HISTORY OF AQUIFER TESTING IN MINNESOTA, PRESENT PRACTICE, AND FUTURE DIRECTIONS

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TOPICS

Documented tests: 'Aquifer Test Database' Brief history of testing in Minnesota Notable unusual historic tests 'Recent' developments in data collection methods Need to develop methods to deal with 'bigger' data Appeal – Bring Out Your Tests!

NO DEEP WEEDS IN THIS PRESENTATION

► Relax...

► Descriptive

► No analysis, etc.



ORIGINAL COMPILATION - 478 TESTS

- USGS compiled list of existing tests, 1993
- Index: TRS location, test date, properties (T & S) and analysis method
- ► Total of ~1500 tests to-date
- Additional tests from:
 - MDH/consultant tests of public water supply wells
 - Other sources (MDNR, MPCA, & consultant files)
- Data currently stored in Microsoft Access

POSSIBLE NUMBER OF TESTS PER YEAR

► New Wells

Community PWS, 10-30

Other high-capacity, 100-400

Existing Wells

MDNR: permit, interference, resource assessment - ?

- MPCA remedial investigation ?
- MDH source water protection models, 50
- USGS research ?
- ► Gross estimate: ~ 200-400

SMALL FRACTION OF TESTS IN DATASET

- ~1500 tests in dataset, versus
- 25 years * ~300 tests/year ~= 7500 tests

Numbers of tests of record is about 20% of the number of tests performed over the 25-years that the data have been actively compiled

For the visually oriented: there is spatial bias in the dataset of test locations...

DOCUMENTED TEST LOCATIONS

~1500 Tests



LOCATIONS OF 2,900 ACTIVE COMMUNITY PWS WELLS

> Bias in test locations because of MDH priority on PWS wells



LOCATIONS OF ~8000 ACTIVE IRRIGATION WELLS

Existing dataset: contains ~10% of potential tests on high-capacity wells



BENEFITS OF AQUIFER TEST DATABASE

A means to record your work
Estimates of aquifer properties state-wide
Index of data sources, file search
Source document - flow model parameters
Potential time and cost savings

CURRENT STATUS, MDH - AQUIFER TEST DATABASE

MDH decided not to upgrade database to 'enterprise' standards in 2012

A workgroup was formed in 2014 to determine future of dataset (MDH, MGS, MPCA, MDNR, USGS, & Met-Council)

- Needs assessment
- Data model

MDNR has taken the lead in development of next generation database

NEW, MDNR - AQUIFER PROPERTIES DATABASE

- Name change because:
 - Intended to contain more than 'aquifer tests'
 - Enterprise DBA (MnIT) had a problem with any database name with the word '<u>test</u>' in it – vulnerable to summary deletion
- Data schema changed slightly for MDNR needs
- Programming has started

TEST-TYPES IN CURRENT AND NEW DATABASES

- Database designed for:
 - Classic constant-rate tests with observation wells
 - Production tests; variable rate, and step
- Test-types currently not included:
 - ► Slug
 - Specific capacity
 - Geophysical (flow logging)

WHY EXCLUDE TEST-TYPES ?

Slug – too small a volume to be of interest, otherwise easily carried in the database structure – Slug tests are useful for low 'k' materials

- Specific capacity carried in CWI already
- Geophysical managed by MGS

QUALITY OF TESTS OF RECORD?

Hard to determine because dataset is not complete
 Unique well numbers as a basic indicator of quality
 Of the 478 tests, <u>238</u> did not have a unique well number
 The present ~1500 tests, <u>63</u> remain without a unique well number

Moral hazard of data collection - management

A BESTIARY OF TESTS

Medieval morality tale ascribing human character traits to animals. Adapted to describe data accessibility and/or quality through lens of popular culture

► Dead	Bad
► Dark	Very nearly dead
► Stub	Barely alive
▶ Live	Possibly good



Rochester Bestiary, c. 1230–1240

MORAL CHARACTER OF DEAD-DATA

Dead – No one knows that there was a test but for a file in a box (scanned archive) somewhere



"This parrot is dead"

MORAL CHARACTER OF DARK-DATA

Dark – there was a test, but <u>only you</u> know that it occurred



"Only mostly dead"

MORAL CHARACTER OF A TEST-STUB

Stub – minimal documentation: a unique number, date, & who did the test are perhaps the only things known



Courageously fighting on, without all parts intact

MORAL CHARACTER OF LIVE-DATA

Live – data, documentation, and calculated hydraulic properties are known; suitable for review and...



perhaps even re-animation

STATUS OF DATASET, ~1500 TESTS

- Majority of tests are 'Stubs' with source of data
- Approximately half are single-well, production, tests
- All data associated with ~250 tests has been entered
- MDH has ~22 Gb misc. documents pertaining to ~700 tests on file

MDNR and MPCA are in process of scanning files...

PRIMARY SOURCES OF TEST DATA

Well Drillers, Service Companies, & Owners, 1870's >
Mn. Dept. of Natural Resources, 1938 >
U.S. Geological Survey, 1948 >
Geotechnical/Engineering firms, MPCA, 1970's >
Mn. Dept. of Health, 1993 >

OCCASIONAL SOURCES OF DATA

University of Minnesota, Dept. of Agriculture, Extension Service Geology (hydrology field camp) Geotechnical Engineering U.S. Army Corps of Engineers ► Johnson Screen, UOP

UNTAPPED SOURCES OF DATA

Irrigation System Sales and Service Companies?

> ...

Anyone in the audience today?

EARLIEST PUBLISHED HYDRAULIC TESTS

▶ Permeability testing of quarried blocks of St. Peter Sandstone by U.S. Army Corps of **Engineers** for the St. Anthony Lock and Dam, 1939



Sandstone Specimen No. 5 partly unpacked from crate.

EARLIEST PUBLISHED CONSTANT-RATE TESTS

April 1948 -March 1949 at Camp Ripley, USGS Water Supply Paper 1669-A (1963)



TOTAL NUMBER OF USGS TESTS ?

At least 100 publications containing estimates of aquifer properties based on classic constant-rate methodology

Location	Length of test (hours)	- Average pumping rate (gal/min)	Aquifer characteristics		
			Transmissivity (ft ² /d)	Average hydraulic conductivity (ft/d)	Specific yield
121.42.31bdb	44	475	9,600	344	0.15
120.43.2cbd	56	1,150	14,700	306	0.2
122.42.29bac ¹	65	495	31,000	561	0.27

¹Porosity determined by tracer test was 0.39.

USGS PUBLISHED TEST RESULTS

Significant effort required to find unique well numbers based on TRS, date drilled, use, and capacity

			Aquifer characteristics		
ration	Length of test (hours)	Average pumping rate (gal/min)	Transmissivity (ft ² /d)	Average hydraulic conductivity (ft/d)	Specific yield
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Porosity determined by tracer test was 0.39.

Original data usually not published

MDNR TESTS

Cooperative relationship with USGS from 1950's for water resource assessment

Historic DNR tests also performed to resolve well interference complaints

Few published results - DNR Bulletin 8, 'Selected Aquifer Tests in Minnesota' (1980)

Lots of test data still remain to be 'mined' from DNR permit files

NOTABLE 'EXOTIC' HISTORIC TESTS

- I968 MDNR permit to Minnegasco for the Waterville Underground Gas Storage Facility
- I980's Aquifer Thermal Energy Storage (ATES) project on the University of Minnesota Campus
- I 1980's U of M Agricultural Extension, Staples multiple tests on a grid of 10 shallow wells, funded by U.S. DOE

CACHE OF UNUSUAL DATA IN CWI

~100 test holes in south-central Minnesota, up to 3000 ft. deep

- Pre-date well code
- With geophysical logs
- Some are MDNR obwells
- What is going on?



FieldWaseca - Waterville			
WellName Dable (Omar) Number 1			
108 N Bre 22 \pm Waseca County Blooming Grove Township			
Twp. <u>100</u> , nge. <u>22</u> W. <u>Waseca</u> County, <u>Sittlemiting Brove</u> Township.			
Lease Number W 84 Reference Elevation 1117.53 DF			
Spud Date7/21/70 Completed (Rot.)7/31/70T.D149 (GL			
Completion Tools <u>9/14/70</u> Completed <u>9/14/70</u> T.D. <u>1100</u> Well Tune Storage - Observation Permetian Mt.Simon "A" Sand			
Carles Comment	Plasticophia Dete		
1 Casing Summary	Stratigraphic Data		
	Ton Redrock Shakopee 189 ±929		
9-5/8" Csg. Set # 564 '	Top Jordan425+693		
In 13 3/4" Hole (7/28_Date)	Top St. Lawrence 517 +601		
330? Sx. Cement	Top Franconia 610 +508		
Csg Equip 3 Centralizers	Top <u>Galesville</u> <u>744</u> +374		
<u>Float Shoe</u>	T_{op} Mt.Simon"UT" 832 +286		
	Top Mt.Simon"BT" 858? +260		
	Top <u>Mt.Simon "A" 928 +190</u>		
	Top <u>Mt.Simon "B" 1003</u> +115		
	Top		
	Geophysical Logs		
In 8_3/4" Hole (7/31_Date)	Open Hole: Saraband Depth Date 7/30/70 Logs DIL SNP BHC 1149		
310 Sx. Cement	Date 7/30/70 LogsEDC,CBL,9 5/8 1149		
Calculated Top Circulate	Cased Hole:		
Actual Top <u>Circulated</u>	Date 9/14/70 Logs CBL, GRN (W) 1100 Date 9/14/70 Logs GRN(D)CCL-P 1100		
Csg. Equip. Float Collar,	Date Logs		
6 Centralizers, 35	Date Logs		
Rotating Scratchers			
	Core Data		
Date 9/14/70 Shots/Ft. 4			
Plug @1100_'	н <u>1</u> н н		
Open Hole Interval	Drill Stem Test(s) 7/20/70		
	Interval <u>857 ' 905</u> ' Pressure <u>*300</u>		
NOTES: * <u>Cement Additives</u> :	Recovery 770 ft. H20-No Gas(*@847')		
1.25% CFR 2, 18% NaCl	Interval Pressure _		
	Gas Entered Depth		
L			

EXAMPLE WELL RECORD OIL-FIELD TECHNOLOGY

	Drill S	tem Test(s) 7/29/70
Interval _	<u>857 ± 90</u>	<u> </u>
Recovery_	770 ft.	H20-No Gas(*@847')
Interval _	<u><u>t</u></u>	' PressurePsi
Recovery		
Gas Enter	ed	Depth'

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DRILL-STEM TEST

Oil-field equivalent of a slug test, quick - affects a small volume of aquifer

A short constant-rate flow period and a longer recovery (shut-in)

Analyzed as Theis recovery (t / t'); or, more recent method, Agarwal (T_p * t' / t)

MT. SIMON SANDSTONE

Anticline structure target for seasonal gas storage



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STRUCTURE CONTOUR MAP TOP OF MT. SIMON SANDSTONE

 Approximate extent of seasonal gas storage, MDNR files



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RESURRECTING (VERY NEARLY) DEAD DATA

Archived data files exhumed (thank you MDNR)

- Minnegasco/MDNR retained Dr. Paul Witherspoon to supervise testing of the anticlinal structure
- 60-day gas injection test, Sept. Dec. 1968, on wells completed in the Mt. Simon Sandstone
- ~1 mcfd of natural gas was injected per day, pressure of 300 PSI at the wellhead

TYPICAL DATA RECORD OF 60-DAY GAS INJECTION TEST



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WATER ELEVATION, 60-DAY GAS INJECTION TEST



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TEST AREA

 Change in water elevation, nominal extent of gas after 60 days injection



TEST AREA VERSUS RESERVOIR AREA

- Reservoir contains multiple 10° cubic feet of natural gas
- Difficulty for analysis of test data is conversion of gas injection rate to water injection rate





BRING OUT YOUR TESTS!

Historic tests can contain a significant quantity of useable data

Generally worthwhile to exhume data for analysis rather than the expense and bother of re-collecting

DEVELOPMENTS IN DATA COLLECTION

 Mobile technology - making your social coordination device [truly] useful... for data acquisition/documentation

Increasing use of automated data acquisition and control systems (SCADA) by well owners and operators





SCADA DATA COLLECTION - COMMON ISSUES -

Data collection interval driven by MDNR 'monitoring' group - <u>Currently does not include actual start/stop</u> <u>time of pump</u>

Programming SCADA system is highly specialized and costly – <u>Data display not self-documenting</u>

Poor quality water level sensors used, inadequate sensitivity to water level change - <u>False Economy</u>

HOW TO COMPENSATE FOR SCADA DATA COLLECTION ISSUES Request (everyone say 'Please') MDNR to improve 'monitoring' data format (in process), Well owners invest in better-quality sensors and programming Back to basics Reconsider field methods Search published data collection techniques



WHILE WE ARE WORKING TO MAKE THE IOT (THINGY-NET) USEFUL



What resources do we carry around in our pockets?





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- NOTHING NEW -USGS WATER SUPPLY PAPER 1545-A, 1961 Close up

Setup





manometer & stop watch

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movie camera & stop watch



MOBILE DATA COLLECTION VERSION, 0.1 HYBRID ANALOG/DIGITAL

Mobile device photo

- Totalizing flow meter at pumped well
- Self-documenting elapsed time
- Irregular (manual) photo timing



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- VERSION, 0.2 – DIGITAL DATA COLLECTION

Sensor display in the well house is updated continuously

- Date/time captured from photo file header (exif)
- Irregular (manual) photo timing



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METHOD IMPROVED, BUT NOT AUTOMATIC, RAPID, OR SELF- DOCUMENTING

Need for enhanced data recorder application:

► Take photo at specified time-interval.

Date/time imprinted on photo, more complete documentation and ease of data transcription



YES, THERE IS AN APP FOR THAT

Cost of mobile device ~\$200

Incremental cost of iOS app is negligible, <u>\$1</u>

Available on android devices?



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REPURPOSE EQUIPMENT YOU ALREADY OWN

Use that selfie-stick that you got for the holidays, with -

the camera tripod gathering dust in the closet, and

judicious application of duct tape



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- VERSION 0.3 -WORKS GREAT !

- 5-second interval
- Transfer data to spreadsheet

Integrate with city SCADA data



IS NOT "SET AND FORGET"

- Digital display time-out (inadvertent selfie)
- Remember to check time difference between SCADA & mobile device



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ALSO CHECK SCADA SYSTEM BEFORE TEST FOR:

Sensor problems

'Flat-line' output, does not track changes in nearby wells
 Electrical problems

Transient unexplained water level fluctuations, data gaps

Computer-database problems

Inverted water-level output, data gaps



RECENT SCADA TIME-SERIES DATA – ANALYSIS?



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DATA SELECTED FOR CONVENTIONAL ANALYSIS



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MEASURABLE INFLUENCE IN PRAIRIE DU CHIEN > 2 MILES FROM PUMPING WELLS



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FUTURE DIRECTIONS OF AQUIFER TEST METHODOLOGY AND ANALYSIS

Dependent on the quality of the foundational datasets

- ► well, (MDH/MGS)
- ► well use, and (MDNR)
- ► water level (MDNR, et al.)

Better tools for analysis of time-series data
 academia, USGS, software vendors

BETTER TOOLS NEEDED

► To incorporate:

- multiple pumping wells and water level observation points
- effects of <u>well efficiency</u> and <u>leakage</u>
- Likely starting points for tool development (my opinions)

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- TTim written in Python (Dr. M. Bakker)
- WellFieldModel written in Matlab (Dr. M. Royayne)
- MLU for Windows from microfem.com (Kick Hemker)

BRING OUT YOUR TESTS!

Data are dead if they remain unknown

Leave a place in a better condition than how you found it.



Rochester Bestiary, c. 1230–1240

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PROPOSED MGWA DARK-DATA ROUNDUP

Seeking volunteers, 'Roundup' steering committee

► Agenda

Legal defense fund for 'Dark-Data Liberation Front'

Venue for fund raiser?

Auditions for talent show:

'Mostly-Dead Field-Workers' mime troupe,

'Not Dead, Yet' Chorale, and

'Bring Out Your Tests' bell ringers (seasonal)

4-step DDAR meeting (Dark-Data Amnesty and Reconciliation)