A DISTANCE-DRAWDOWN ANALYSIS PROCEDURE TO IDENTIFY THE EFFECTS OF BEDDING-PLANE FRACTURES AND IMPROVE THE ESTIMATES OF HYDRAULIC PROPERTIES IN THE PALEOZOIC BEDROCK AQUIFERS OF SOUTHEASTERN MINNESOTA

An investigation of the impact of well efficiency on the variability of hydraulic properties

MINNESOTA MDH DEPARTMENT OF HEALTH

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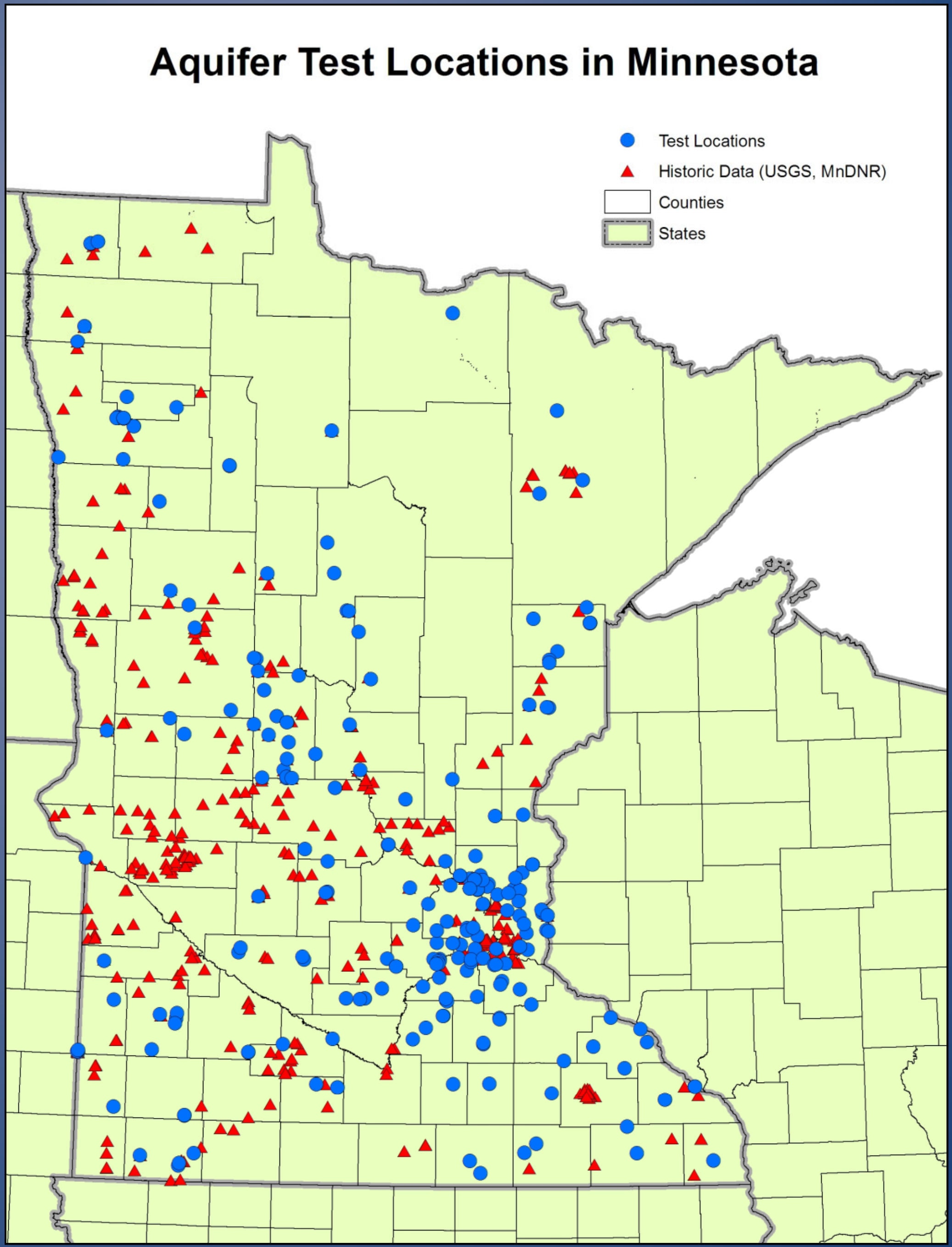
USED EXISTING DATA SETS

About 900 total tests (that we know of)

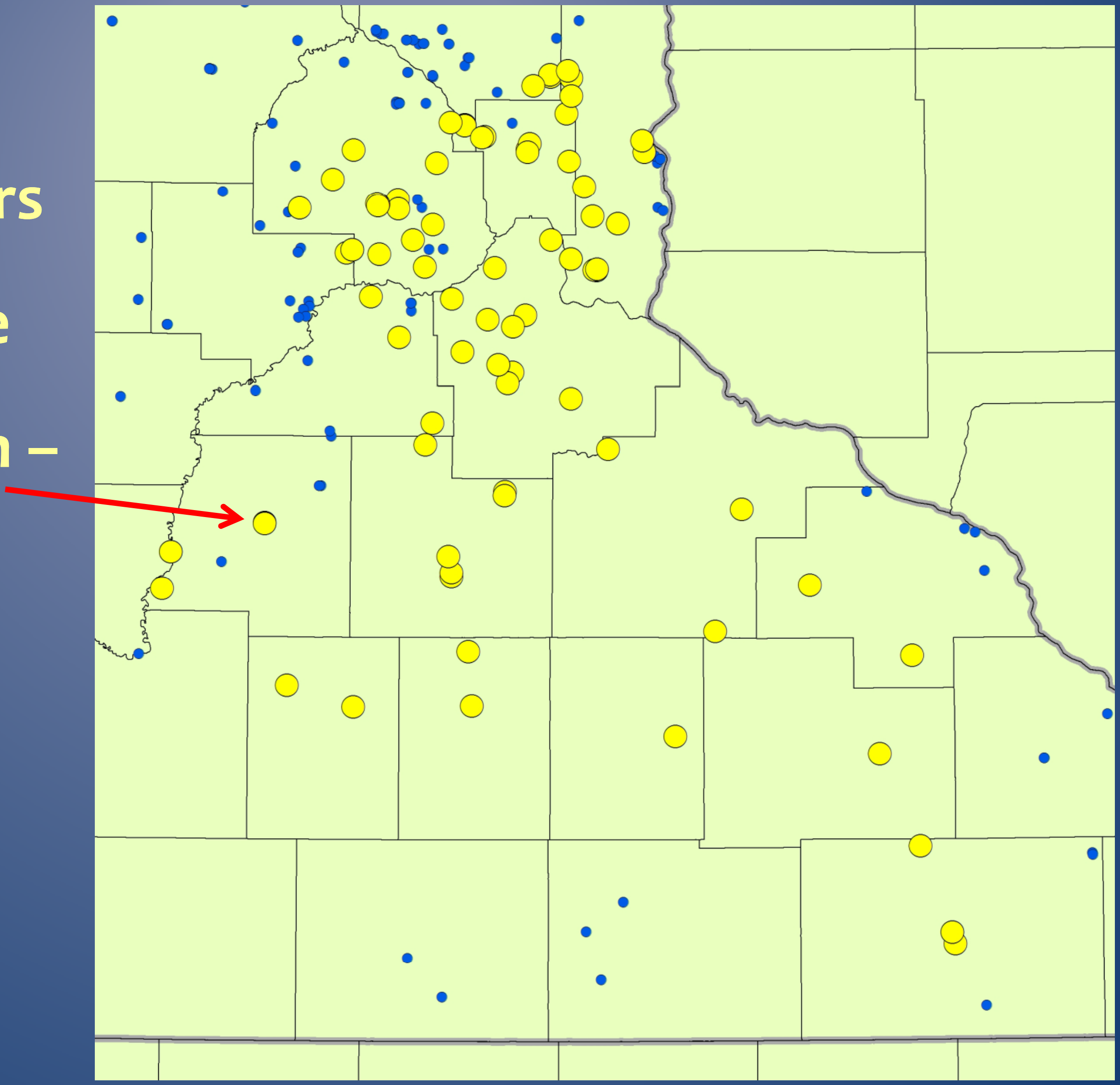


~490 WITH UNIQUE WELL NUMBERS

~190 tests in bedrock aquifers

~ 90 tests in the St. Peter – Prairie du Chien – Jordan Aquifer System

~10 tests re-evaluated, so far



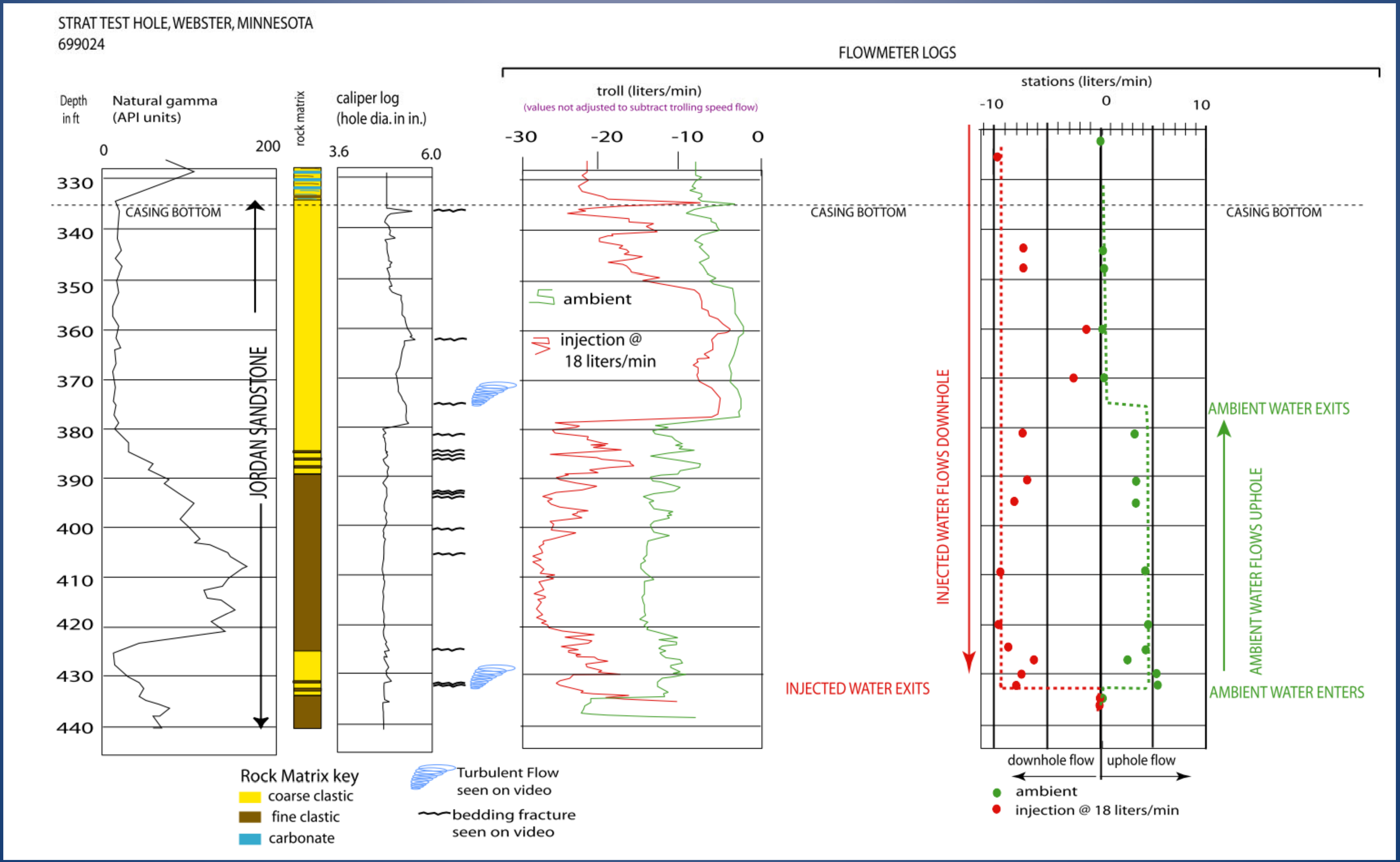
HOW DO WE KNOW THERE IS FRACTURE FLOW?

- **MGS has Identified Bedding-Plane Fractures in Bedrock**

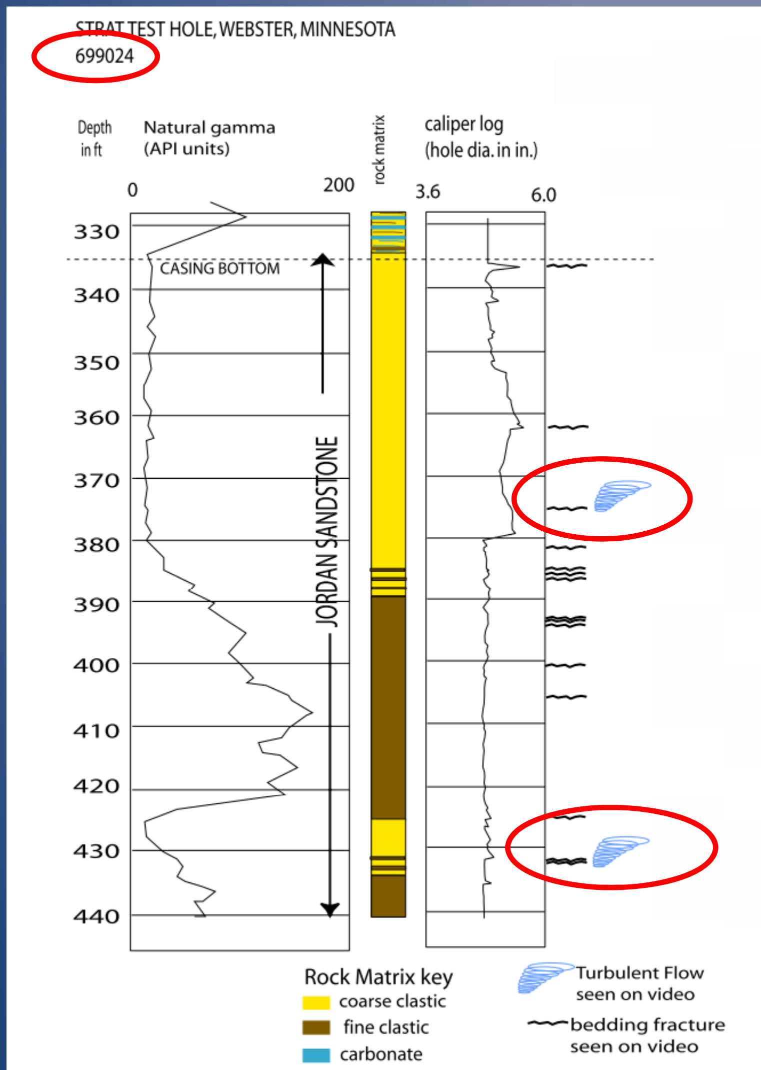
  “Every Place we looked.”

- **Other lines of evidence, primarily hydraulic response**

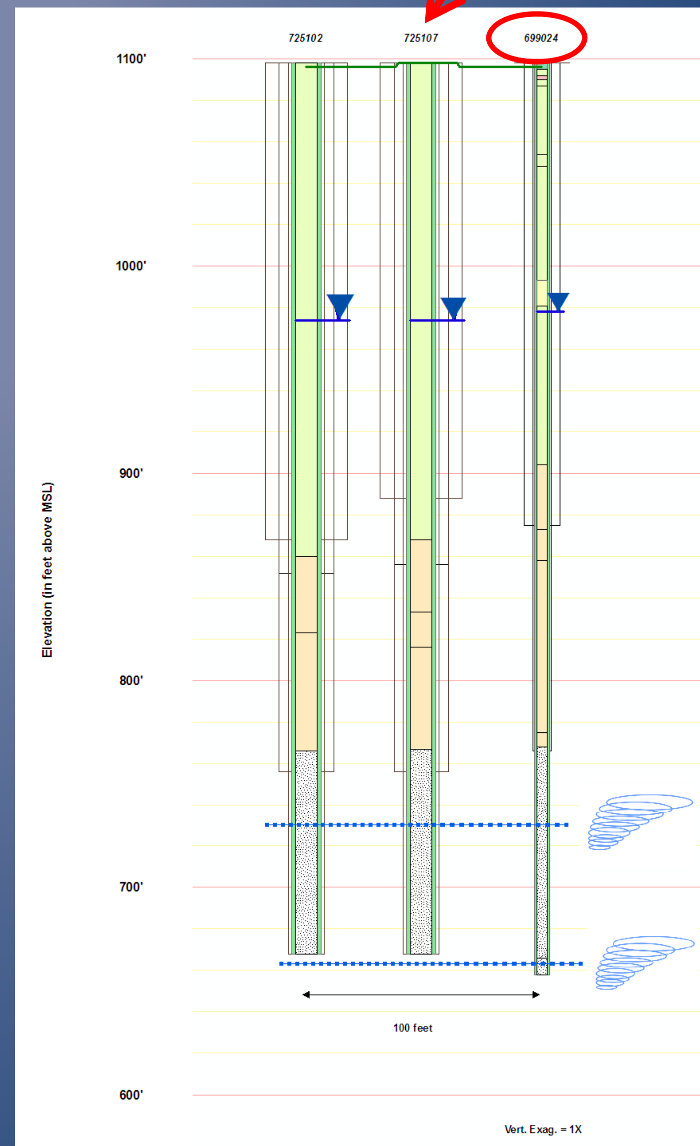
GEOPHYSICAL LOGGING
JORDAN SANDSTONE



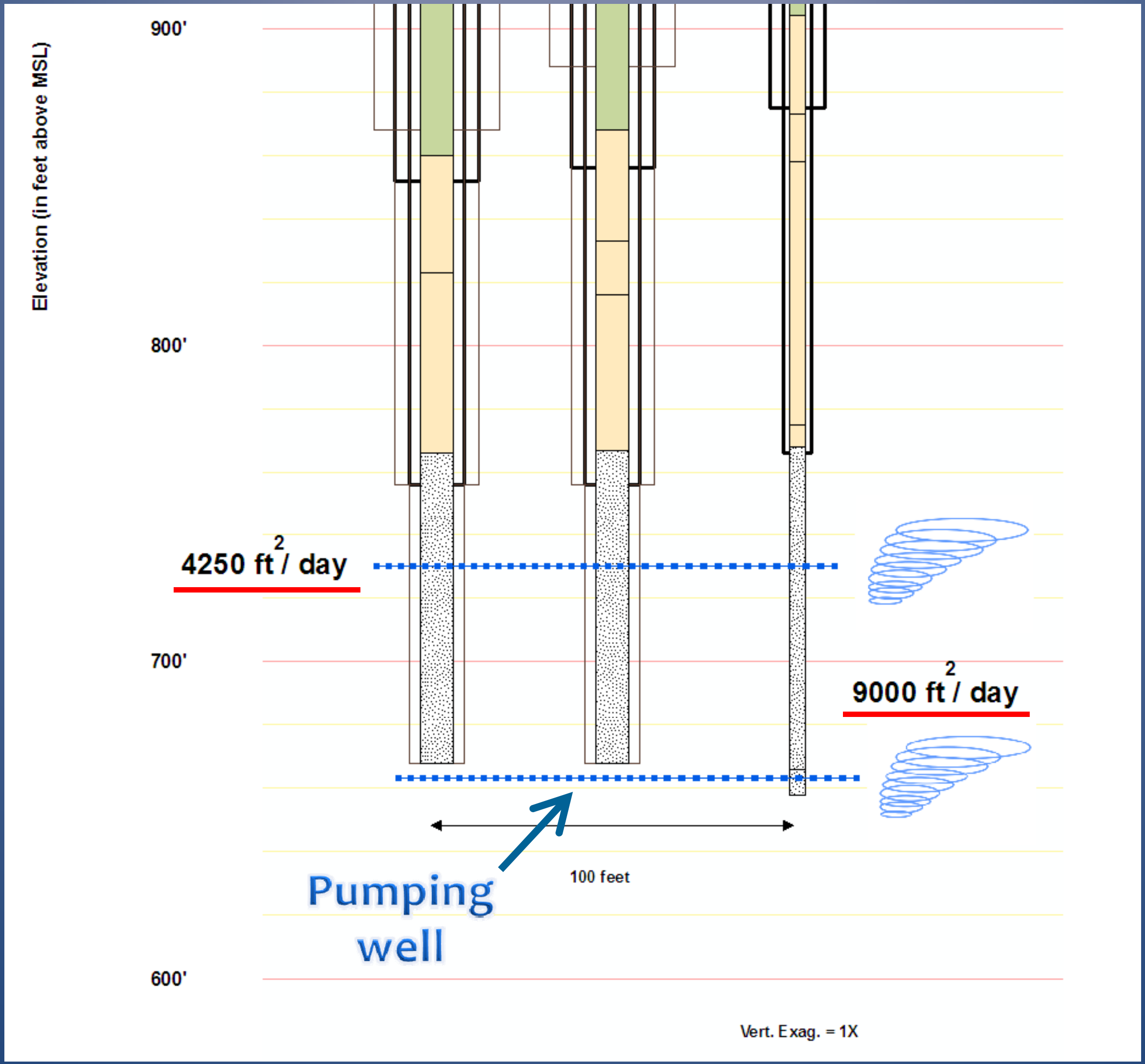
COMPARISON OF FLOW LOGGING AND RESULTS OF PRODUCTION TEST



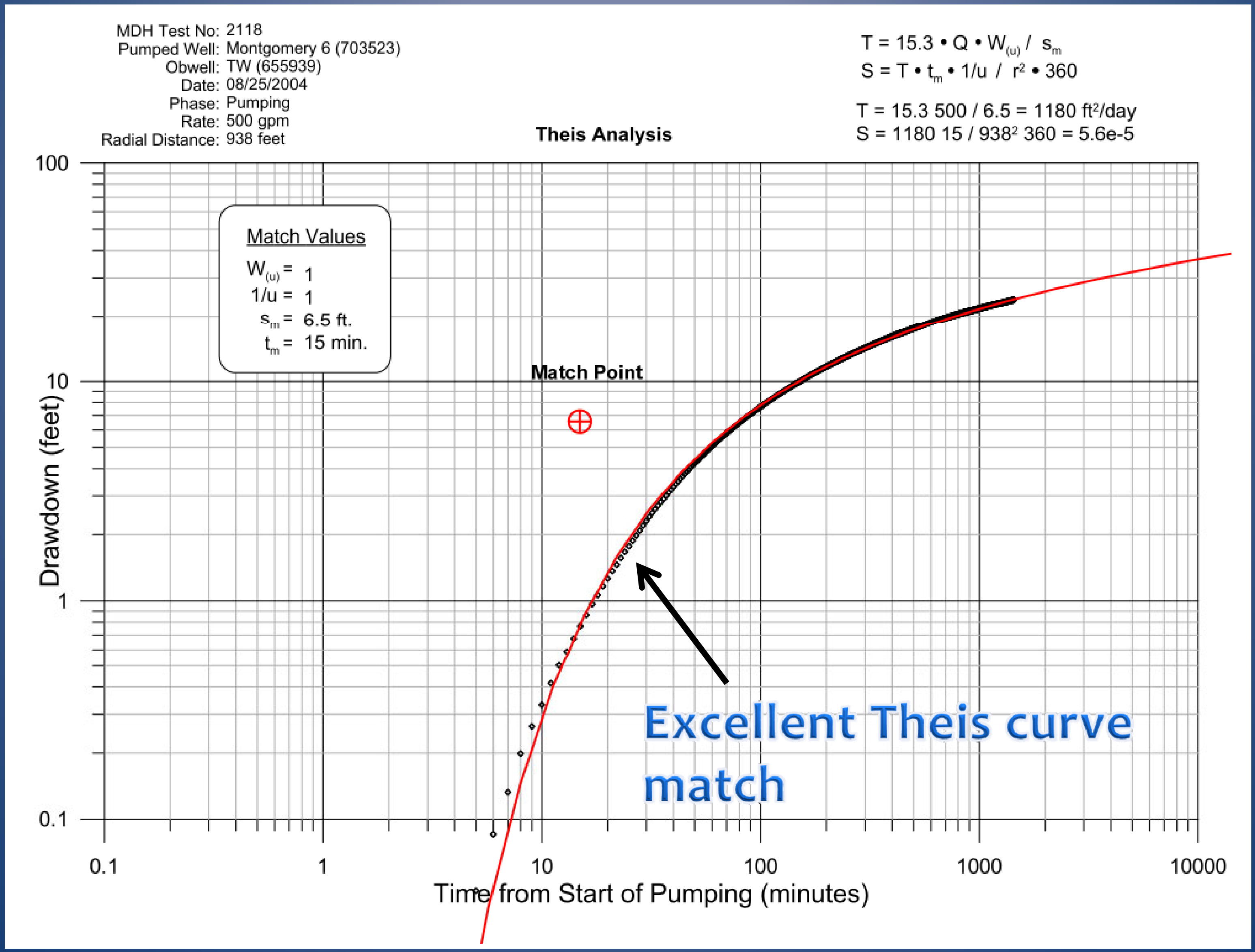
Pumping well



HIGH VARIABILITY IN PROPERTIES BETWEEN WELLS, DURING TEST OF THIRD WELL

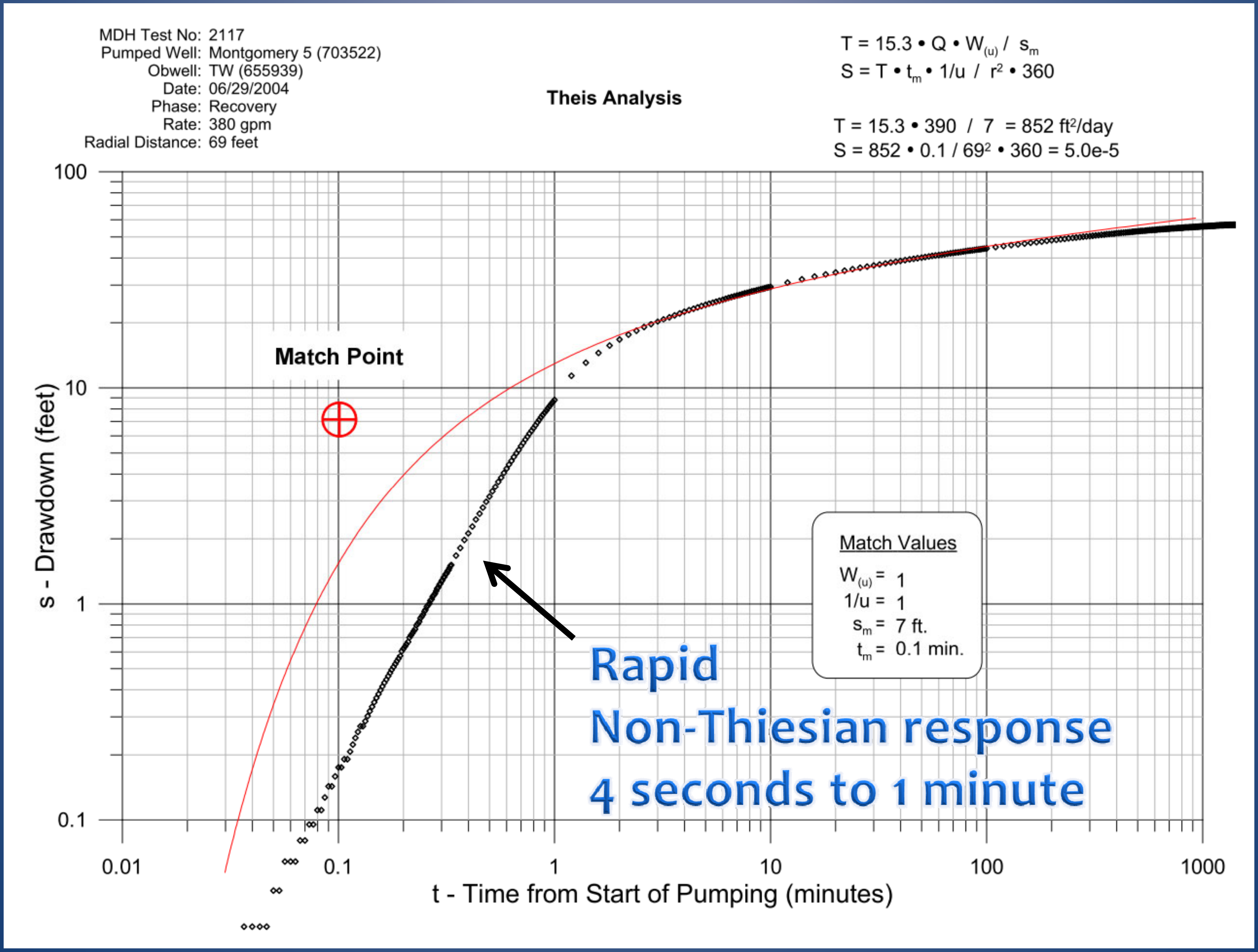


HYDRAULIC RESPONSE OF POROUS MEDIA FLOW
WONEWOC SANDSTONE - RADIAL DISTANCE 940 FT.

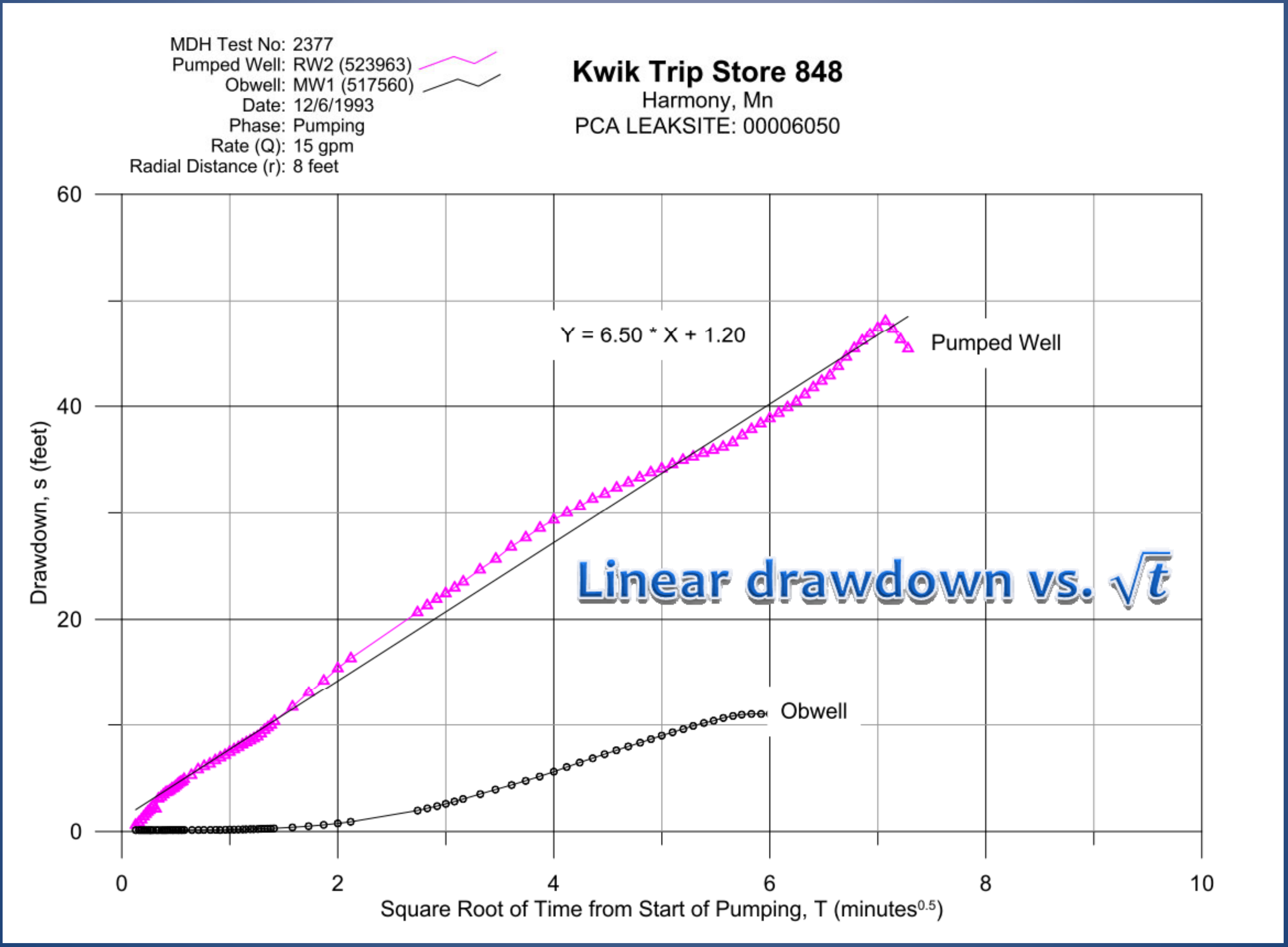


HYDRAULIC RESPONSE OF FRACTURE FLOW

WONEWOC SANDSTONE - RADIAL DISTANCE 70 FT.



HYDRAULIC RESPONSE OF FRACTURE FLOW
GALENA GROUP



HYDRAULIC INDICATORS OF FRACTURE FLOW

- **Large differences in transmissivity over short distances and/or differences in open interval**
- **Non-Thiesian response in early-time**
- **Linear drawdown versus $\sqrt{t}$**

And, possibly

- **Unreasonably large well efficiency**

ANOMALOUS HIGH-EFFICIENCY WELLS RESULT FROM AN ENHANCED WELLBORE:

- **Common well construction techniques such as ‘blasting and bailing’**

– And / or –

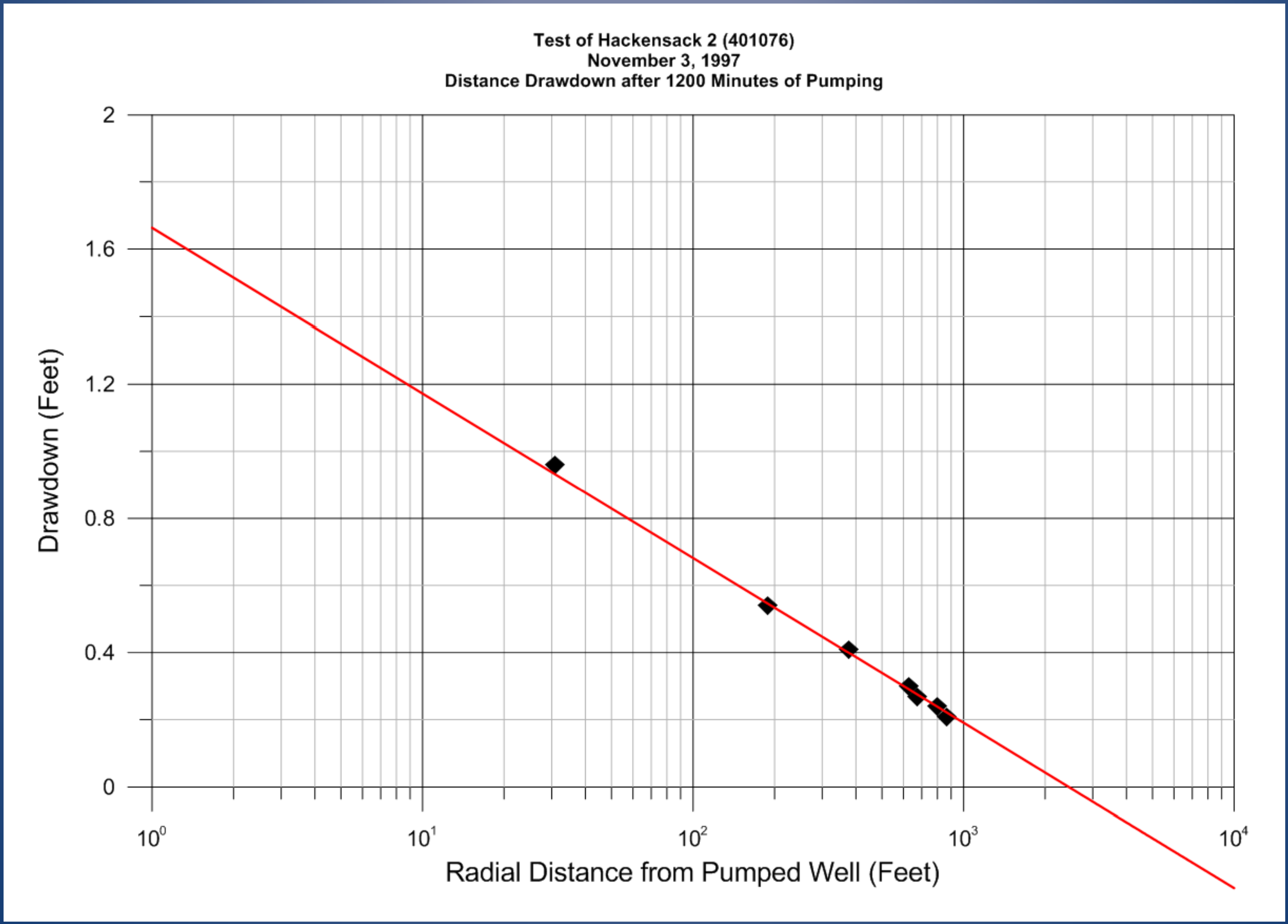
- **Naturally occurring bedding-plane fractures**
- **Result in an increased surface area of aquifer available to the well**

QUESTIONS

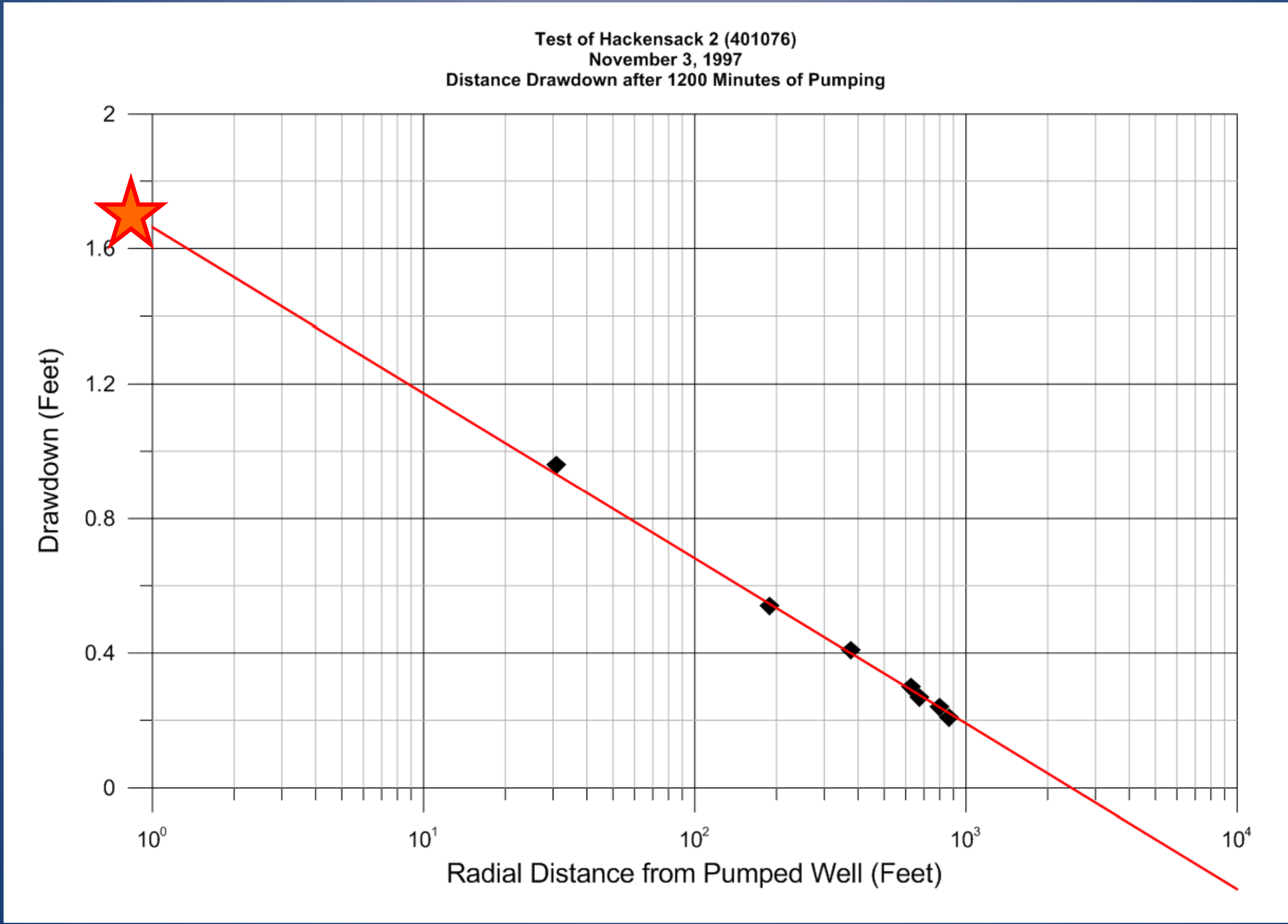
IMPACT OF HIGH WELL EFFICIENCY ON:

- **Drawdown at the pumping well?**
- **Drawdowns at nearby observation wells?**
- **Estimates of hydraulic properties?**

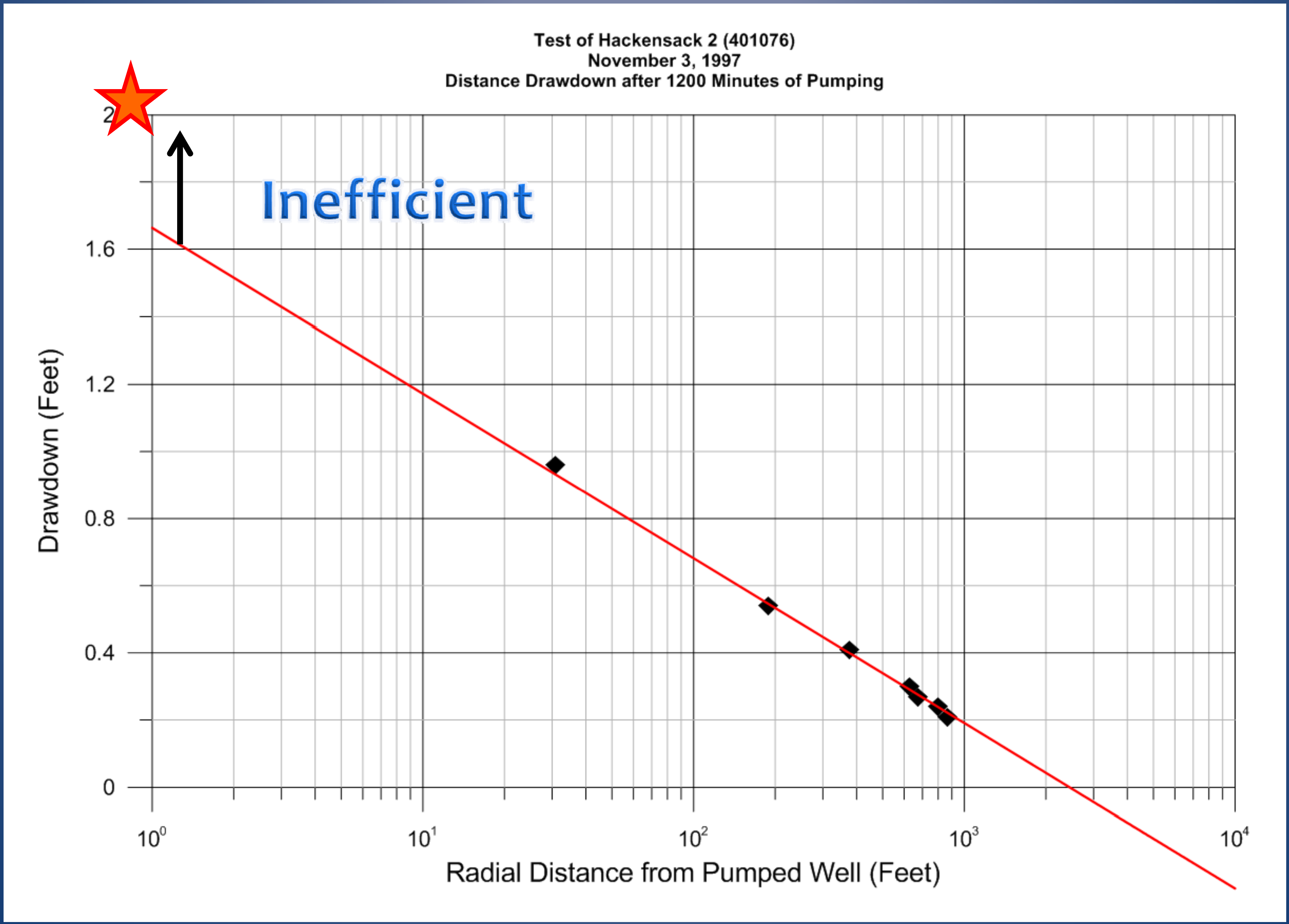
WHAT IT IS 'SUPPOSED TO' LOOK LIKE
- DATA FROM TEST IN GLACIAL OUTWASH -



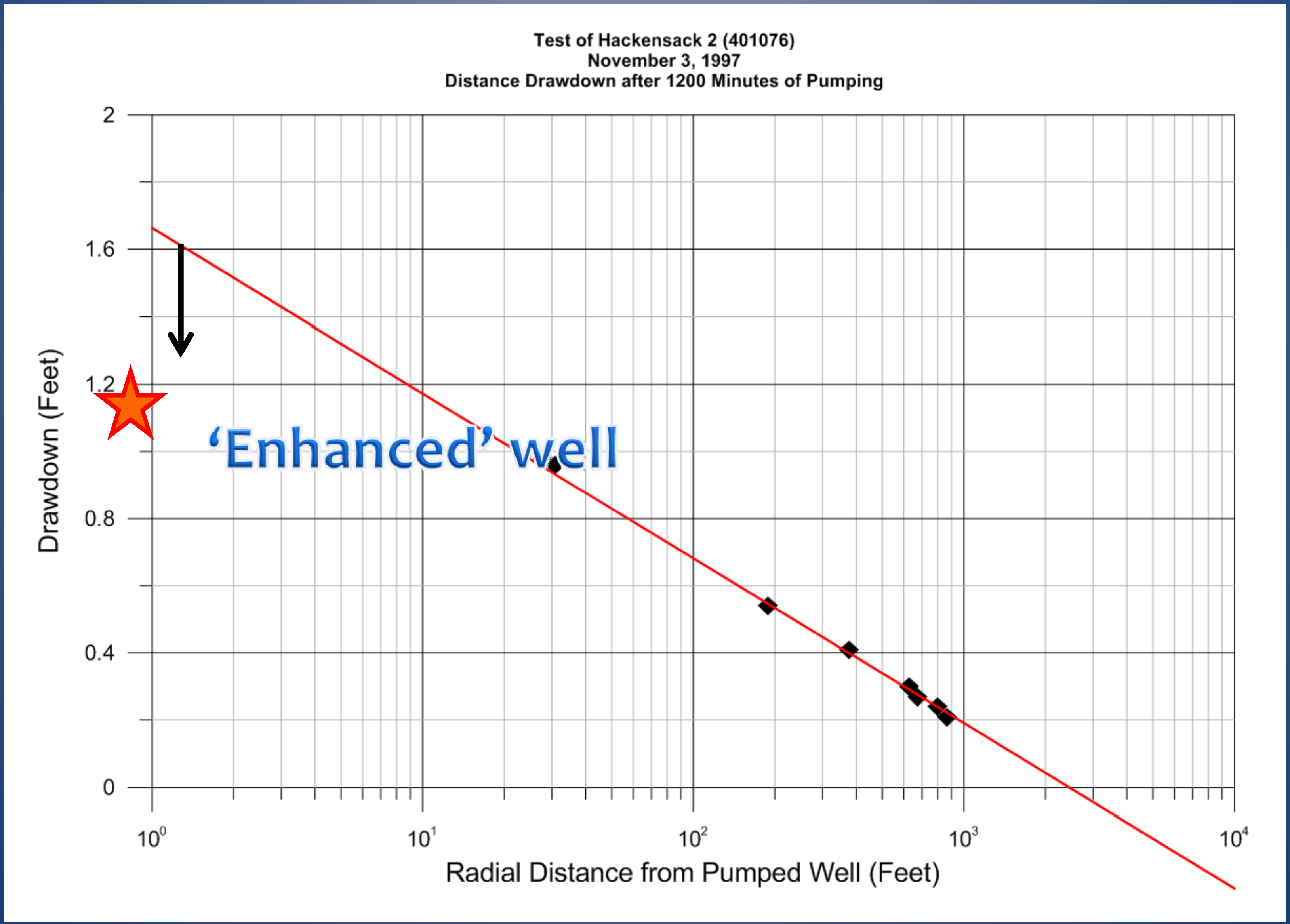
DRAWDOWN IN A 100 % EFFICIENT PUMPING WELL



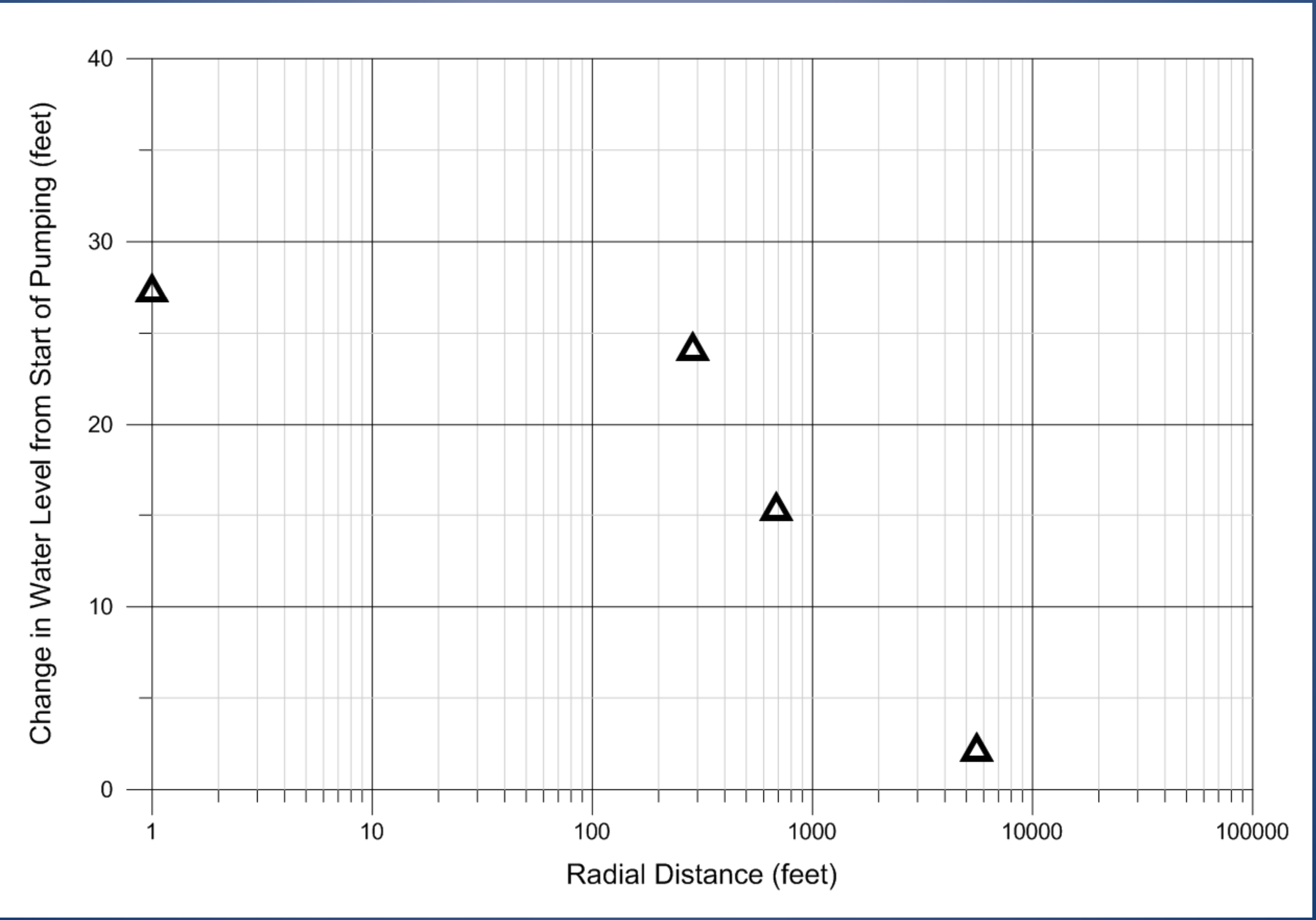
DRAWDOWN IN AN INEFFICIENT PUMPING WELL



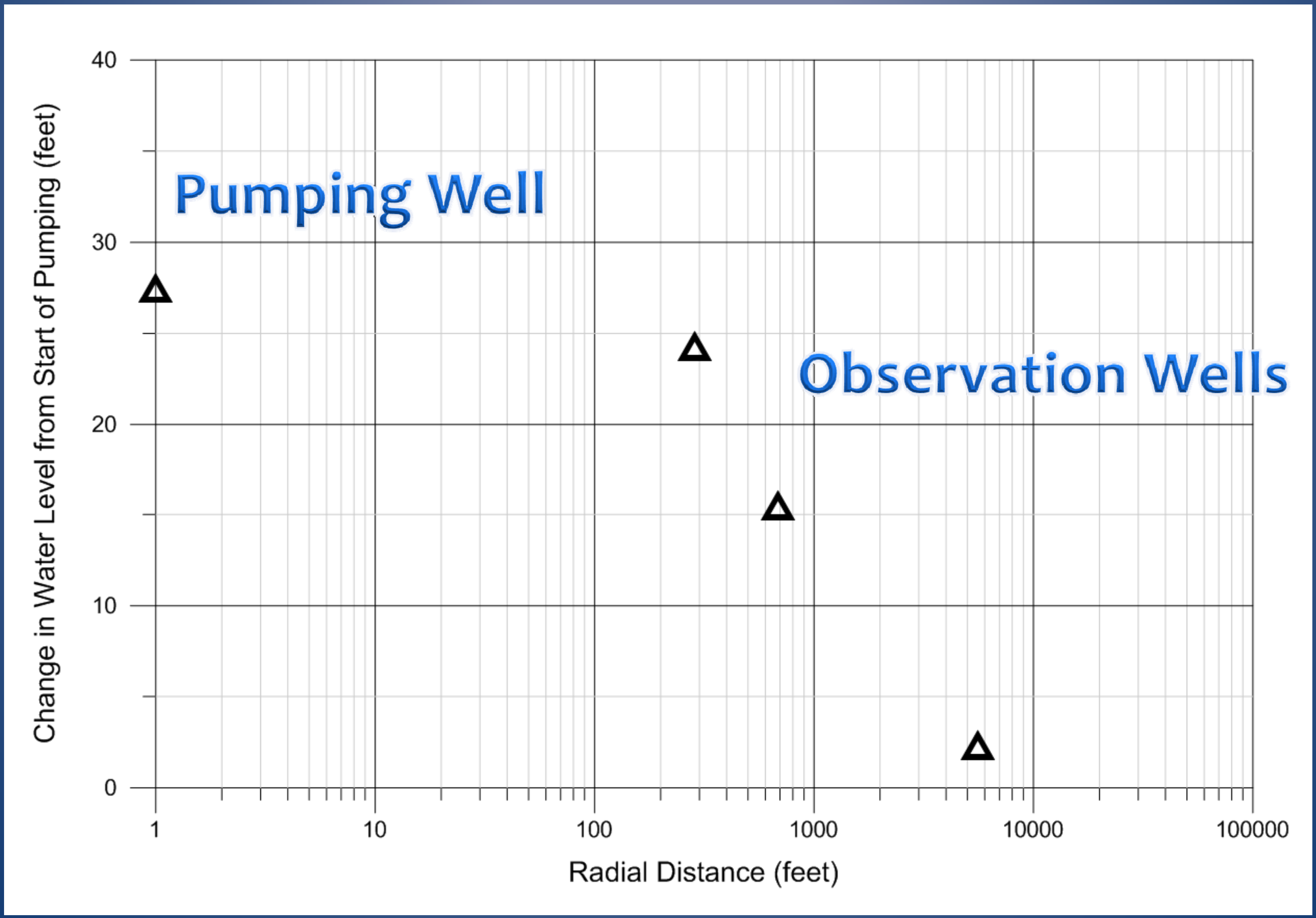
DRAWDOWN IN AN 'ENHANCED' PUMPING WELL



TEST DATA FROM CANNON FALLS PWS WELLS, 1999
JORDAN SANDSTONE

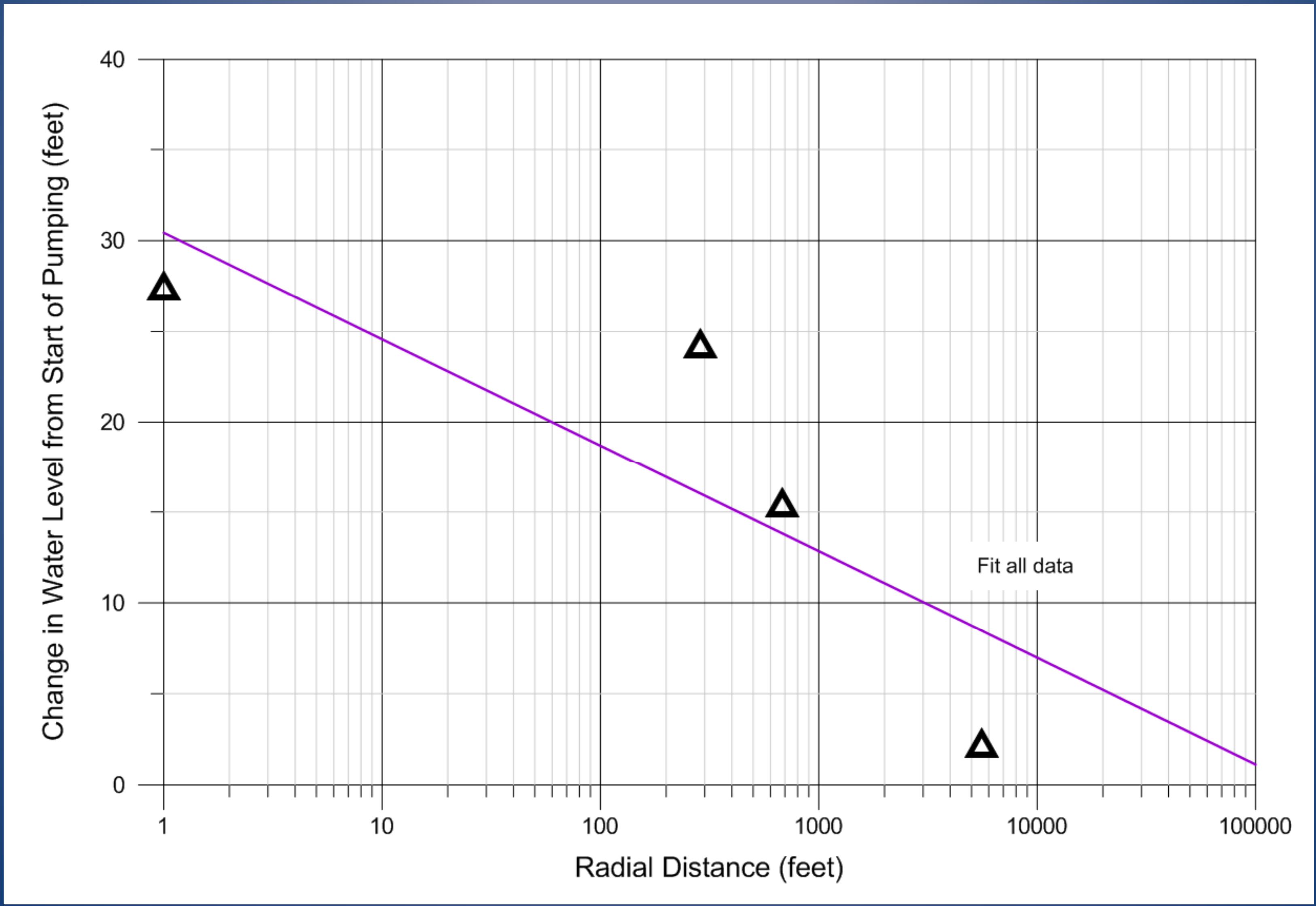


‘TYPICAL’ OBSERVED DISTANCE–DRAWDOWN RELATIONSHIP

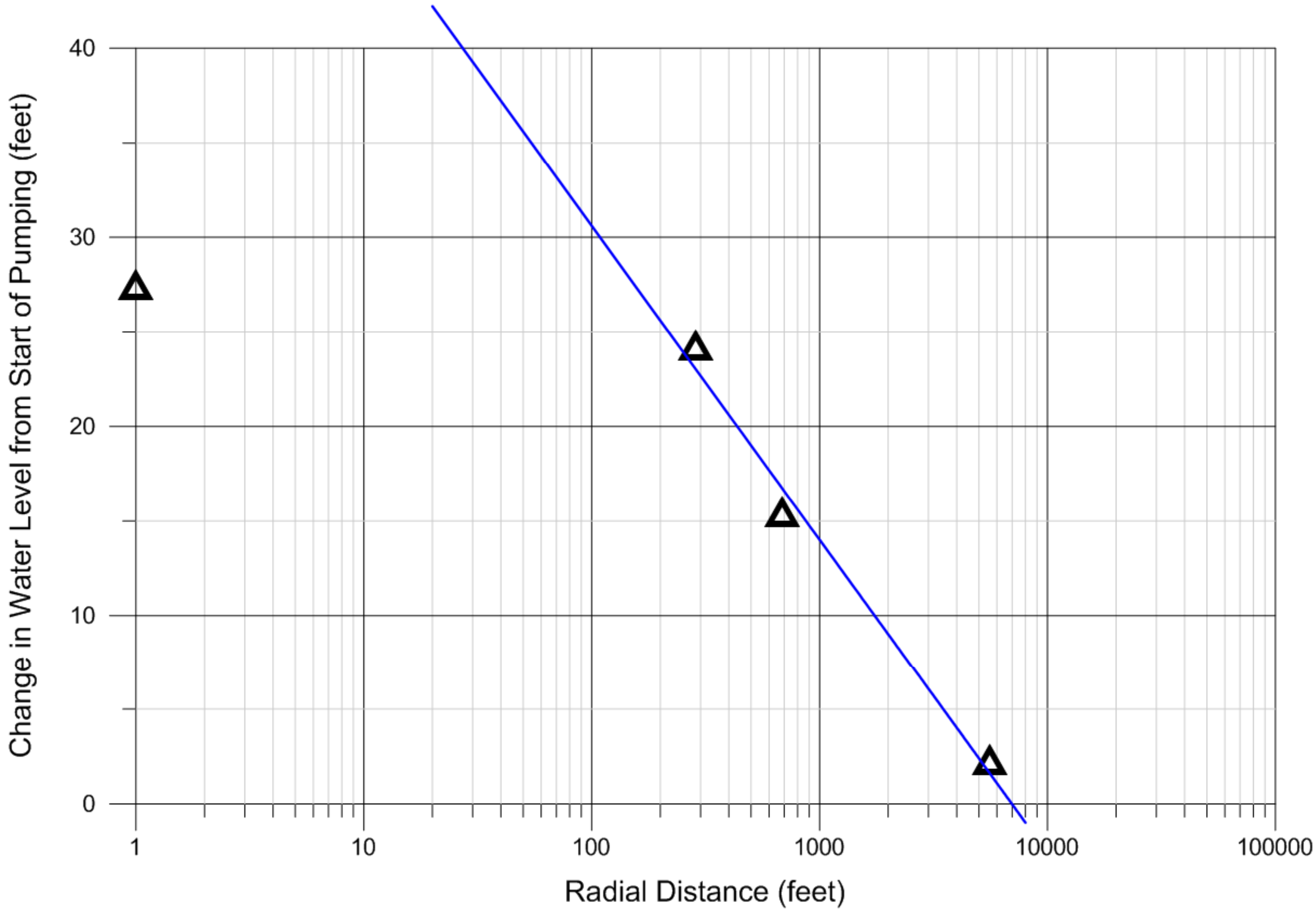


NOT A GOOD FIT

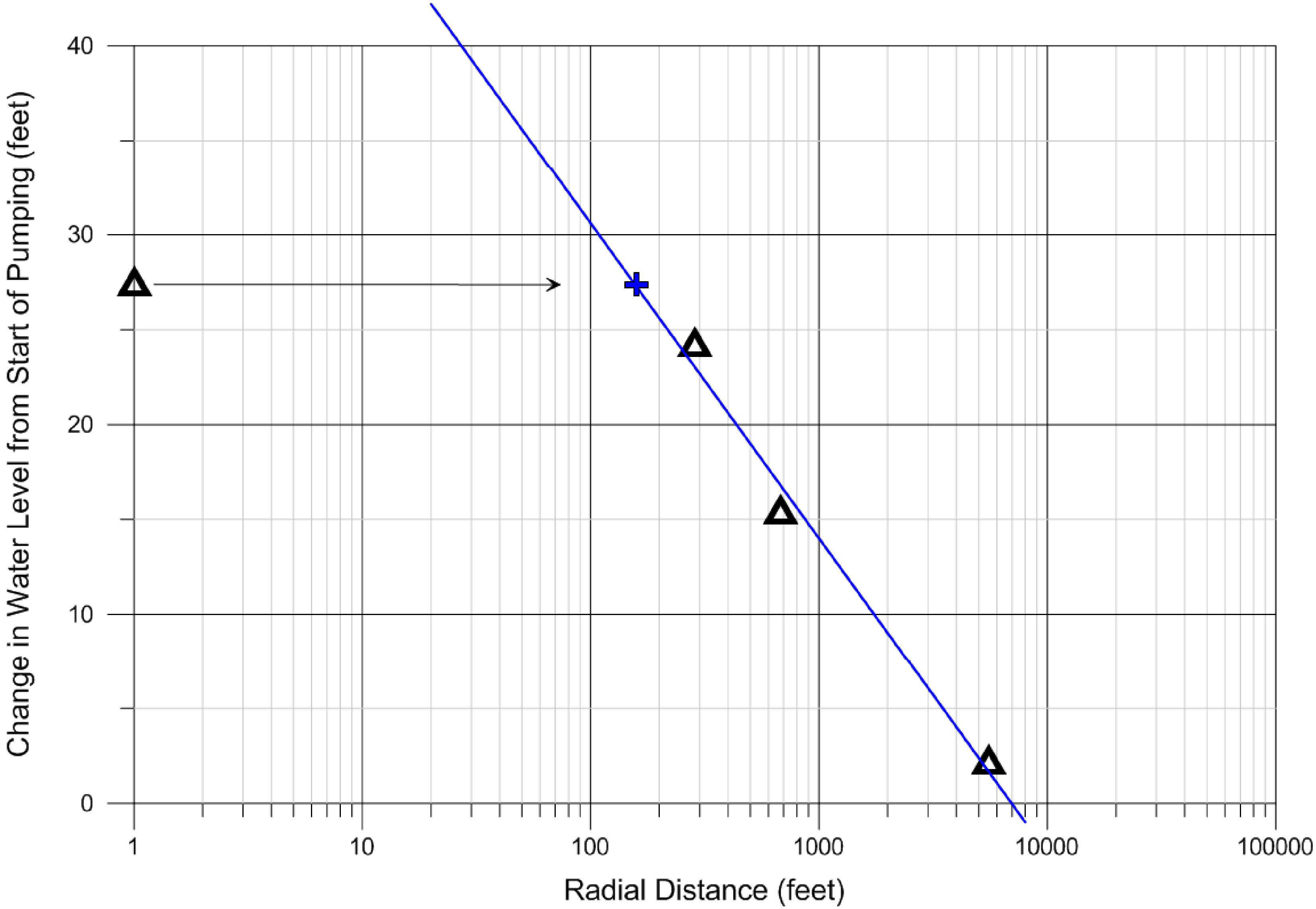
Breakdown of logarithmic relationship between drawdown and distance?



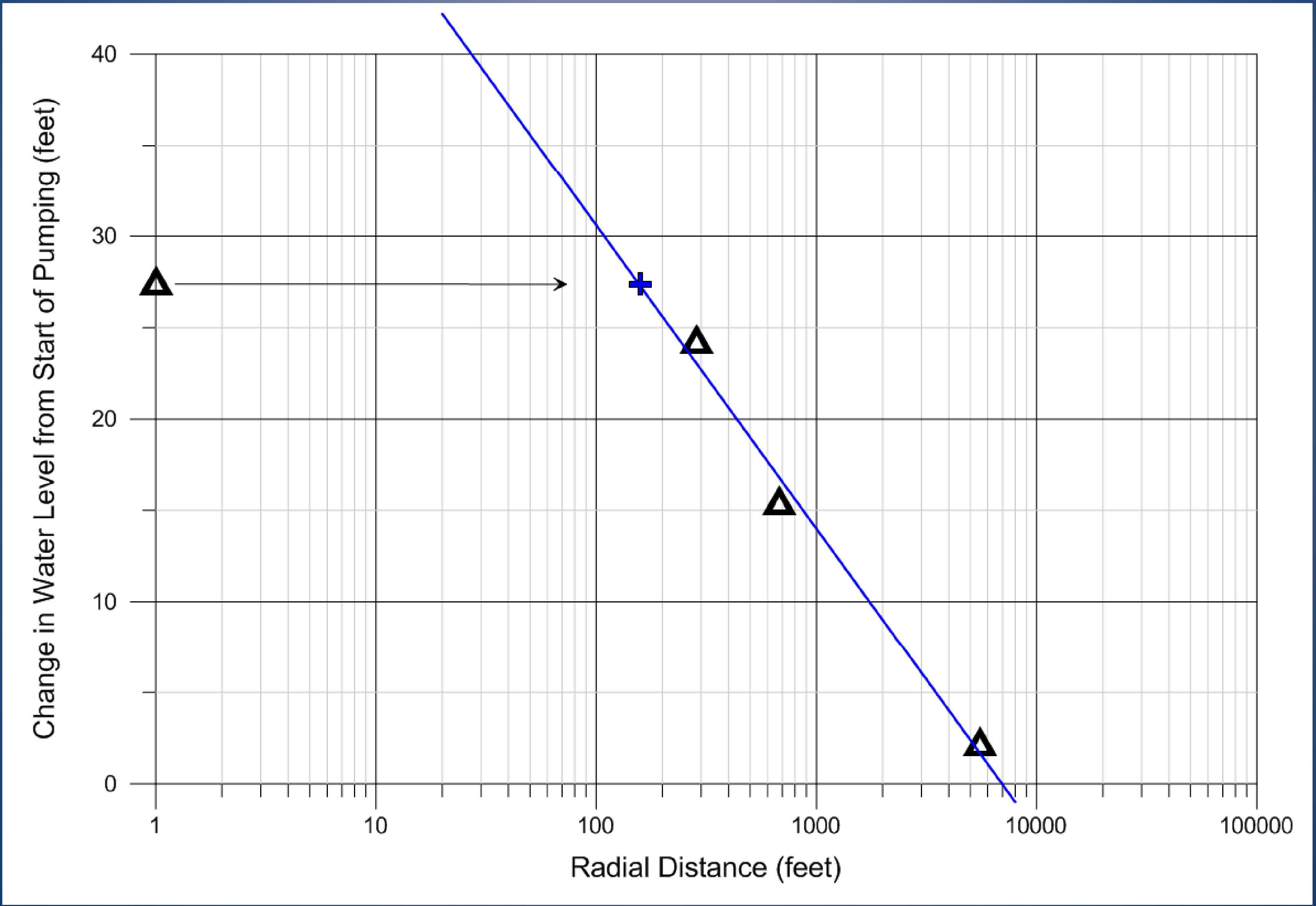
MATCH OBWELL DATA ONLY, BETTER FIT



WHY IS PUMPED WELL SO EFFICIENT?



WHAT IS THE 'EFFECTIVE RADIUS' OF THE WELL?

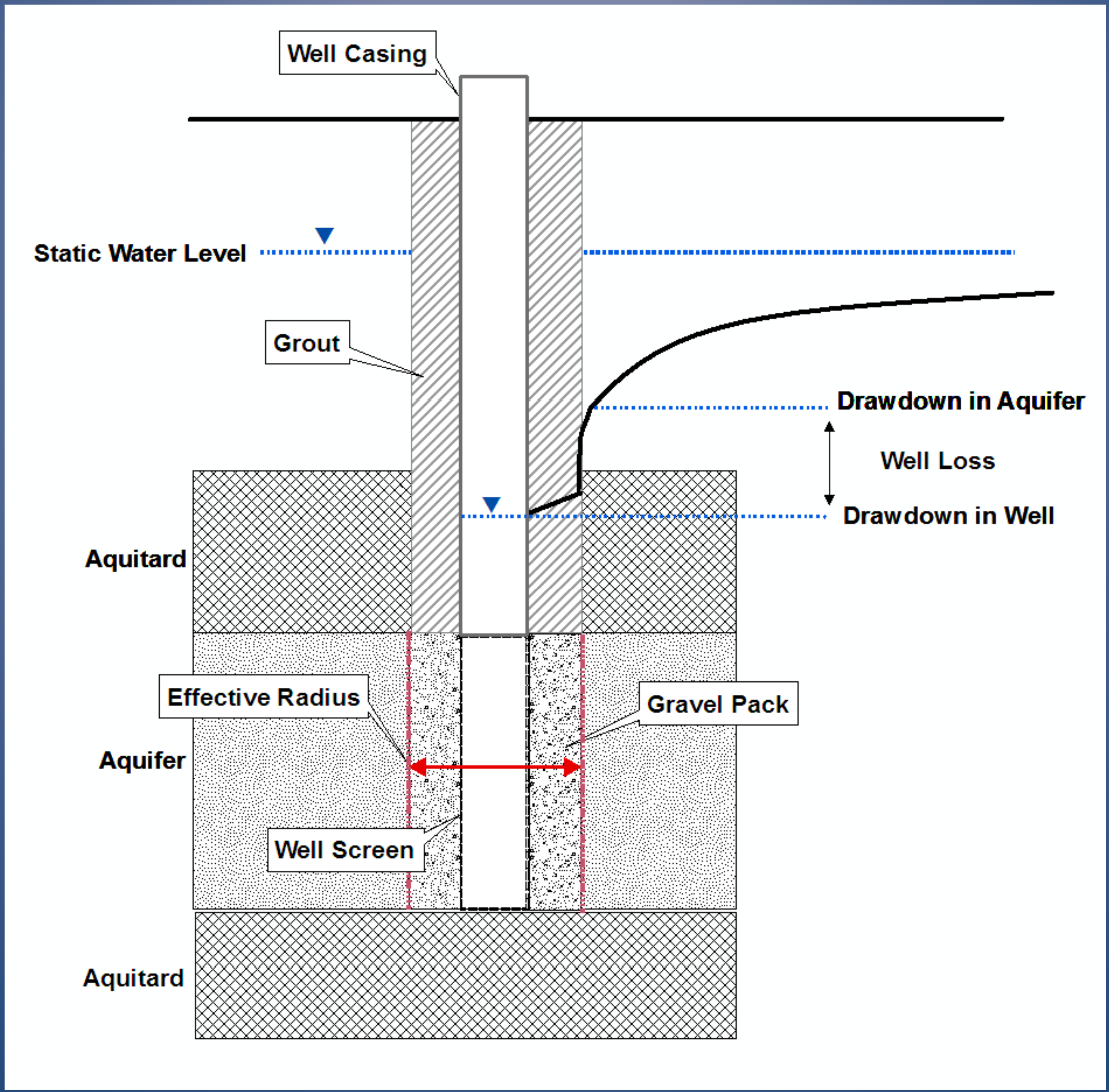


DEFINITION IN LITERATURE

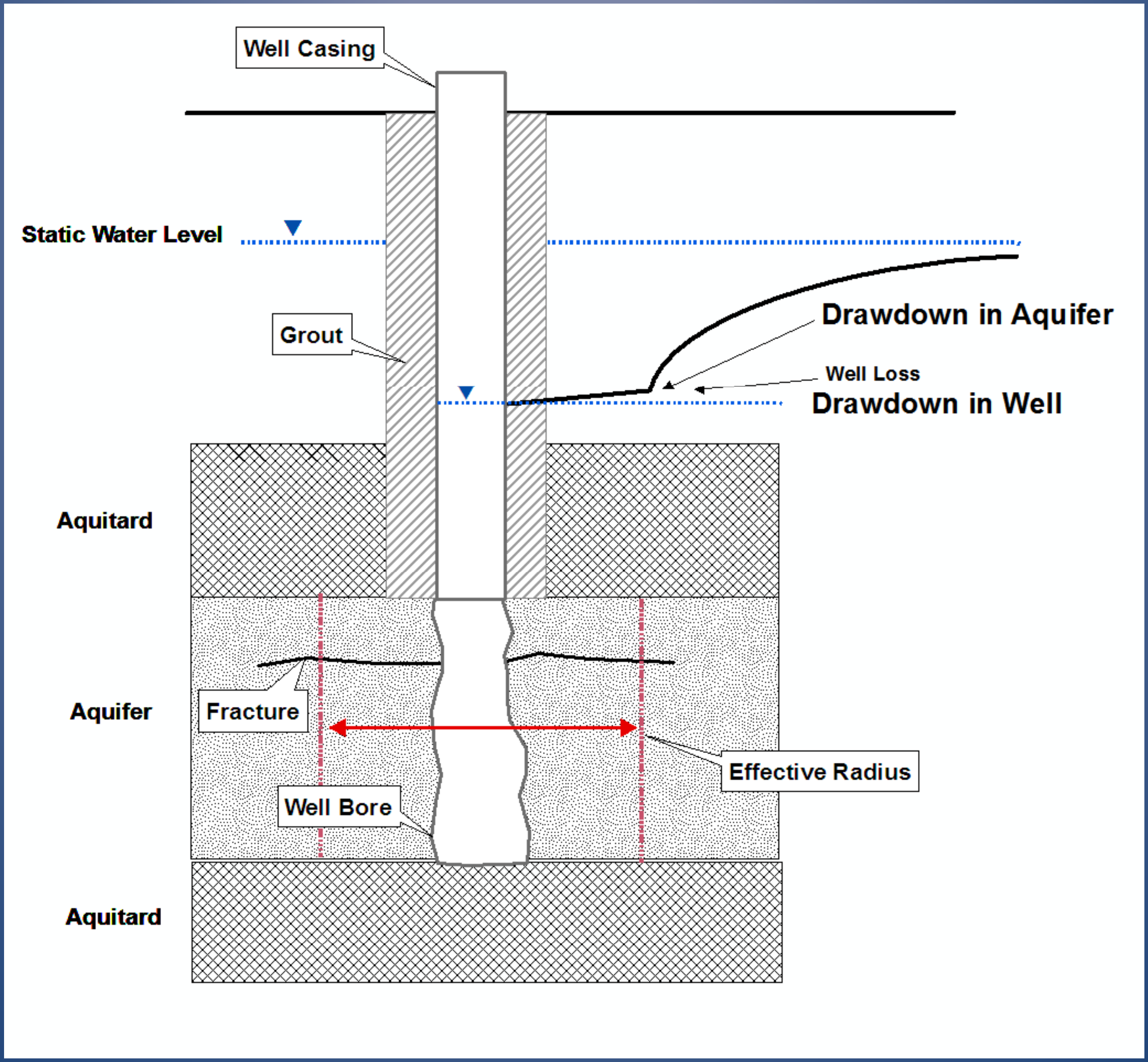
Effective Radius - ***Distance from the well that the theoretical drawdown equals the drawdown outside the screen.****

*: JACOB, C. E. (1947) Drawdown Test to Determine the Effective Radius of Artesian Wells, Trans. ASCE, 112:1047.

EFFECTIVE RADIUS OF SCREENED WELL – SCALE: INCHES



'EFFECTIVE RADIUS' OF ENHANCED BOREHOLE – SCALE: FEET +



STEADY STATE CONDITIONS

Thiem Equation

For radial flow in a planar fracture intercepted by a well

$$T = \frac{Q}{2\pi\,(H - hw)}\, ln \frac{R}{r_w}$$

Where:

R = radius of influence

r_w = radius of well

H = hydraulic head at r = R

h_w = hydraulic head at r = r_w

STEADY STATE CONDITIONS

Thiem Equation

Effective radius of enhanced borehole = radius of influence ?

$$T = \frac{Q}{2\pi\,(H - hw)}\, ln\frac{R}{r_w}$$

Where:

R = radius of influence

r_w = radius of well

H = hydraulic head at r = R

h_w = hydraulic head at r = r_w

POSSIBLE DEFINITIONS
- SPECIFIC FOR FRACTURED ROCK AQUIFERS -

<u>Enhanced Well Radius</u> ***– Distance from the pumped well that the drawdown in the fractured rock aquifer equals the drawdown in the well.***

<u>Radius of Fracture Influence</u> ***- Distance from the pumped well that the vertical head differences in the fractured rock aquifer caused by fracture-flow are negligible.***

HOW DOES WELL EFFICIENCY IMPACT AQUIFER TEST DATA?

INTERIM CONCLUSIONS:

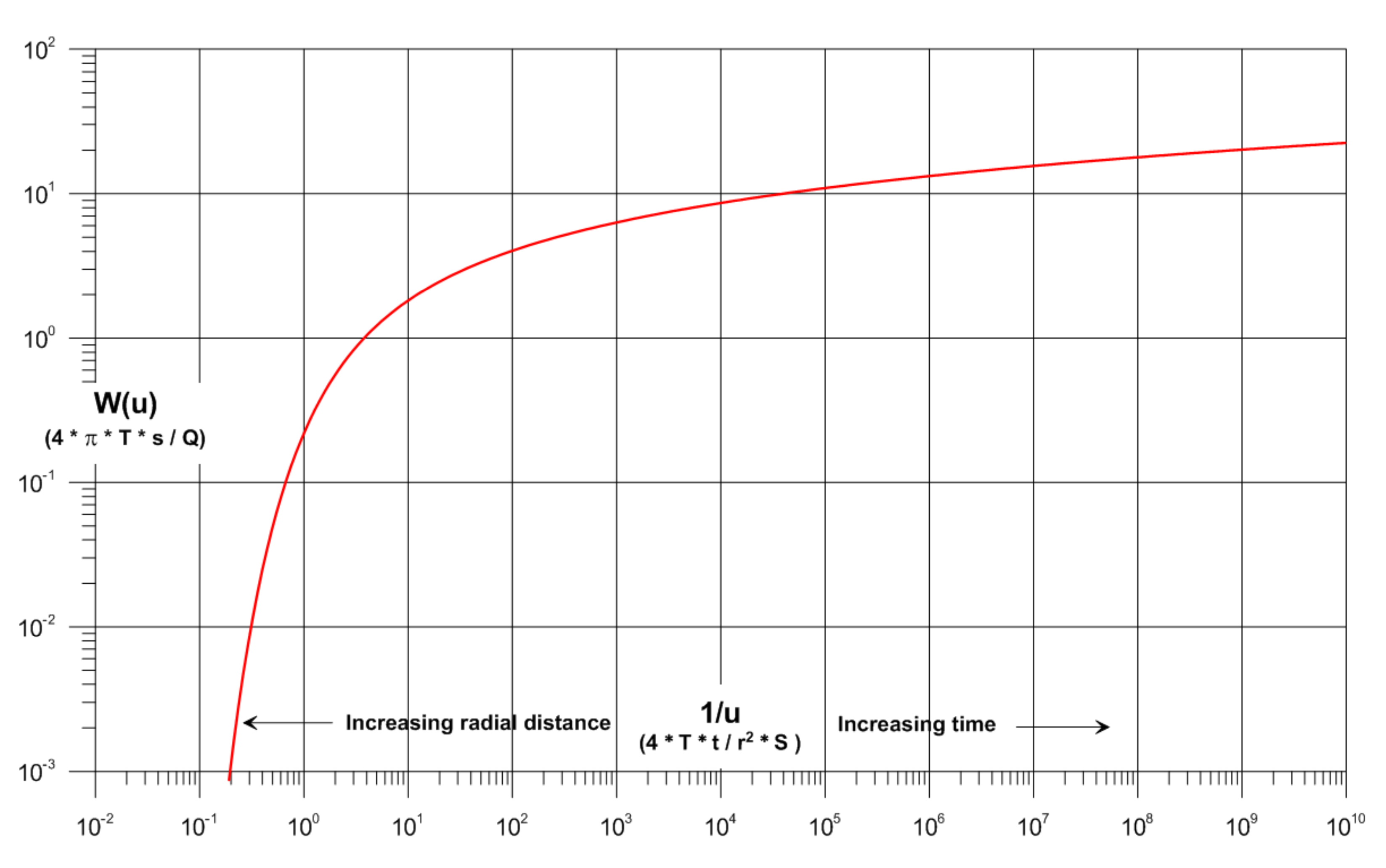
- **Drawdown in the pumping well is not representative of intergranular conditions within the aquifer system**
- **Efficiency affects the steady-state analysis, apparent transmissivity is too large when pumping well is included**
- **These characteristics are caused by a large effective radius of the pumping well, on the scale of tens to hundreds of feet**

HOW DOES WELL EFFICIENCY IMPACT AQUIFER TEST DATA?

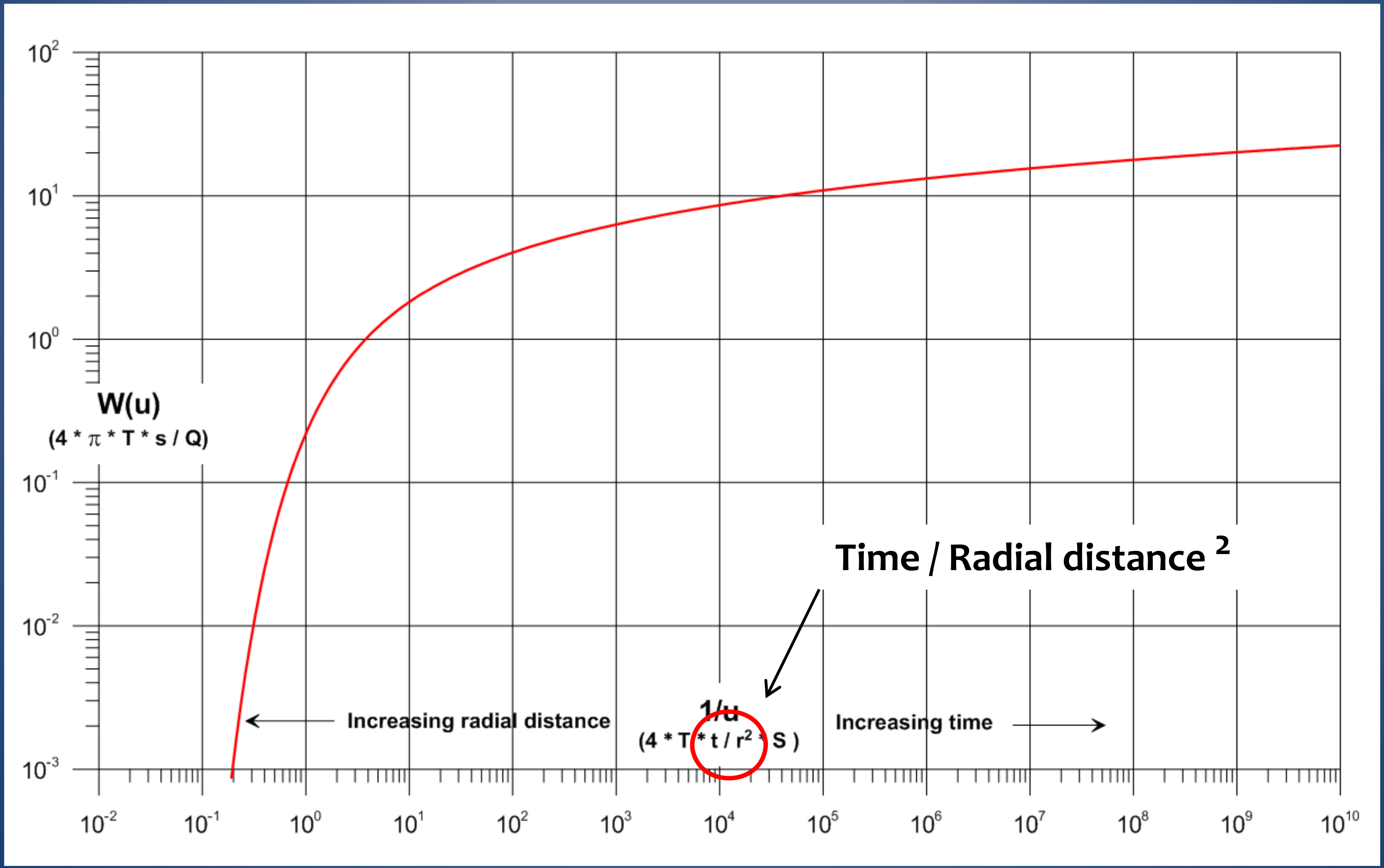
ADDITIONAL QUESTIONS:

- **Is the "enhanced well radius" correct and is it useful?**
- **How does high well efficiency affect transient data?**
- **What analysis technique(s) work best to evaluate this issue?**

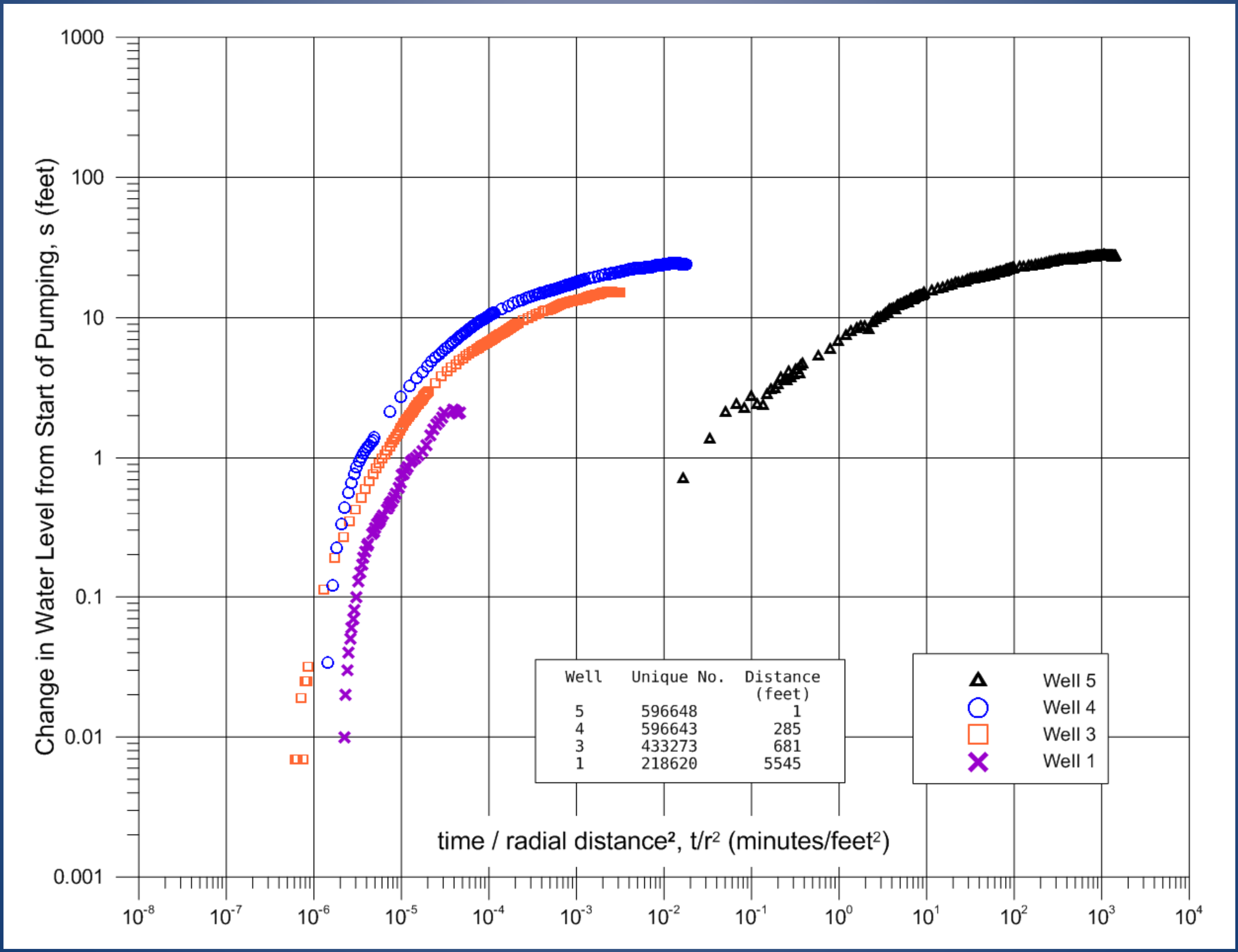
TRANSIENT (THEIS) DISTANCE-DRAWDOWN TYPE CURVE



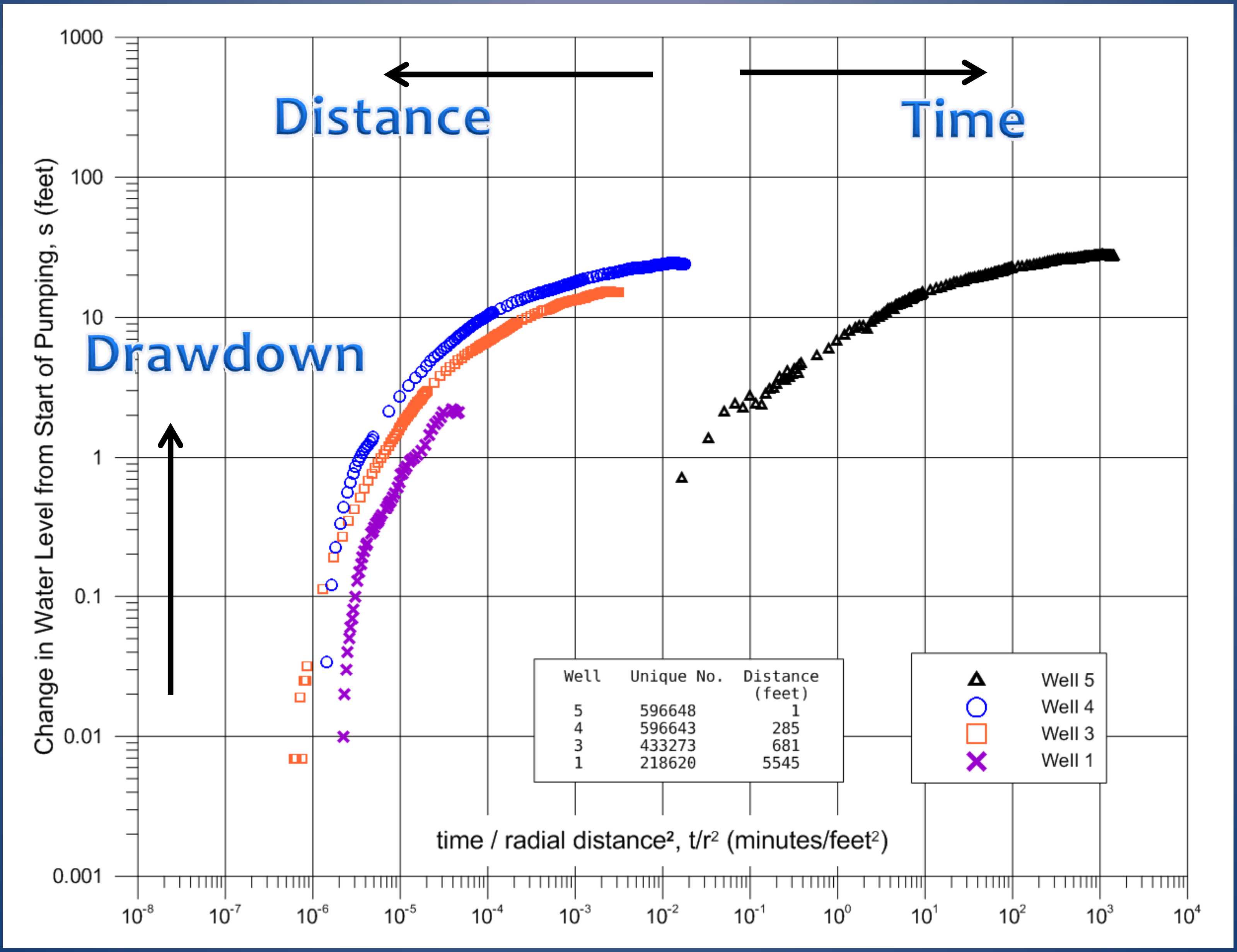
TRANSIENT (THEIS) DISTANCE-DRAWDOWN TYPE CURVE



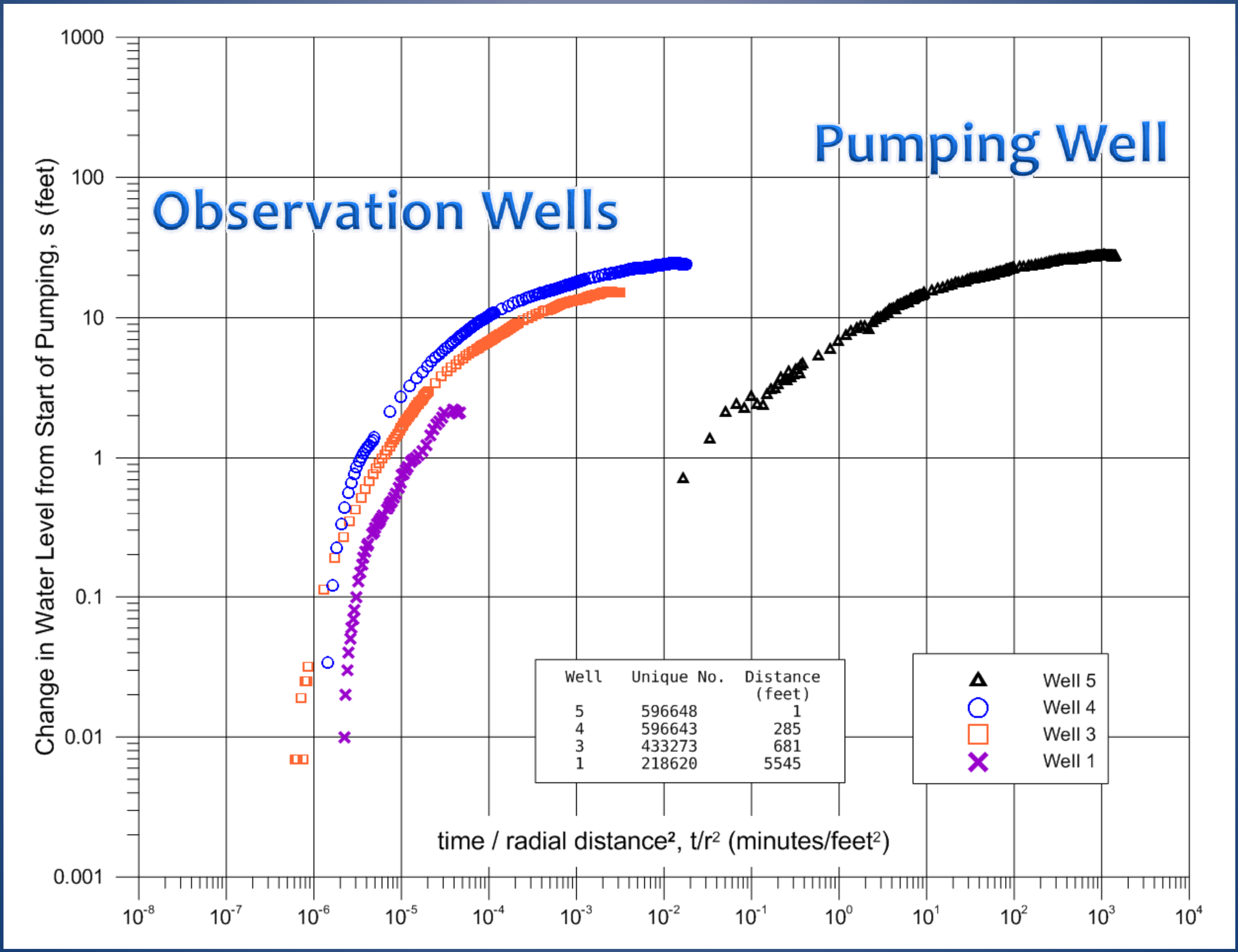
THEIS DISTANCE-DRAWDOWN – CANNON FALLS DATA



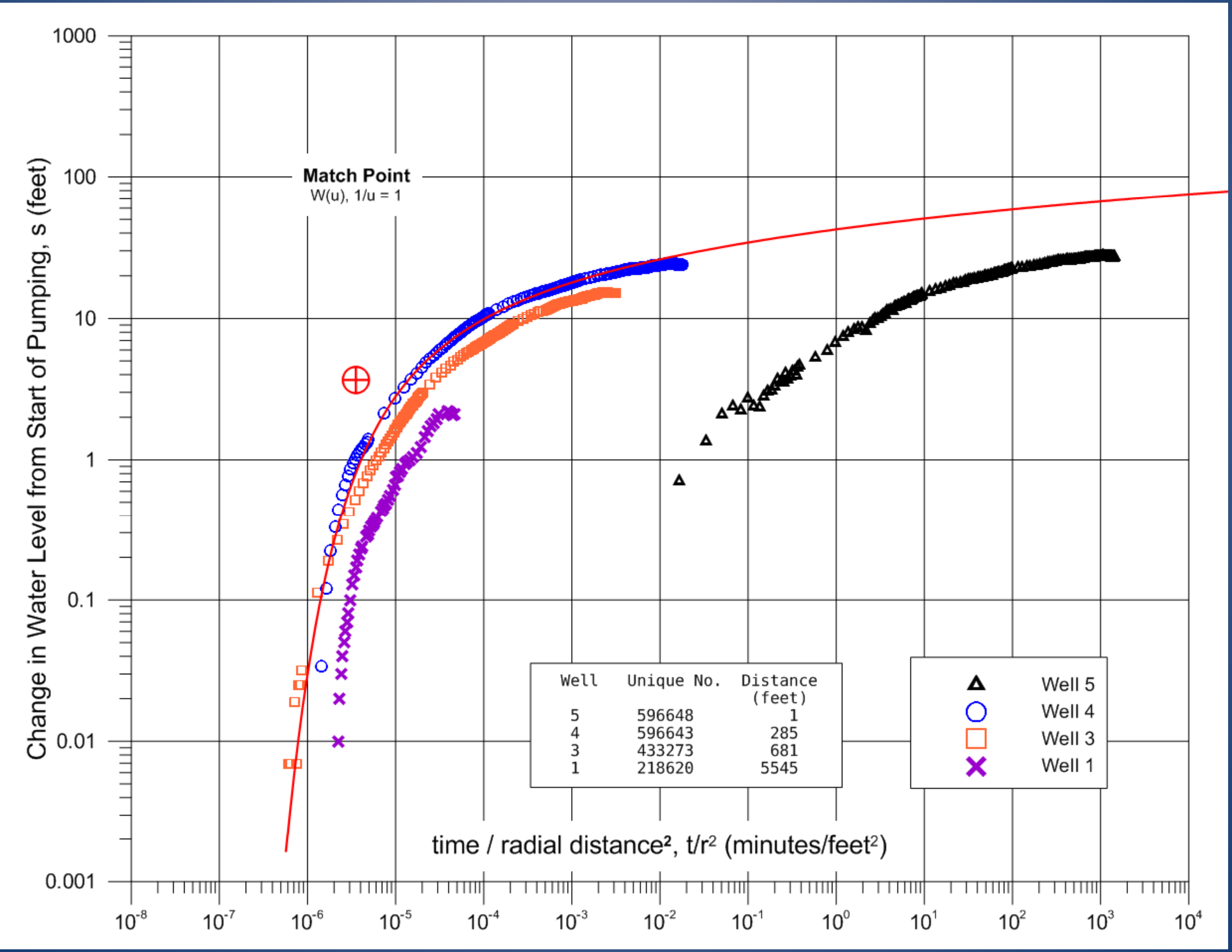
THEIS DISTANCE-DRAWDOWN PLOT



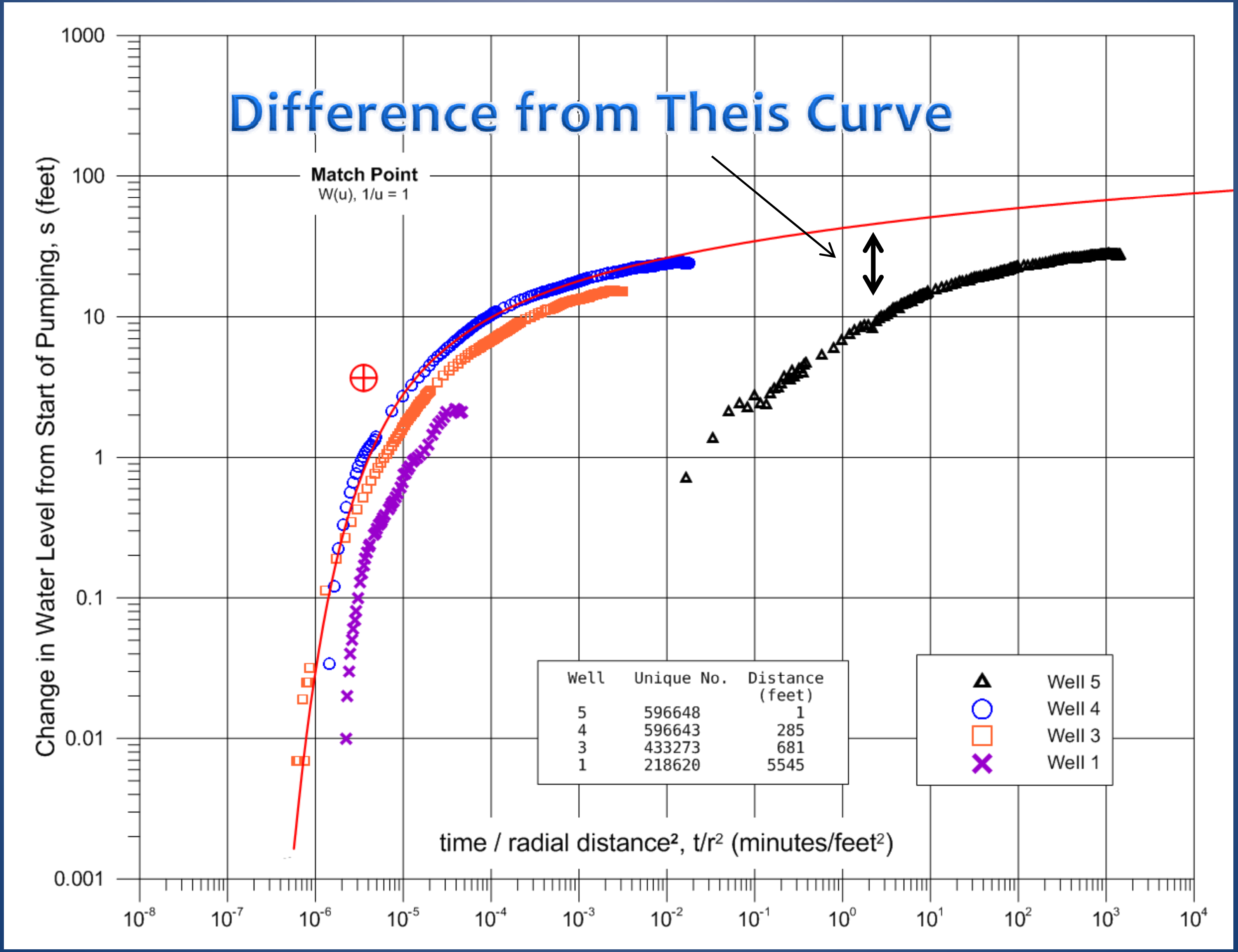
THEIS DISTANCE-DRAWDOWN PLOT



THEIS CURVE MATCH – CLOSEST OBWELL



EFFECT OF AN ENHANCED WELLBORE



Well	Unique No.	Distance (feet)
5	596648	1
4	596643	285
3	433273	681
1	218620	5545

CAN MATCH OF PUMPING WELL DATA BE IMPROVED?

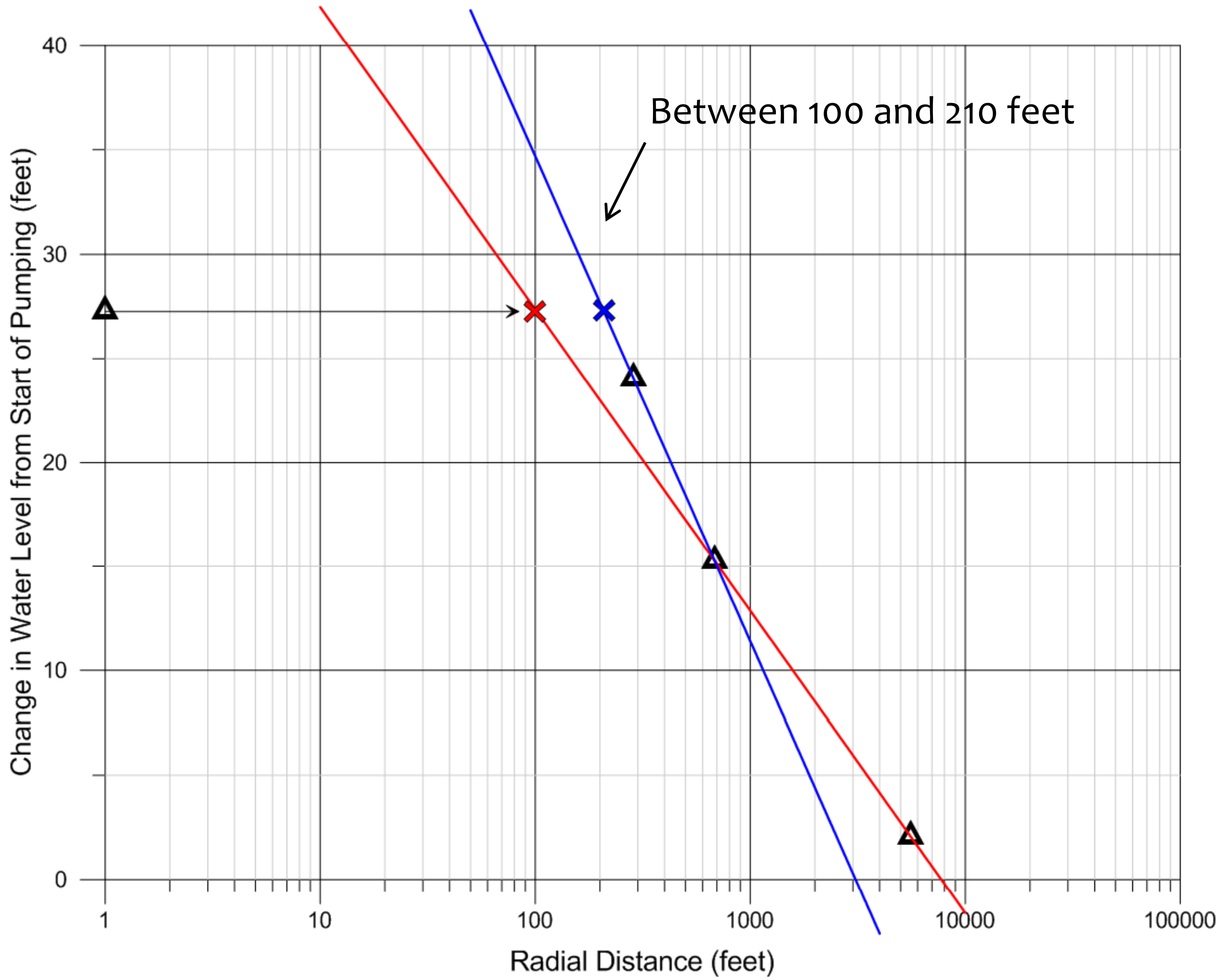
MODIFY DRAWDOWN?

- **Too hard to do (much like modeling)**

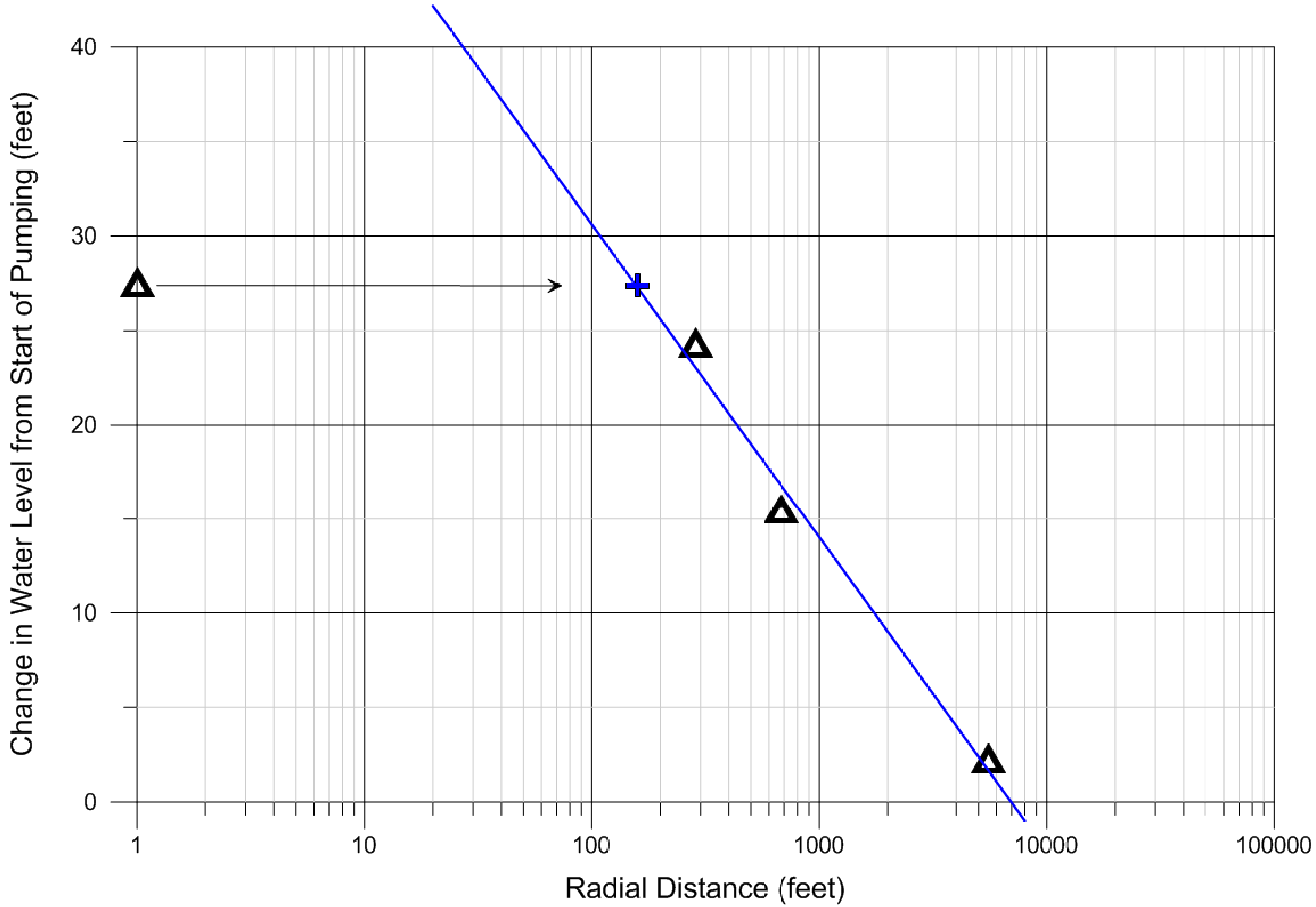
MODIFY RADIAL DISTANCE?

- **Use range of enhanced radii from steady-state plot**
- **Pick an average radius (out of a hat)**
- **Project the data from a twenty-four hour test to 10,000 minutes to estimate 'true' steady-state conditions**

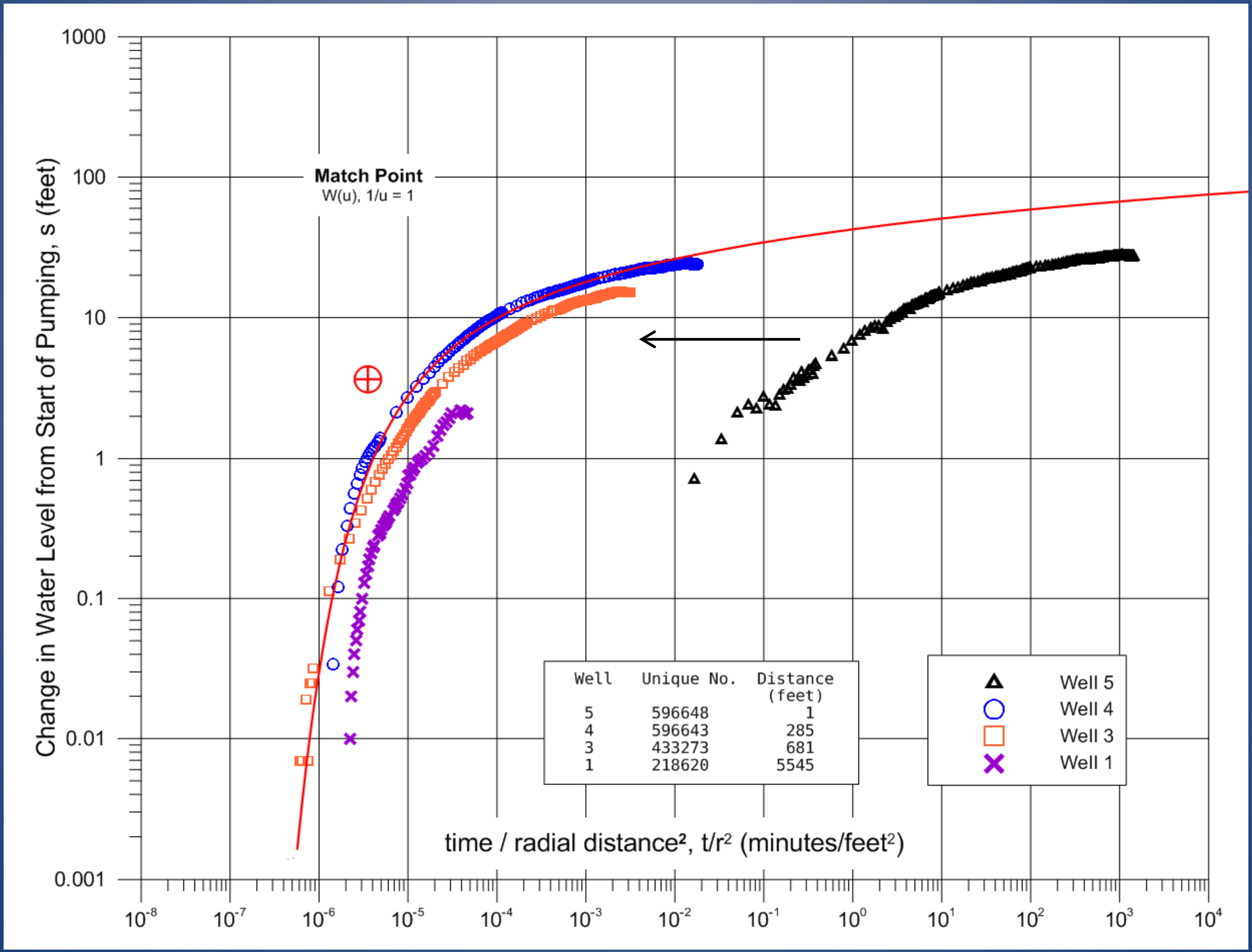
ENHANCED WELL RADIUS - UNCERTAINTY



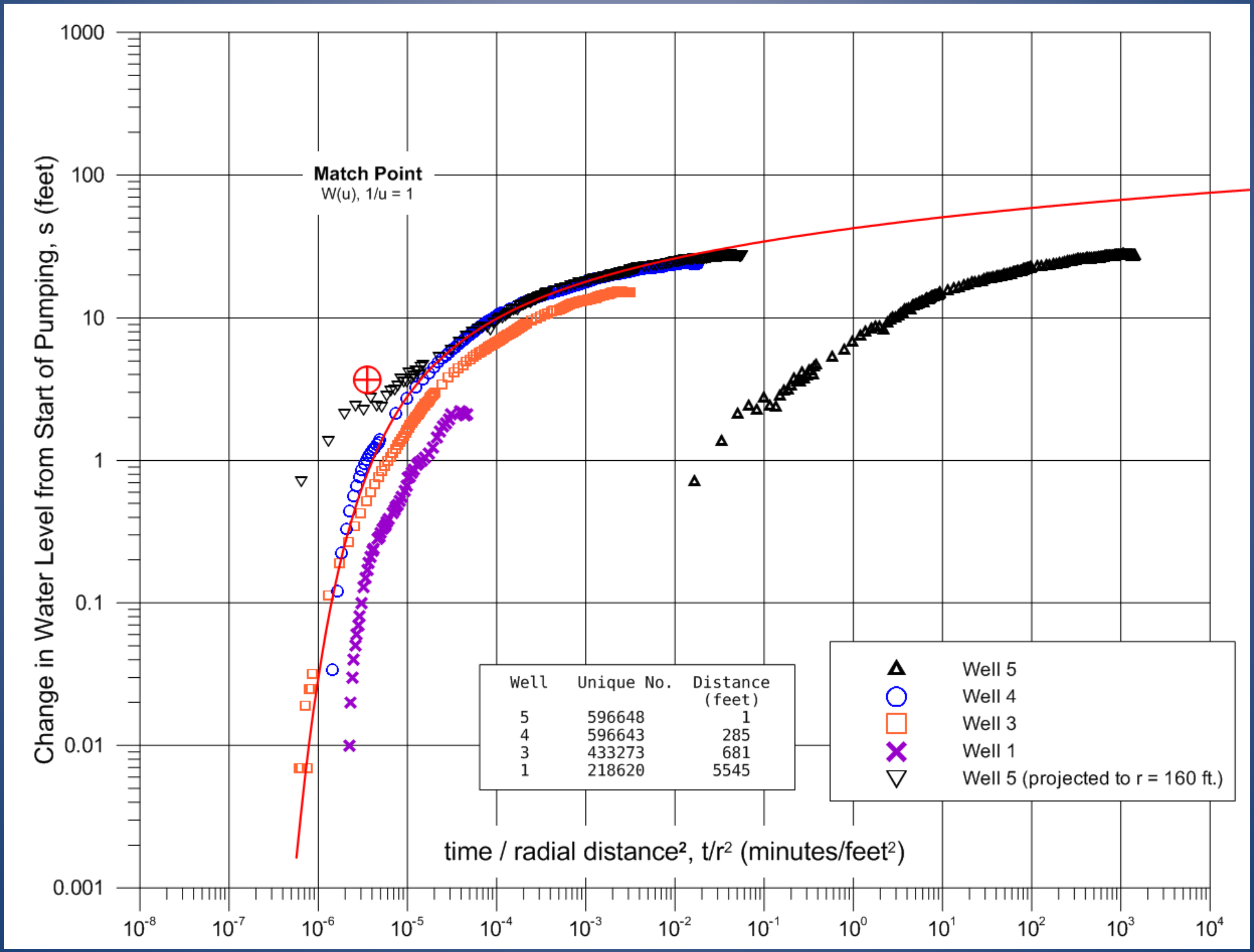
TRY ENHANCED WELL RADIUS OF ~160 FEET



THEIS DISTANCE-DRAWDOWN PLOT



GOOD MATCH OF PUMPING WELL AND NEAREST OBWELL



HOW DOES WELL EFFICIENCY IMPACT AQUIFER TEST DATA?

CONCLUSION:

- **Both steady-state and transient analysis are affected in a symmetrical way**
- **These distance-drawdown analysis techniques, used together, can work to evaluate and correct the influence of anomalous well efficiency on T, S, and L**
- **The process is highly circular (use with caution)**

ESTIMATED HYDRAULIC PROPERTIES?

Original

T = 5,500 ft^2/day, +/- 800 ft^2/day

S = 5.0e-5

L = 1760 feet

ESTIMATED HYDRAULIC PROPERTIES?

Original

T = 5,500 ft^2/day, +/- 800 ft^2/day

S = 5.0e-5

L = 1760 feet

Revised

T = 4,250 ft^2/day, +/- 220 ft^2/day

S = 5.0e-5

L = 4000 feet (minimum)

HOW DOES THIS PROCEDURE IMPROVE ESTIMATES OF HYDRAULIC PROPERTIES?

- **Forces consistency between conceptual models of flow system:**

  for a given T, and storage (transient) is consistent with leakage (steady-state)
- **Identifies wells with an anomalous response to pumping**
  - **Potentially corrects response, or**
  - **Allows well to be excluded from analysis**
- **Reduces number of individual analyses (plots/well) and produces summary plots**

PROCEDURE

- **Gather bunches of data**

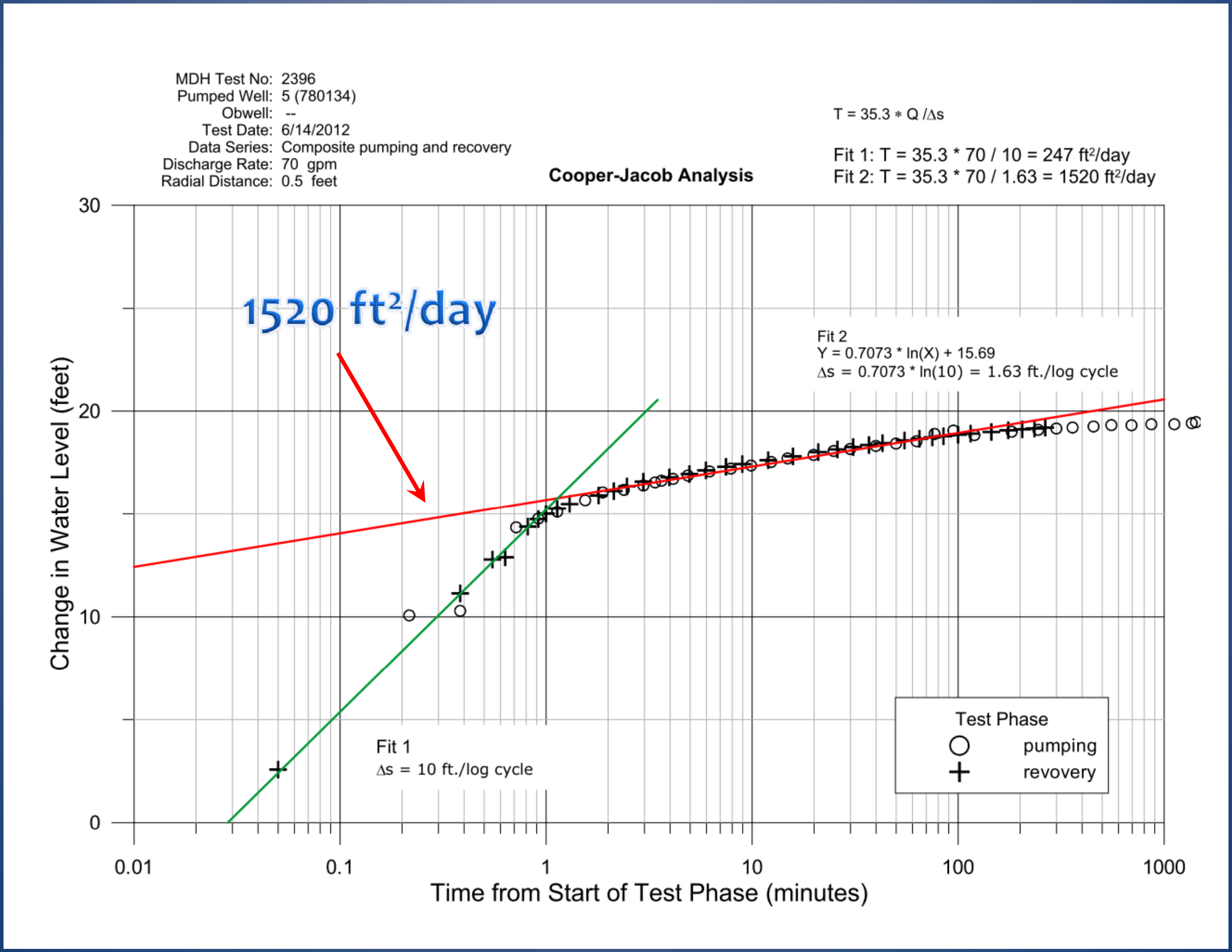
  minimum 24-hour test duration

  pumping well and a minimum of two

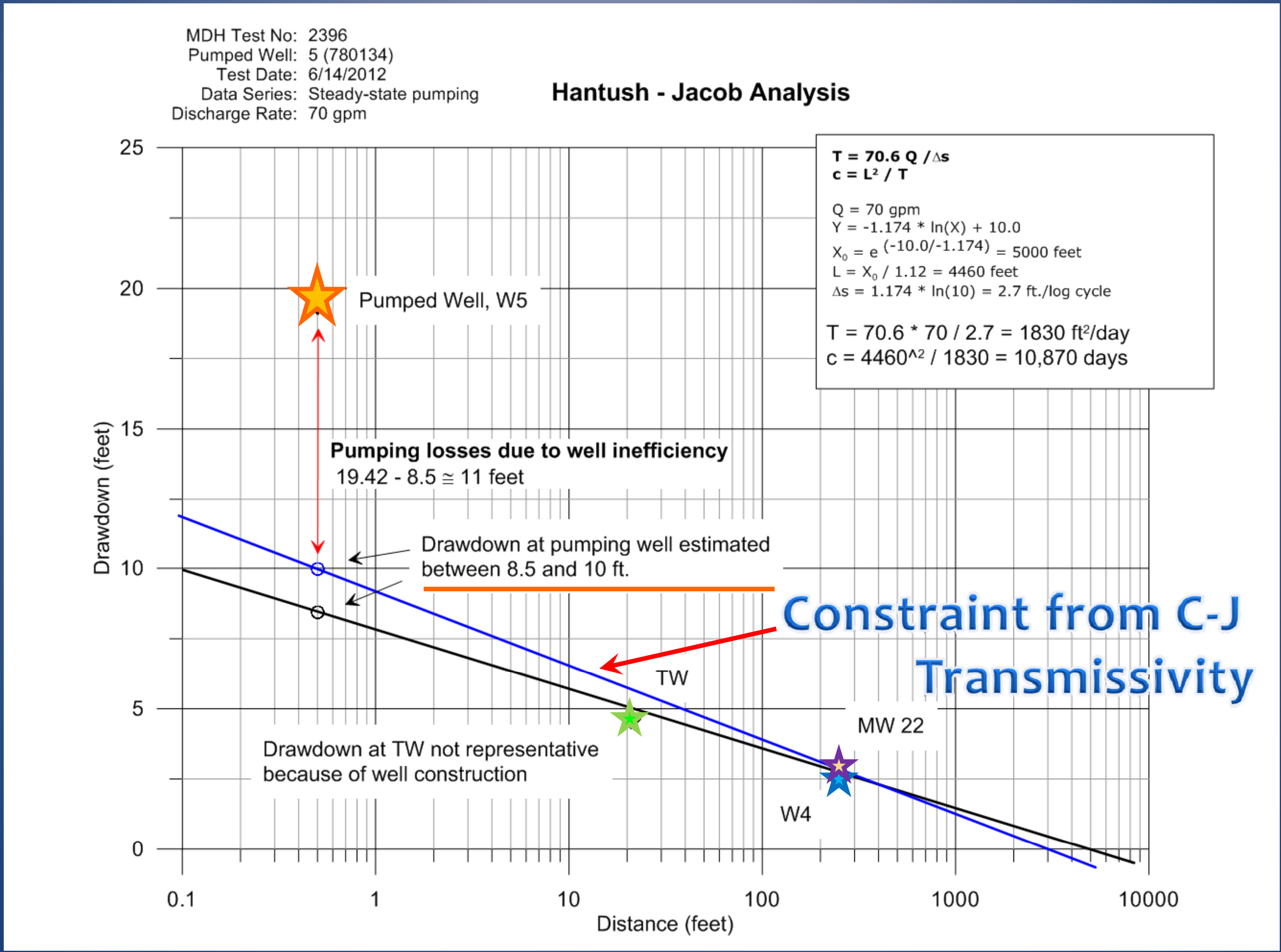
  observation wells at different radial distances
- **Apply both steady-state and transient solutions to Identify well-efficiency issues and other poorly matched data**
- **Estimate the enhanced radius of pumping well from steady-state analysis (semi-log plot)**
- **Test the revised radius with Theis distance-drawdown plot**

CAN PROCEDURE BE USEFUL IN OTHER SETTINGS?

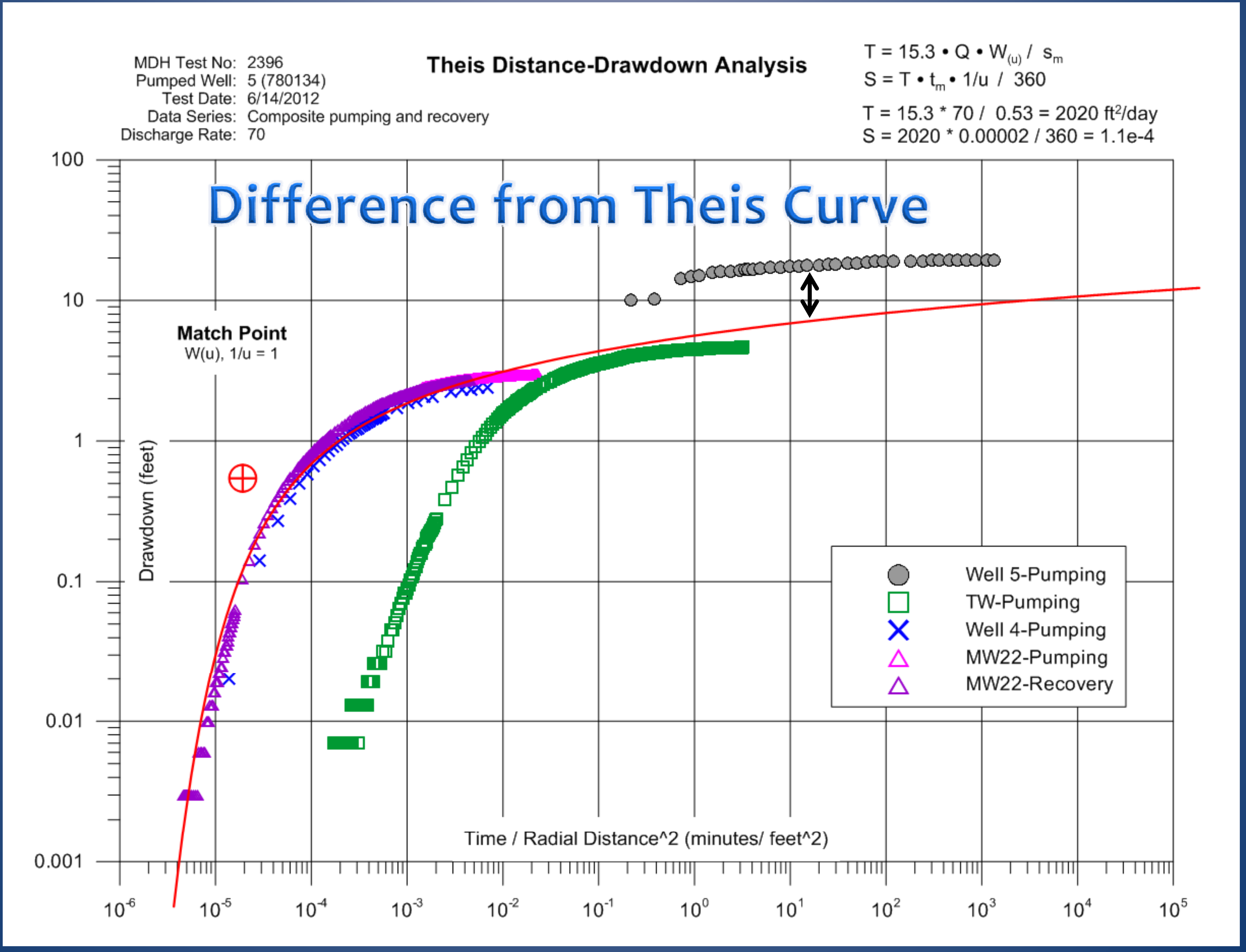
AS APPLIED TO AN INEFFICIENT WELL
SEMI STEADY-STATE



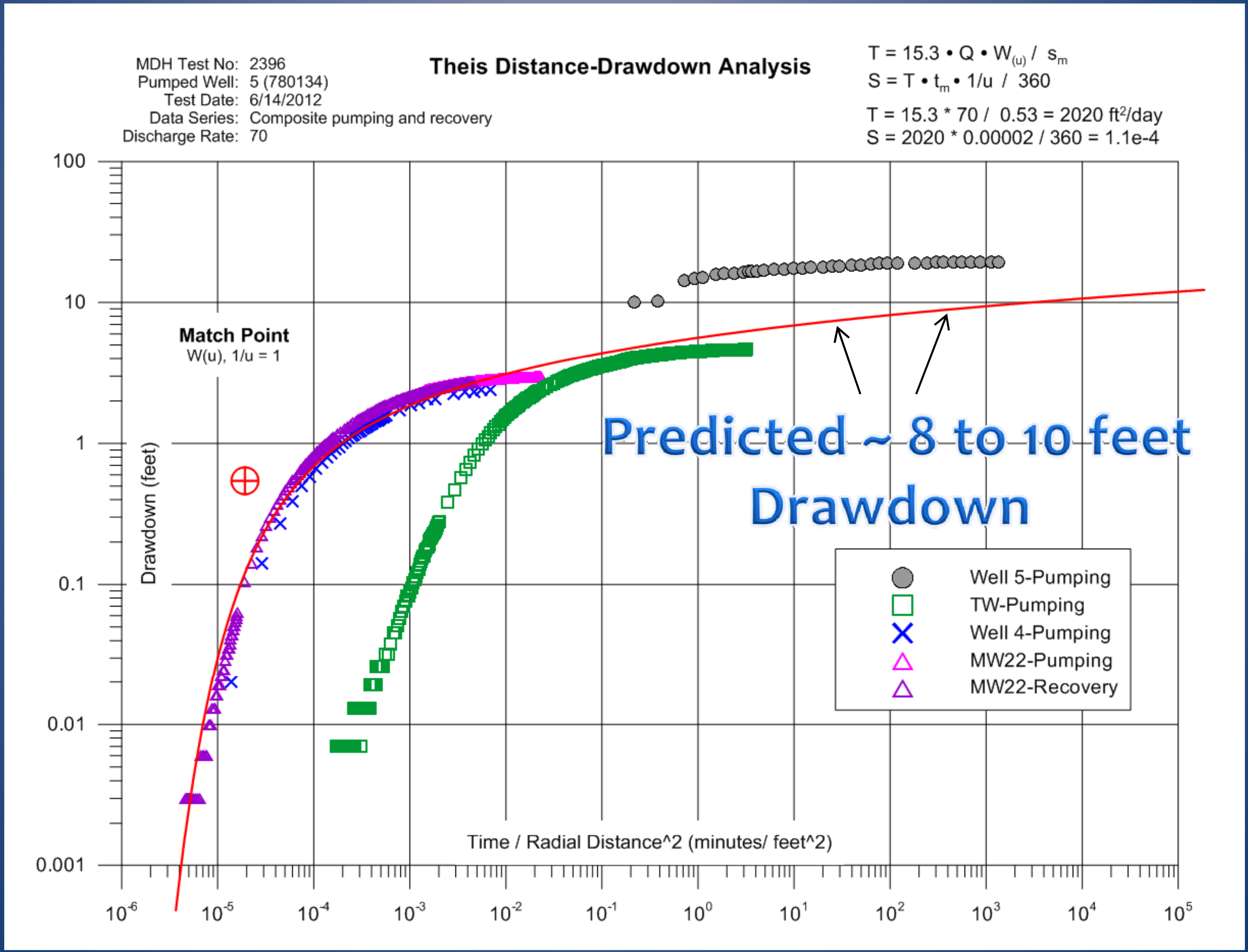
AS APPLIED TO AN INEFFICIENT WELL
STEADY-STATE



EFFECT OF NEGATIVE WELL EFFICIENCY



EFFECT OF NEGATIVE WELL EFFICIENCY



BRING OUT YOUR TESTS

- **Distance-drawdown techniques appear to work well to detect and correct the influence of a borehole with an effective radius that differs from the well construction**
- **Many existing datasets are amenable for re-evaluation for the influence of an enhanced wellbore**
- **Minimum data requirements are a pumping well and at least two observation wells at different radial distances**