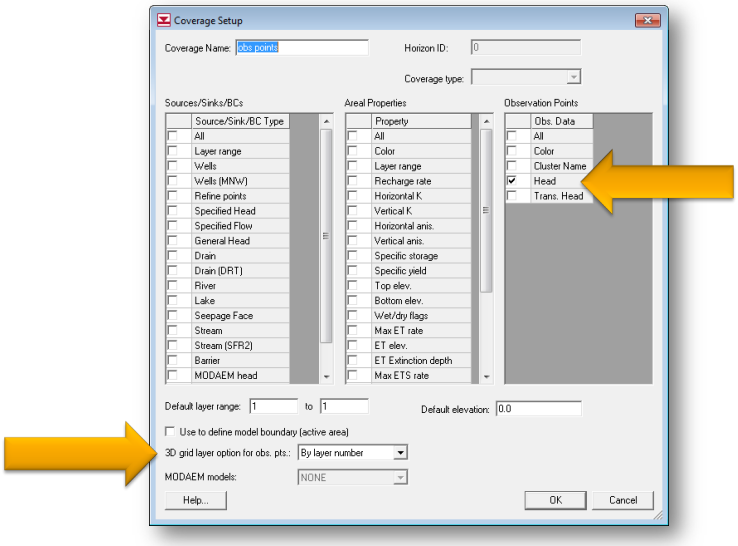
Observation Coverage Setup



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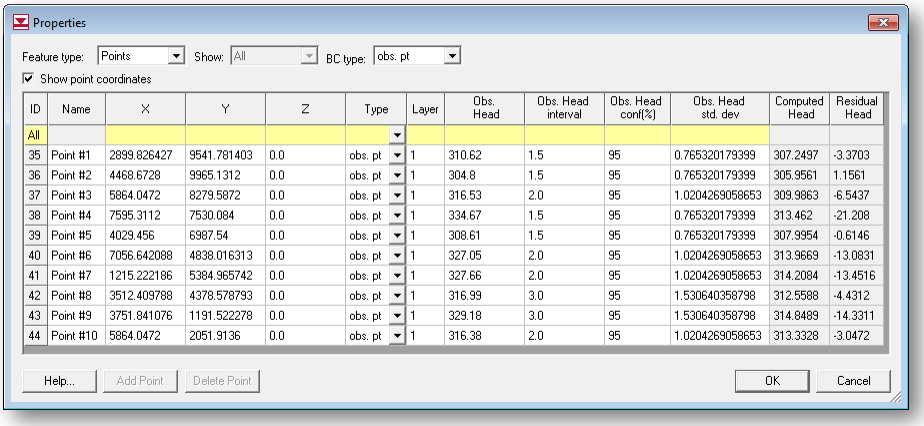
Observation Point Properties



ID	Name	X	Y	Z	Type	Layer	Obs. Head	Obs. Head interval	Obs. Head conf(%)	Obs. Head std. dev	Computed Head	Residual Head
All												
35	Point #1	2899.826427	9541.781403	0.0	obs. pt	1	310.62	1.5	95	0.765320179399	307.2497	-3.3703
36	Point #2	4468.6728	9965.1312	0.0	obs. pt	1	304.8	1.5	95	0.765320179399	305.9561	1.1561
37	Point #3	5864.0472	8279.5872	0.0	obs. pt	1	316.53	2.0	95	1.0204269058653	309.9863	-6.5437
38	Point #4	7595.3112	7530.084	0.0	obs. pt	1	334.67	1.5	95	0.765320179399	313.462	-21.208
39	Point #5	4029.456	6987.54	0.0	obs. pt	1	308.61	1.5	95	0.765320179399	307.9954	-0.6146
40	Point #6	7056.642088	4838.016313	0.0	obs. pt	1	327.05	2.0	95	1.0204269058653	313.9669	-13.0831
41	Point #7	1215.222186	5384.965742	0.0	obs. pt	1	327.66	2.0	95	1.0204269058653	314.2084	-13.4516
42	Point #8	3512.409788	4378.578793	0.0	obs. pt	1	316.99	3.0	95	1.530640358798	312.5588	-4.4312
43	Point #9	3751.841076	1191.522278	0.0	obs. pt	1	329.18	3.0	95	1.530640358798	314.8489	-14.3311
44	Point #10	5864.0472	2051.9136	0.0	obs. pt	1	316.38	2.0	95	1.0204269058653	313.3328	-3.0472

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Importing Calibration Points

- Can be entered/organized in spreadsheet
- Import options
  - Save to *.txt file and open using *Text Import Wizard*
  - Cut and paste directly to *Properties* dialog

	A	B	C	D	E	F	G	H	I
1	ID	Name	X	Y	Z	Layer	Head	Interval	Conf.
2	1	Point #1	2899.8	9541.8	876.3	1	310.62	1.5	0.95
3	2	Point #2	4468.7	9965.1	877.2	1	304.8	1.5	0.95
4	3	Point #3	5864.0	8279.6	850.1	2	316.53	2	0.95
5	4	Point #4	7595.3	7530.1	901.7	1	334.67	1.5	0.95
6	5	Point #5	4029.5	6987.5	872.1	1	308.61	1.5	0.95
7	6	Point #6	7056.6	4838.0	903.4	1	327.05	2	0.95
8	7	Point #7	1215.2	5385.0	885.9	1	327.66	2	0.95
9	8	Point #8	3512.4	4378.6	845.2	2	316.99	3	0.95
10	9	Point #9	3751.8	1191.5	883.1	1	329.18	3	0.95
11	10	Point #10	5864.0	2051.9	892.7	1	316.38	2	0.95
12									

Required. All other columns are optional.

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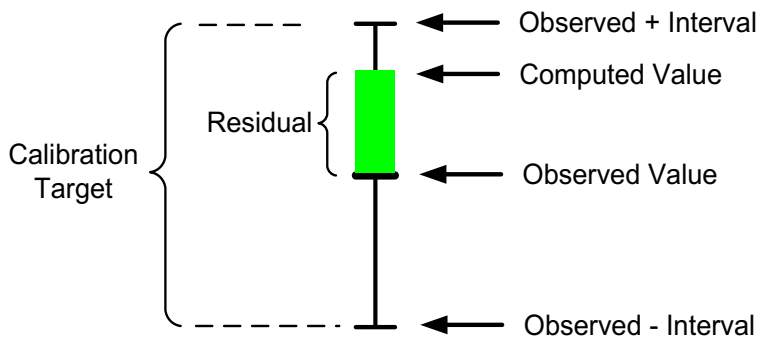
Calibration Targets



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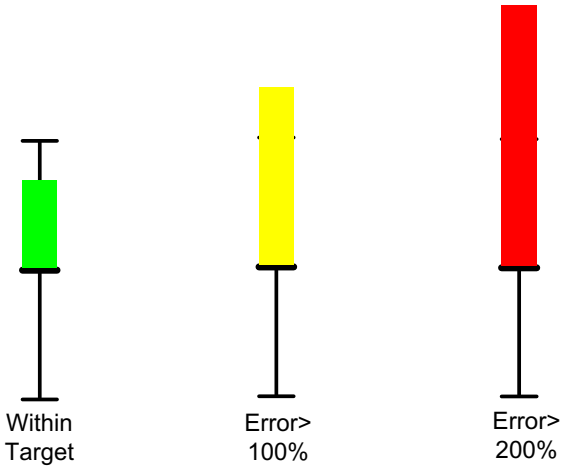
Magnitude of Error



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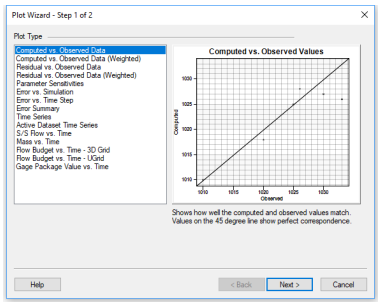
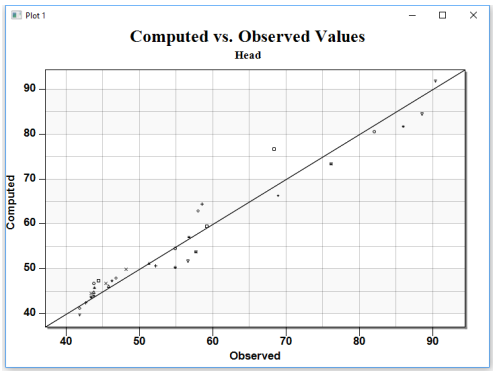
Calibration Statistics Plots

- Click on *Create Plot* macro 
- Select plot type





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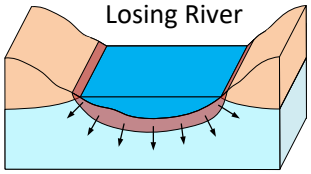
Flow Observations

- Represents
  - Gain/loss in streams
  - Gain/loss in reservoirs and lakes
- If flow observations are not included, the solution may be **non-unique**



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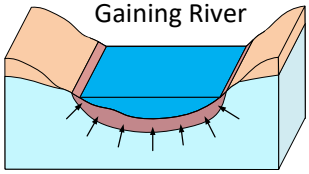

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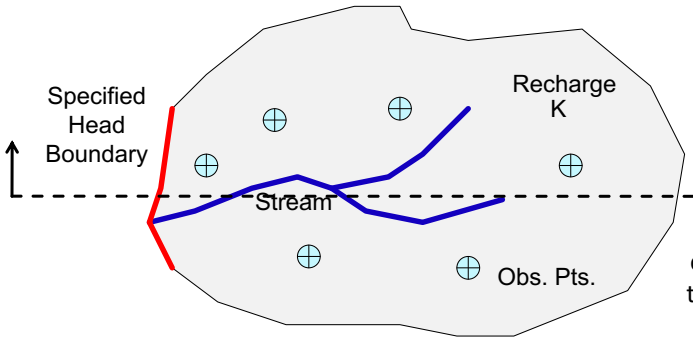
Model Uniqueness

Consider a model of a basin where the only input is recharge. Water leaves system through stream and spec. head boundary. Main parameters are recharge and K.



Let's look at cross section through main axis of site (next slide)

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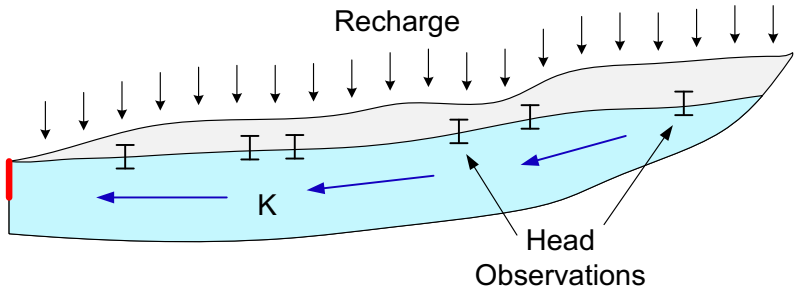
Model Uniqueness



- Calibration is achieved by adjusting parameters so that the water table raises or lowers until it fits the head observations
- In order to lower water table:
  - Increase K (water leaves system more rapidly)
  - Reduce Recharge (less water entering system)
- In order to raise water table:
  - Decrease K (causes water to mound)
  - Increase Recharge (causes water to mound)

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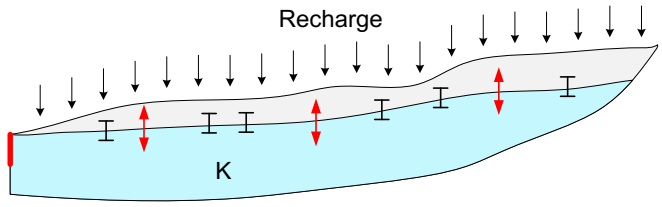
Model Uniqueness



- Looking at head observations only, calibration can be achieved via:
  - Low K, low recharge
  - High K, high recharge
- Theoretically, there are an infinite number of combinations of recharge/K that will "calibrate" the model

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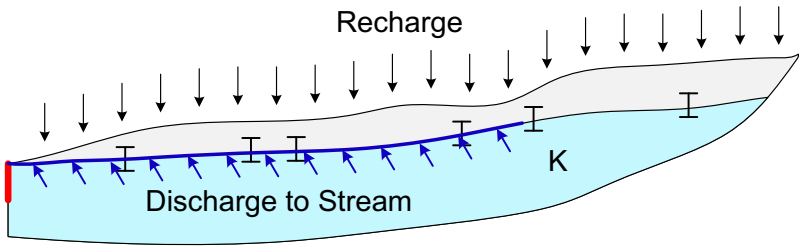
Model Uniqueness



- If we include a flow observation for the stream, we eliminate one unknown/degree of freedom from the system since the **recharge** then becomes fixed.
- The only remaining unknown is then the hydraulic conductivity (**K**) and the number of combinations of parameters resulting in "calibration" is drastically reduced

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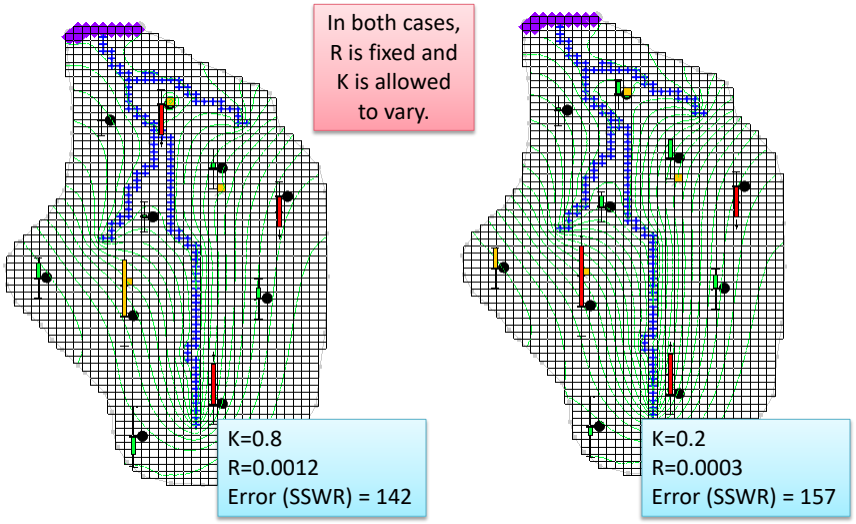
Example



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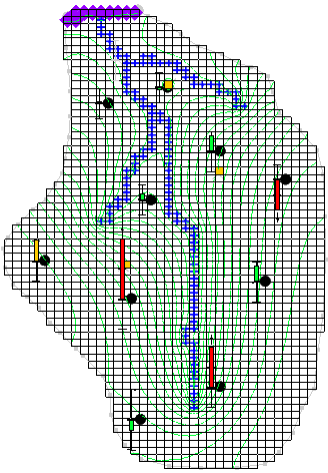
Example, cont.



In this case, we add a flow observation to the river network and solve again for K and R

K=0.42
R=0.00067
Error (SSWR) = 125 (including flow error)

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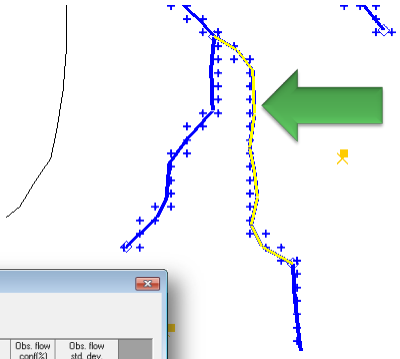
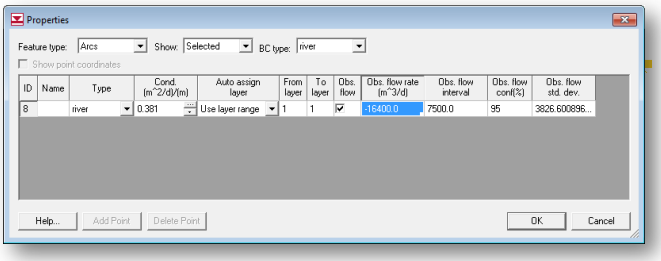
Observed Flows

Assigned to arcs and polygons in source/sink coverage





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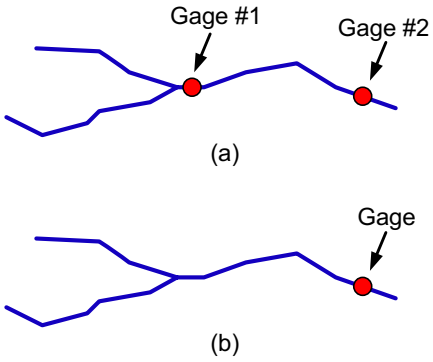
Arc Groups

- Observed flows may span multiple arcs
- Arc group must be defined so that computed flow is summed correctly

Create Group
  Select arcs
  Select *Create Arc Group*
Assign Flow
  Select with *Select Arc Group* tool



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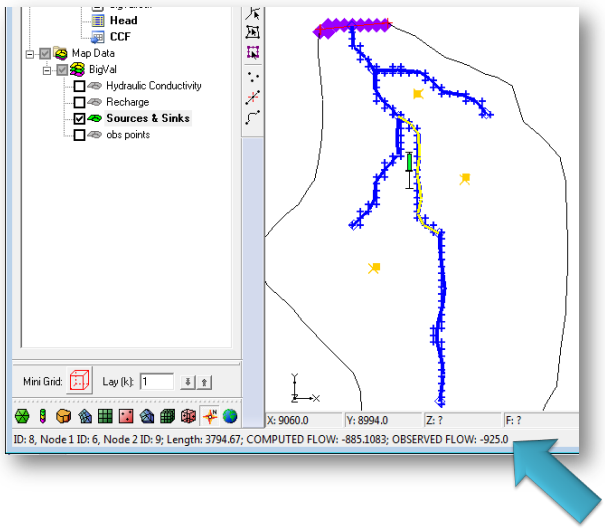
Displaying Computed Flows



Selecting object displays flow

Multi-select for total flow

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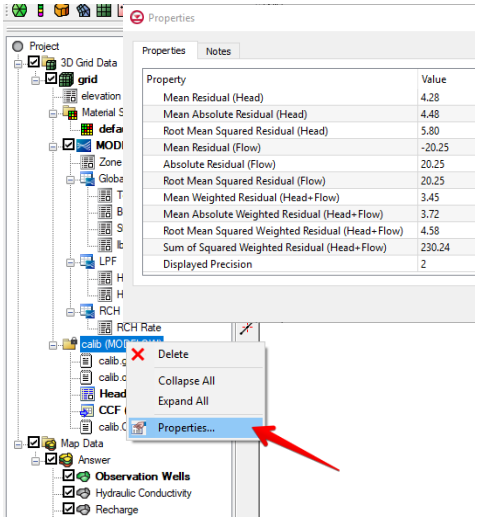
Comprehensive Error Summary

- Right-click on solution folder in Project Explorer window
- Select Properties



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