STES NEWSLETTER
A Quarterly Review of Seasonal Thermal Energy Storage
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EARTH SCIENCES DIVISION/LAWRENCE BERKELEY LABORATORY/UNIVERSITY OF CALIFORNIA
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A NOTE FROM THE EDITOR

The upcoming Conference on Seasonal Thermal and Compressed Air Energy Storage represents probably the biggest international gathering of researchers and managers of STES in the last two or three years. With the permission of the conference organizers, the papers to be presented and their authors are listed in this issue. The readers are encouraged to attend this meeting or to write to the authors directly for any papers in which they may be interested.

After some discussion, we have decided to make a change in the time schedule followed in publishing the STES Newsletter. Therefore, beginning with the next issue, we are asking that all contributions be received one month earlier than usually requested. For the upcoming December 1981 issue, the due date will be November 6, 1981.

We strongly encourage all our readers to submit articles concerning current plans, new developments, and key results. It is not necessary to wait for the completion of a project before writing about it. In this way, we can all keep abreast of the current status of STES worldwide.

The STES Newsletter is a compilation of written contributions from researchers working in the field of seasonal thermal energy storage. Articles and reviews of current events, and new developments in this field are welcome.

Contributions and suggestions for the next issue and changes of address should reach us by November 6, 1981. Send to:

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STES PROGRAM ACTIVITIES

Contact: J. R. Raymond, Underground Energy Storage Program, Pacific Northwest Laboratory, P.O. Box 999, Richland, Washington 99352, U.S.A.

The Seasonal Thermal Energy Storage Program has included the development of projects to demonstrate thermal energy storage in aquifers, numerical modeling, laboratory investigation of geohydrology and geochemistry, and environmental assessment. Current Department of Energy (DOE) policy emphasizes the development of technology rather than cost sharing construction and the operation of demonstration systems.

At Bethel, Alaska, production and monitoring wells were completed for aquifer characterization. These wells, drilled through 122 m of permafrost to a depth of 198 m, located a previously unidentified aquifer capable of supplying good quality water. This project is in the process of termination.

At the Stony Brook campus of the University of New York, the Dames and Moore Company completed a well field designed for aquifer characterization. 68,000 m^3 of water were chilled to 6°C, stored 30 days, and recovered. Injectivity in the reinjection well was impaired and the cause of this problem is now under investigation. Data from the chill cycle is now being numerically modeled to evaluate aquifer performance in longer cycles.

At the University of Minnesota, monitor wells have been completed and production wells are being drilled. Initial monitor well placement is designed for a series of 24-day tests (8 days injection, 8 days storage, 8 days recovery) over the injection temperature range of 100° to 150°C. Upon completion of these short cycles, an expanded monitor well pattern is planned which will take data from 90-day tests. Short cycle tests are scheduled to begin in the fall of 1981.

The economics of heat storage have been evaluated utilizing the AQUASTOR code at the Pacific Northwest Laboratory, and the results will be reported at the STES/CAES International Conference in Seattle in October, 1981.

The results of environmental studies of thermal energy storage in aquifers have been published by G. E. Wukelic and D. L. Lee as "Environmental Assessment: Aquifer Thermal Energy Storage Program," DOE/EA-0131.

SEASONAL CHILL STORAGE AT STONY BROOK-FEASIBILITY STUDY RESULTS

Contact: W. V. Skinner, Dames and Moore, Cranford, New Jersey 07016, U.S.A.

An aquifer thermal energy storage feasibility study is underway to evaluate the feasibility of using a portion of the Magothy Aquifer underlying the State University of New York's (SUNY) Stony Brook Campus on Long Island, N. Y., for seasonally storing chilled water for air conditioning purposes.

The upper Magothy Aquifer was characterized through an extensive drilling program followed by a doublet well test in which 18.2 million gallons of chilled water were injected and recovered to evaluate overall chill energy recovery efficiency. Observation wells were used to track the movement of chilled water and to obtain other data needed to calibrate a computer model for the design of a demonstration project. Other model simulations were used to evaluate campus air conditioning needs. An existing cooling tower and a chilled water distribution system were evaluated to determine how they could be used in an ATES system.

Borehole data and baseline measurements indicate the upper Magothy Aquifer is semiconfined, highly stratified, of variable transmissivity (1.24×10^2 to 3.47×10^2 m^3/meter), and lacks well-defined confining layers above and below the 90 to 106 m injection zone. Horizontal conductivity was found to be approximately 200 times the vertical conductivity. Groundwater seepage (or approach) velocity was found to be approximately .36 m per day, based upon both the hydraulic testing and non-isothermal simulations. Effective porosity is approximately 25%. An observed anomalous thermal gradient is thought to be the result of the injection of water warmed by the campus air conditioning system.

Results of the doublet test indicate the injected chilled water was generally confined by the thinly bedded sediments to a vertical thickness of 19.8 m. Total first-cycle recovery was approximately 60%, based upon one injection volume. The total energy recovered at temperatures usable in the existing Stony Brook system was 37%. The maximum permissible rise from injection through recovery is 1.9°C. The GREASE II numerical model, prepared by Dr. Huyakorn, successfully simulated the doublet test results.

Difficulties occurred with the 15 cm doublet well upon reinjection of the recovered chilled water at a rate of 68.2 m^3/hr. An investigation is planned to evaluate the cause for, and engineering solutions to, the change in well specific capacity upon injection.

Two preliminary conceptual designs are being prepared for SUNY's consideration in their 1982-83 funding. Estimates for a 9,000-ton central plant option and a 300-ton two-building option are being prepared.

SEASONAL THERMAL ENERGY STORAGE AT THE UNIVERSITY OF MINNESOTA

Contact: James C. O'Gara, Assistant Supervising Engineer, University of Minnesota, Physical Plant Operations, 200 Shops Building, 319 15th Ave., S.E., Minneapolis, Minnesota 55455, U.S.A.

Construction of a field test facility incorporating a 300 gpm, 300°F maximum temperature well doublet and monitoring well system will be completed in October, 1981 on the University's St. Paul Campus. A series of five cycles, comprised of injecting constant temperature water from 100°C up to 150°C at 300 gpm into the Franconia-Ironton-Galesville (FIG) aquifer, will be conducted over a 5 to 6 month period. The aquifer, which lies beneath the St. Paul Campus, is approximately 200 feet thick and about 560 feet below the surface. During each of the five cycles, hot water will be injected for eight days, stored eight days, and then withdrawn for eight days through a doublet well system of thermal conversion (steam to water), thermal injection, thermal recovery and heat extraction, and water return to the aquifer.

Numerical modeling, utilizing geohydraulic and chemical data known from core, chemical, and water analysis, predicted that the thermal bubble of stored hot water will take on an hour-glass configuration in the FIG aquifer. Numerical modeling has also indicated recovery efficiencies in excess of 80% on repeated cycle analysis.

If the five short-term tests are successful, long-term testing will be conducted in 1983. The three-fold intent of the field tests is to obtain research data, conduct data analysis, and qualify the environmental and technical feasibility of seasonal thermal energy storage systems utilizing naturally occurring aquifers.

PRELIMINARY ASSESSMENT OF PROMISING NONAQUIFER STES

Contact: Don Blahnik, Pacific Northwest Laboratory, P. O. Box 999, Richland, Washington 99352, U.S.A.

A preliminary assessment of pond, lake, cavern, tank, earth, rock, and ice seasonal thermal energy storage has been completed. These seven nonaquifer concepts were evaluated, on a relative basis, for development status, cost and thermal effectiveness, site availability, sizing requirements, and overall potential for use.

A rough relative comparison of these selected STES concepts is provided in Table 1. The assessment indicates that tank storage is the most developed concept and that lake storage is the least developed. Economics look most attractive for storage in lakes, rock boreholes, abandoned mine caverns, gravity dam tanks, and ice. Annual thermal inventory turnover rates can have a strong bearing on costs. All of the concepts have good thermal recovery potential, although the heat is degraded more in earth and rock well storage. Tank, earth and pond stores have the greatest number of potential sites available with each concept having different market size requirements. For cost and thermal effectiveness, each concept usually requires a market equivalent of over 50 homes. Concepts which might become attractive in the 1- to 50-home market size include tank, pond, earth, and ice STES. All of the concepts have fair-to-good potential based on this preliminary general evaluation.

Heat pumps coupled to STES systems also have good potential and should always be considered in STES projects. They can extend storage capacities, reduce costs, and provide operating flexibility.

More research and development is needed for effective, low-cost insulation and lining materials for all the concepts. Improvements in construction designs and methods would also be economically beneficial for all the concepts. Design criteria are needed to cope with the wide range of variations (e.g., geology, climate) that occur between sites.

Annual thermal inventory turnover is an important factor when determining costs. When the inventory can be turned over more than once per year (solar 2 to 3 times and power or industrial plant waste heat 4 to 20 times), use of the more expensive storage systems, such as tanks, can be justified.

THE HEATING OF SOFT, SATURATED SOIL BY MEANS OF CLOSELY PACKED, VERTICAL HEAT TRANSFER PIPES

Contact: Prof. C. Van Koppen, Laboratory for Heat Technology, Eindhoven University of Technology, Eindhoven, The Netherlands

Studies in seasonal thermal energy storage at Eindhoven University of Technology and the Delft University of Technology involve the heating of soft, saturated soil by means of closely packed, vertical heat transfer pipes. Since the construction (1975-78) of the first order engineering model, attention has been directed toward transient heat transfer and the possibility of natural convection phenomena occurring around the individual pipes. The work is both experimental and theoretical in nature.

Other current studies consider the possibility of thermal stratification occurring and the means by which it can be controlled. As budgets are limited, the progress is rather slow and no external reports are as yet available.

The research is being done in cooperation with the Department of Applied Physics, Delft University of Technology (Professor C. Hoogendoorn), and the Laboratory for System and Control Engineering of the Eindhoven University of Technology (Prof. O. Rademaker).

Table 1: Rough Relative Comparison of Concepts

	Development Stage	Cost(a) Effectiveness	Thermal Effectiveness	Site Availability	Equivalent Capacity (f)	Home Overall Rating
Pond (e)	Good	Good	Good	Good	50-10,000	Good
Lake (e)	Poor	Excellent	Good	Fair	500-1,000,000	Good
Cavern (e)	Fair	Fair(b)	Good-Fair(c)	Fair-Poor	100-10,000	Fair
Tank (e)	Excellent	Poor(d)	Excellent	Excellent	50-500 and >10,000	Good
Earth	Good-Fair	Good-Fair	Fair-Poor	Excellent - Good	1-1,000	Good - Fair
Rock Borehole	Fair	Good	Fair-Poor	Fair	100-1,500	Fair
Ice	Good	Excellent	Excellent	Good-Fair	1-10,000	Good

Notes: (a) Based on single annual thermal inventory turnover
(b) Natural caverns or abandoned mines are better
(c) With insulation, rating is good
(d) Much lower cost with gravity dam tank
(e) Can exceed one thermal inventory turnover per year and thus better economics than shown in second column.
(f) number of homes - annual energy requirement

AUBURN UNIVERSITY FIELD STUDIES OF THE AQUIFER THERMAL ENERGY STORAGE CONCEPT

Contact: Fred Molz or Joel Melville, Principal Investigators, Department of Civil Engineering, Auburn University, Auburn, Alabama 36849, U.S.A., and David Myers, Field Test Facilities Coordinator, Pacific Northwest Laboratory, Richland, Washington 99352, U.S.A.

The first of three injection/storage/recovery cycles in the third series of such experiments at the Mobile, Alabama, field test site was completed on May 17, 1981. (See ATES/STES Newsletters, Vol I, No 4; Vol II, No 1 and 2; Vol III, No 1 and 2.) The total volume injected was 26,500 m^3 (6.7 x 10^6 gal) at an average temperature of 58.9°C Bromide tracer was injected continuously with the heated water at an average concentration of 17 ppm. No measurable clogging of the injection well was detected. Temperatures at 6 elevations were recorded in 12 observation wells during the complete cycle. The injection-recovery temperature was recorded also. Bromide measurements were recorded at 2 observation wells and in the injection-recovery well.

Tracer recovery concentrations indicate that significant thermal convection occurred during the one month of storage. Data from the tracer observation wells indicated a dispersivity near 0.1 m. However, the tracer recovered from the injection well was at a concentration much lower than expected given a 0.1 m dispersion length. Thus the data strongly suggested thermal convection which introduced relatively cool native groundwater near the bottom of the injection well during recovery.

Data from the temperature observation wells supported the thermal convection hypothesis also. Throughout the storage period, groundwater temperatures dropped much more in the bottom half of the aquifer than in the upper half. This and a relatively small injection volume led to an energy recovery efficiency of 55-56% in a recovery volume equal to the injected volume. Previous experiments at the Mobile site based on an injection volume of 55,000 m^3 and a partially penetrating injection-production well resulted in recovery efficiencies of 66% and 76% during the first and second cycles, respectively.

At the present time (June 25, 1981) the second injection-storage-recovery cycle is well underway. Approximately 30,000 m^3 of water have been injected at an average temperature near 84°C. No clogging is being observed at an injection rate of 0.68 m^3/min (178 gal/min). However, the higher injection temperature drove relatively large volumes of gas out of the supply water, which required modification of the piping system to allow for release. This was accomplished by simply adding an open stand pipe near the injection well.

The second injection will continue at least through September 30, 1981 and probably through the middle of October. This should result in an injection volume greater than 60,000 m^3 at a temperature above 80°C. Two months of storage and two months of recovery will follow. During this time a third injection-storage-recovery cycle will be designed in an attempt to optimize energy recovery at the 80°C plus injection temperature used during the second cycle.

INVESTIGATION OF THE POTENTIAL OF AQUIFER THERMAL ENERGY STORAGE IN THE UNITED KINGDOM

Contact: R. Kitching and B. Adams, Institute of Geological Sciences, Hydrogeological Unit, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, United Kingdom

In the latter part of 1980 the Hydrogeological Unit of the Institute of Geological Sciences of Great Britain completed a literature study into Aquifer Thermal Energy Storage (ATES). This literature survey was coupled with a desk study into aquifers suitable for preliminary experiments into ATES within the United Kingdom; the study was funded by the U. K. Department of Energy. It was concluded that the Lower Greensand aquifer in the Cambridge area and the Sherwood Sandstone of the Midlands are apparently suitable for ATES experimental studies. Differences in aquifer thickness and the potential availability of hot injection water in these areas suggested that the scale of experiments in the two aquifers would be somewhat different.

The apparent lack of suitable source water and the thinness (13 m) of the Lower Greensand aquifer of the Cambridge area suggests that it would be more suited to a relatively small-scale experiment where injection water would be heated on site--the available heating capacity probably constituting the limiting factor with regard to injection rates and temperatures. By the end of spring, drilling of an injection/extraction borehole and three observation boreholes had been completed. It is hoped that injection of water at about 60°C and a rate of 30 m^3/day over 50 days will commence this summer. Storage and extraction periods of similar duration will follow.

On the other hand, the high level of industry in the Trent Valley (above the Sherwood Sandstone of the Midlands) suggests that, when the thickness of the aquifer is also considered (up to 300 m), this area may be suitable for a somewhat larger ATES study using industrial waste water as the injection source.

Reference: "Investigation of the potential of aquifer thermal energy storage in the United Kingdom" by B. Adams, R. Kitching, J. A. Barker, and D. L. Miles, International Conference on Energy Storage, Brighton, United Kingdom, April 29-May 1, 1981.

REMINDER

Contributions for the next issue of the Newsletter are due November 6, 1981.

SIMULATION OF THE MOBILE EXPERIMENTS

Contact: T. A. Buscheck, C. Doughty, and C. F. Tsang, Lawrence Berkeley Laboratory, Berkeley, California 94720 U.S.A.

While the first cycle of the 1981 series of ATES experiments was being carried out by Auburn University at Mobile, Alabama, LBL performed a numerical simulation based on the field operating conditions to predict the outcome of the experiment before its conclusion. The goal was to test our understanding of the aquifer storage problem and to verify our numerical model CCC.

Details of the Mobile experiment are described elsewhere in this issue and in STES Newsletter, Vol III, Nos 1 and 2. The basic idea is that water at approximately 55 to 60°C is injected over a period of one month into an aquifer approximately 21 m thick and with a permeability of about 63 darcies. It is then stored for one month and subsequently produced. The injected water is obtained from a supply well perforated in the same aquifer 240 m away from the injection/production well. LBL was provided with the basic geological, well test, injection flowrate, and injection temperature data.

The simulation method was smilar to that used by LBL to model the 1979-1980 Auburn experiment. The well test data and geological information were studied and analyzed to obtain reservoir parameters and their range of uncertainty. Our results generally confirmed the analyses done by Auburn University. Since the supply well is 240 m from the injection/storage well and the thermal radius is only about 25 m, it was decided that a radial calculation mesh would be adequate. Based on the injection flowrates and temperatures provided, we employed the numerical model CCC to calculate production temperature and energy recovery factor for a given production flow rate schedule. The experimental results were made known to us after we completed and presented our results. The predicted energy recovery factor is 0.62 compared to the experimental value of 0.56. This agreement is satisfactory. The predicted production temperature versus time curve shows a high initial production temperature, followed by a more rapid decrease than the experimental curve shows.

Subsequent to comparing our predictions with the experimental results, we made a series of parameter sensitivity studies in an attempt to understand the differences between the predicted and experimental results. Several sets of calculations were made, including:

(1) Mesh variation. Results are found to be nearly mesh-independent.

(2) An arbitrary increase of aquifer permeability from 63 darcies to 94 darcies. The calculated recovery factor is reduced from 0.62 to 0.55.

(3) Two-layered-permeability aquifer, in which the upper layer is 1.5 times as permeable as the lower but with an average of 63 darcies, corresponding to the field value. The recovery factor is calculated to be 0.60.

(4) Three-layered-permeability aquifer, in which the middle layer is 1.5 times as permeable as the upper and lower layers while keeping the average at the field value of 63 darcies. The recovery factor is calculated to be 0.62.

(5) Simulation of a large thermal dispersion effect. We followed Sauty who approximated this effect by using an effective thermal conductivity value. A value ten times the normal value was used. Based on an approximate relationship developed by Doughty et al., this corresponds to a dispersion length of 3 m. The energy recovery factor is calculated to be 0.57.

Several additional parameter-sensitivity calculations were made. It was found that although the recovery factor can be made to reproduce the experimental data, the time rate of decrease of calculated production temperature for many alternative cases is always faster than the experimental value. After these studies, we came to the preliminary conclusion that this production-temperature discrepancy may be due to either thermal dispersion or vertical inhomogeneity within the aquifer. Efforts have been initiated to study both processes. Understanding the cause of this discrepancy is important for further prediction calculations. Although the comparison of experiment and calculation may be considered satisfactory, we want to be sure that the discrepancy will not increase with changes in storage temperature or other conditions.

AN INTERNATIONAL CONFERENCE: SEASONAL THERMAL AND COMPRESSED AIR ENERGY STORAGE

October 19-21, 1981, Seattle, Washington, U.S.A.

The following is a list of talks in the field of Seasonal Energy Storage to be presented at the conference. For further information, please contact Jim Minor or John Raymond, Pacific Northwest Laboratory, P. O. Box 999, Richland, Washington 99352, U.S.A.; or MCC Associates, 8534 Second Avenue, Suite 400, Silver Spring, Maryland 20910, U.S.A.

SESSION I: STES OVERVIEW

"Actual Applications of Low Temperature Storage Systems in Sweden," B. Svedinger, VIAK AB, Sweden.

"Status of R&D Work for Long Term TES in Germany," F.J. Friedrich, Kernforschungsanlage, W. Germany.

"General Overview of CNEN Thermal Storage Programme and its State-of-the-Science and Technology," R. Vellone, Com. Naz. Per L'Energia, Italy.

"Alternative Energy Storage for the Swedish IEA National Base," T. Lindbo/T. Bruce, Swedish State Power Board/Sodertalje Energiverk, Sweden.

"Preliminary Assessment of Promising Nonaquifer STES," D. E. Blahnik, Pacific Northwest Laboratory, U.S.A.

"Technical Possibilities and Economies of Large-Scale Thermal Storage Application in Cogeneration District Heating," R. Jank, Munich, W. Germany.

SESSION II: SYSTEMS I - STES PROJECTS

"Seasonal Heat Storage in Greenhouse Soil," A. Nir, Weizmann Institute of Science, Israel.

"Aquifer Storage Using the Doublet Well Configuration," F. J. Molz, Auburn University, U.S.A.

"Heat Storage and Recovery in Aquifers with Significant Regional Flow," T. Yokoyama, Yamayata University, Japan.

"STES for Heat Pumps," D. M. Jardine, Kaman Sciences Corporation, U.S.A.

"The ATES Program at the Univeristy of Minnesota," M. Walton, University of Minnesota, U.S.A.

"The Development and Application of Aquifer Storage in China," F. Woo, Tsinghua University, Peoples' Republic of China.

"Aquifer Based Cooling--A Demonstration," S. G. Angus, Hooper & Angus Associates, Canada.

"Two Concrete Projects of Space Heating with Solar Energy and Seasonal Aquifer Thermal Use," P. Iris, Ecole Nationale Superieure, France.

"The Sunstore System: Deep Ground Heat Storage, Low Temperature Collectors and Indoor Heaters," O. Platell, Sunstore KB, Sweden.

"Experimental Results of an Earth-Storage System of 350 M^3," P. Chuard, Sorane SA, Switzerland.

"Field Experimentation of the 'Soil Therm' International Storage System," G. Vachaud, Institute de Mecanique, France.

"Solar Heat Storage in the Bedrock," O. Seppanen, Ekono, Inc., Finland and U.S.A.

"Managing Energy Through TES in an Aquifer," D. Supkow/P.S. Huyakorn, Dames & Moore/GeoTrans Inc., U.S.A.

SESSION III: SYSTEMS II - STES METHODOLOGY

"Sealing and Insulation of Long-Time Heat Storage in Wolfsburg," J. Strickrodt, Forschungsgesellschaft, West Germany.

"Heat Storage in Rock--Multiple Well System," S. Andersson, Allmanna Ingenjorsbyran, Sweden.

"A New Laboratory Test Facility for Aquifer Materials," S. C. Blair, Pacific Northwest Laboratory, U.S.A.

"Study for Active Solar Annual Heat Storage for the Coast Guard Site in Seattle, WA," A. Jeffries, Alternative Energy Systems, U.S.A.

"A Group of Solar Houses with Seasonal Heat Storage in the Soil," A.J.Th.M. Wijsman, Institute of Applied Physics, The Netherlands.

"Conceptual Design Options for a Real-World STES Application," W. Hausz, ECO-Energy Associates, U.S.A.

"The Block-Filled Cavern and Pond--New Systems for Low-Cost STES," U. Lindblom, AB Jacobson & Widmark, Sweden.

"'Free-Cooling' Applications Using Annual TES," W. J. Schaetzle, University of Alabama, U.S.A.

"Advantages of Subdivided Seasonal Hot Water Reservoirs," F. Scholz, Institute fur Reaktorbauelemente, West Germany.

"Once-Through Heat Transport & Seasonal Storage for City of Bellingham," I. Oliker, Burns & Roe, Inc., U.S.A.

"Energy Storage Development," R. Van Der Maas/ R. O'Hara, U. S. Solar Homes Corporation, U.S.A.

SESSION IV: MODELING AND ECONOMICS

"Analytical Description of the Heat Losses from Underground Thermal Seasonal Heat Stores," P. N. Hansen, Technical University of Denmark, Denmark.

"Aquifer Thermal Energy Storage: Recent Parameter and Site-Specific Studies," C. F. Tsang, T. A. Buscheck, and C. Doughty, Lawrence Berkeley Laboratory, U.S.A.

"Above Ground Thermal Energy Storage Tank Heat Transfer Analysis," G. T. Williams, Hooper & Angus Associates, Canada.

"Dimensioning of Duct Systems for Ground Heat Storage," G. Hellstrom, Lund Institute of Technology Sweden.

"The Recovered Energy of Hot Water Storage," J. Straub, Technical University of Munich, West Germany.

"Analyses and Modeling of Ground Heat Storage Systems," J. Claesson, Lund Institute of Technology, Sweden.

"Time Constants in Energy Storage and Distribution," J. H. White, Canada Mortgage & Housing, Canada.

"The Value of Storage in Annual Cycle Solar Heating Systems," S. Sillman, SERI, U.S.A.

"How to Decide Whether to Seriously Investigate an Application of ATES," C. F. Meyer, Santa Barbara, California, U.S.A.

"The Economics of Heat Storage in Aquifers," R. W. Reilly, Pacific Northwest Laboratory, U.S.A.

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