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MEMORANDUM FOR: Malcolm R. Knapp, Chief
Geotechnical Branch
Division of Waste Management

FROM: Richard Codell
Hydrology Section
Geotechnical Branch
Division of Waste Management

SUBJECT: ATTENDANCE AT AMERICAN GEOPHYSICAL UNION MEETING

On May 14, 15, and 16, 1984, I attended the Spring Meeting of the American Geophysical Union in Cincinnati, Ohio. I spent all of Monday and Tuesday, and half of Wednesday, in sessions dealing with groundwater hydrology and transport. Many papers in these sessions related directly to waste repository problems. Abstracts for these sessions are attached to this memo.

On Wednesday afternoon, I attended about half of the session on General Hydrology, in which I presented a paper. The abstracts of this session and an outline of my talk are also enclosed. Papers in this session were not directly involved with nuclear waste management issues.

Among the more interesting papers were:

H11-01

Mark Reeves discussed a coordinate transformation for SWIFT which mapped x and y into stream function and potential coordinates. There were advantages to this technique for solving source-sink problems because the new mapping concentrated grid blocks close to the source and sink. This technique was used in several of the examples for the NRC Benchmarking contract.

H11-04

Ben Ross discussed the significance of head errors caused by temperature differences between wells.

H11-07

Barbara Cooke's presentation on flow parameters in partially saturated soils went without a hitch. Her presentation was polished, and there was good audience interest.

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H11-08

A.Mantoglou presented some work, funded by the NRC under the Office of Research, on stochastic modeling of unsaturated flow in soil. The most interesting finding from this study was that the hysteresis effect could be predicted strictly from the spatial variability of soil properties. Such results could not have been predicted by conventional deterministic methods.

H11-13

K. Novakowski discussed a field measurement of dispersion in a two-well tracer test in a planar fracture in hard rock nearly parallel to the earth's surface.

H11-14

Rick Waddell presented hydrologic data on the Yucca Mountain site, and plans for future monitoring efforts

H12-01

Chen-Fu Tsang discussed ways that heat could be used as a tracer in groundwater studies to determine aquifer properties. Among the interesting techniques was to measure the tilt of the interface between the hot an cold water and back out aquifer properties using the known relationship between fluid density and temperature.

H21A-02

M. Goltz discussed observed differences in equilibrium and non-equilibrium sorption of tracers in a sand aquifer.

H21A-03

A. Valocci discussed an analytical model which demonstrated the mathematical differences between equilibrium and non-equilibrium sorption, and suggest ways to predict when an equilibrium model of sorption would be valid.

H21A-05

Gail Cederberg described the use of the model TRANQL, which is a detailed equilibrium chemistry model coupled to a one-dimensional transport model. An example of its use for multicomponent transport with chemical reactions was given.

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H21A-07

Franklin Schwartz described a modeling method which used particle tracking in a fractured 3-dimensional medium. The movement of the particle is described by a random process in 3 dimensions. The random distribution used for particle movement, however, is derived from a statistical study of a small subdomain.

The results of a computational experiment using computer-generated fracture intersections showed that the technique was successful. Several members of the audience and I commented that the experiment might not have shown the apparent dependence of dispersion on scale, because large features responsible for large scale dispersion would not be represented in a small scale sample.

H21A-11

Jeff Serne described an experimental comparison of packed column data on uranium mill tailings leachate with the MINICUP transport-chemical equilibrium model.

There were several interesting papers presented in the Tuesday afternoon session H22A, which dealt with modeling of immicible chemicals, such as hydrocarbons, in landfills.

After the regularly-scheduled papers were presented, a panel was convened to discuss dispersion in hydrodynamic transport modeling. The Panel included L. Gelhar, E. Frind, G. Pinder, F. Molz and was moderated by L. Konnikow.

Gelhar advocated the stochastic approach. Other members of the panel were skeptical of the usefulness of stochastic models in the field, because of the data needs. Gelhar countered that much of the data needed could be inferred by geologists armed with the knowledge of how the geologic strata were formed.

I made a comment to the panel and audience that I felt that the importance of dispersion is frequently overrated. Knowing dispersion parameters might help a modeler show that his model accurately predicts field observations which would be useful for publishing technical papers. In a regulatory sense, however, field data may never be known well enough to exactly predict the shape of the plume, and even so, there is so much uncertainty in every other area of concern

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that detailed results of a dispersion model would be of limited use. Also, since pollution is likely to be chronic rather than accute, long-term and wide-area averages of concentration make sense for calculating risk in terms of statistical hazards to affected populations. These spatial and temporal averages are much less sensitive to dispersion than the concentrations themselves. Ther was no immediate response to my comments, possibly meaning that the panel agreed completely or that they didn't want to face this issue. Emil Frind commented later, however, that he considers models at this point in time to be tools for understanding phenomena, and not for use in regulation.

H31B-08

Graham Fogg described a field and model study of a multilayer aquifer in East Texas. The complicated pattern of interconnection of sand units was inferred from the mathematical model and measured hydraulic gradients.

H31B-11

Chu-Hua Huang from University of Arizona described his NRC-funded work on numerical models of fracture flow and transport using computer-generated fracture networks.

H31-15

N. Hubbard presented results of groundwater dating of brines in the Palo Duro basin in Texas. Models for mixing and transport of the brines were postulated in an attempt to use the measured Ar-40 and He-4 data to establish their ages. In some areas of measurement, it was possible to establish good ages, but mixing of ancient and younger brines in other regions reduced the reliability of the established dates.

H32-02

W. Grayman presented an interesting screening model for chemical pollutants in surface water under development by EPA. This model is centered on a large data base which contains data on stream flow and stream interconnections for the U.S. and chemical discharge data for many thousands of known sources. The computational models themselves, however, were simplistic.

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I presented my paper on Average Dilution in Rivers next (H32-03). This paper dealt with several interesting phenomena associated with the calculations of the expected value for dilution in rivers. I was fortunate that my paper followed that of Grayman, since it pointed out the very mistake which is often committed in these calculations. Unfortunately, he was not present during my talk since he stepped outside to chat with friends. I collared him later, however, and personally lectured him on my findings.

I was forced to leave this session early to catch my flight home, and did not hear all of the remaining papers.

The conference was enjoyable and informative for the most part. My main criticism is that there were too many papers on too many subjects to assimilate very much. With a time limit of 15 minutes or less for presentation and questions, there was little time for in-depth understanding. Hallway conversations and meals with luminaries during the three days were useful and interesting.

Richard Codell
Hydrology Section
Geotechnical Branch
Division of Waste Management

cc: WMGT Staff w/o encl.
R. Browning
M. Bell

Enclosures:
1. Abstract of sessions attended
2. Copy of slides for presentation with narrative

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Y = 0, was found to reverse in Europe and Asia in 1970. The typical drift rate in Europe was 5°/year. Before 1970, the drift was westward and after 1970, up to 1980, the direction was to the east. In other regions of the world the Y = 0 lines were rather stable during 1956-1978, the period studied here. The shape and orientation of (X,Y)-vectograms of annual means in Eurasian observatories indicate that the wave-like variation observed in the vector horizontal field was due to changes in a regional source (focal point at 45°N, 85°E) near the maximum area of the large Siberian non-dipole Z anomaly.

GP41-10

The Decrease of the Geomagnetic Dipole Field as Part of the General Secular Variation

JOACHIM MEYER (Institut für Geophysik, Herzberger Landstr. 180, 3400 Göttingen, Germany)

The ongoing decrease of the earth's dipole moment has repeatedly been interpreted as a decay of the whole geomagnetic field. However, the dipole part of the secular variation loses its predominant role, if the field is reduced to the depth of the source layer, about 100 km below the core/mantle boundary, as revealed from the spatial energy density spectrum of the field. It is shown that the mean magnetic energy at that depth is already balanced if only two more spectrum terms, i.e., the quadrupole and octupole constituents, are included. The result is in accordance with the idea of energy conservation as inferred from the spectrum secular variation. It strongly supports the concept of the presently observed secular variation to be caused primarily by structural changes of the current system in the source layer associated with an exchange of energy between spherical harmonics of different degrees, without involving a growth or decay of the field as a whole.

GP41-11

Recent Behavior of the Eccentric Geomagnetic Dipole

JOSEPH C. CAIN (USGS, Denver, CO 80225)
DAVE R. SCHMITZ, (Dept of Mathematics, Colorado School of Mines, Golden, CO 80401)

Vestine first discussed the correlation between variations of the earth's rate of rotation and the rate of westward drift of the eccentric dipole. Initial results from 1900-1960 for 1966 confirmed that a slowing of rate followed a decrease in the length of day. This paper reviews evidence from field models produced since the Vestine study. It is shown, using the DGRFs, IGRF 1980, POSTER80, and M[illegible] models, that as the dipole continued its abnormally large decay, the eccentric position continued to drift westward to a 1980 value of 438 km in equatorial projection at some 16 km per decade while the westward drift slowed to a degree per decade. The GSFC(12/66) model showed only a slow decrease in drift from [illegible] per decade [illegible] to 2.5° per decade at 1960, which does not confirm the Vestine curve. However, separate analyses of subsets of these data for the intervals 1900-1920 and [illegible] showed rates of 1.2 and 3.0° per decade respectively. Although the errors in these last two analyses are fairly high, the results would appear to confirm a slower rate for the early part of the 20th century. The [illegible] data is too large to confirm the the phase lag [illegible] Vestine.

GP41-12

Maximum Rates of Change of Geomagnetic Field Directions as Determined from Paleomagnetic Studies of Lacustrine Sediments

KENNETH L. VEROSUB (Department of Geology, University of California, Davis, CA 95616)

Theoretical analyses of the magnetohydrodynamic processes which govern the generation of the magnetic field have shown that significant changes in magnetic field direction can occur on time scales on the order of a few hundred to a few thousand years. What is not determined by the magnetohydrodynamic studies is the upper limit on the magnitude of the changes in field direction. Recent improvements in the techniques used for the collection, measurement and analysis of paleomagnetic samples from lacustrine sediments make it feasible to use lacustrine sequences for the purpose of studying the magnitudes and rates of these changes. For example, confirmation of the existence of the Mono Lake geomagnetic excursion establishes that during an excursion the virtual geomagnetic pole position can change by as much as 90 degrees over a time interval as short as a few hundred years. High-resolution paleomagnetic studies of Holocene lacustrine sediments indicate that even during periods of "normal" secular variation, the virtual geomagnetic pole position can change at a comparable rate although this rate persists for a much shorter period of time. These results suggest that at least some geomagnetic excursions can be interpreted as large amplitude secular variation rather than as aborted polarity transitions.

GP41-13

Magnetostratigraphy of DSDP Leg 94 Sediments and Details of Polarity Transitions from the North Atlantic

B. M. CLEMENT
D. V. KENT (Lamont-Doherty Geol. Observ. and Dept. of Geological Sciences, Columbia Univ., Palisades, NY 10964)
SCIENTIFIC STAFF, LEG 94 OF THE DSDP/IPOD

Hydraulic piston coring and extended core barrel coring during DSDP Leg 94 recovered undisturbed sediment ideally suited for magnetostratigraphic study at six sites in the North Atlantic Ocean. These high sedimentation rate cores (40-50 m/M.A.) provided detailed records of the geomagnetic polarity history for particularly the last 4 M.Y. at each of the sites.

U-channel samples up to 70 cm long were taken across 11 polarity transitions from cores at 4 sites. The U-channels were continuously subsampled at 0.5 cm intervals and measured using a cryogenic magnetometer. Progressive A.F. demagnetization of specimens from the Brunhes/Matuyama, lower Jaramillo and upper Olduvai transitions from site 607A indicated that the transitional magnetizations are dominated by a low coercivity, steeply downward direction interpreted as a present field overprint. Unlike results obtained from some of our previous studies, further demagnetization after removal of the present field overprint reveals multi-component magnetizations. Two or more distinct components, carried in the medium coercivity and high coercivity ranges, are consistently observed through the transition zones. These components are interpreted as transitional field directions which were recorded by grains of different coercivities at different times within the same specimens. This complex behavior allows constraints to be placed on the remanence acquisition processes in these sediments as well as providing constraints on the nature of the transitional fields of the three reversal transitions observed at this site.

GP41-14

Archaeomagnetic Paleointensities from Pottery of the American Southwest

ROB STERNBERG (Department of Geology, Franklin and Marshall College, Lancaster, Pa. 17604)

The Thellier double-heating paleointensity experiment was used on 187 specimens from 77 dated potsherds representing 23 archaeological sites from the American Southwest. These sherds were mostly from the three major Southwestern prehistoric cultures: Anasazi, Mogollon, and Hohokam. The Hohokam data were treated as a separate data set because of disagreement over the absolute chronology for this culture. Paleointensities were interpreted for 127 specimens from 54 sherds. Quality factors ranged from 0.4 to 77 with a median value of 12. The pottery exhibited anisotropy of TRM susceptibility with PTRMs acquired in the plane of the pottery averaging 31% greater than PTRMs perpendicular to the plane. This was attributed to fabric anisotropy. An easy-plane model of magnetization was used to correct the paleointensities for anisotropy, systematically increasing the paleointensities by an average of 5.4%. Specimen paleointensities had a median relative error of 9%, and sherd averages had a median relative error due to dispersion of 5%. The data were combined with other North American paleointensities. Outliers were deleted, and the final data set was smoothed with a 200-year moving window. The resulting record extended from 400 BC to AD 1800. The virtual axial dipole moment was a maximum of 14.0×10^{22} Am² at 300 BC, was a minimum of 8.6×10^{22} Am² at AD 800, and rose again to a high of 12.9×10^{22} Am² at AD 1500 before decreasing towards the present value. This pattern is corroborated by relative paleointensities determined from sediments from LeBoeuf Lake, Pa. by King et al. (J. Geophys. Res., 88, 5911-5921, 1983). The Hohokam data were in general agreement with the other North American data regardless of which of the several Hohokam chronologies were used.

Hydrology

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H11-01 ✓

Finite-Difference Solution of Transport in a Doublet Flow Field Using Curvilinear Coordinates

MARK REEVES, DAVID S. WARD AND PETER S. HUYAKORN (Geotrans, Inc., P. O. Box 2550, VA., 22090)

Recently the authors began an investigation of the possible beneficial effects of using curvilinear coordinates in the solution of transport problems. For simplicity, the frequently encountered two-well doublet flow field was chosen because of its analyticity, and the lines of constant potential and constant stream function were taken as the coordinate axes. A preprocessor was then developed which transformed the finite-difference code SWIFT from a Cartesian system to the desired system by modifying the geometric properties of each individual grid block. No changes, other than simple linkage changes, were required in the transport simulator. This we believe, is an important feature of our approach. Three benchmark problems were executed, one for heat transport and two for radionuclide transport. Two of these problems involved coupled transport in the confining beds. In each case both curvilinear and Cartesian simulations were used, and the relative computational efficiency of the former was found to be significant. Execution times were reduced by factors ranging from 4 to 10, and the number of grid blocks was reduced by factors of 3 to 7. Even for such lopsided efficiency factors as these, however, the Cartesian mesh was still sufficiently coarse that it showed significant numerical dispersion arising from grid orientation.

H11-02 ✓

Chemical and Statistical Methods for Determining the Boundary of Contamination

ROBERT A. SAAR (Geraghty & Miller, Inc., 6800 Jericho Turnpike, Syosset, New York 11791)

It is no challenge to declare a well contaminated if it is located in the heart of a chemical plume emanating from a waste facility or spill. However, the judgement becomes more difficult to make at increasing distances from the source. Where is the boundary of contamination at a given time? The question frequently must be answered by regulated industries, their consultants, and by modelers who are calibrating their models with the help of field water-quality data.

This paper describes several chemical and statistical techniques, their advantages and disadvantages, and ways to use them, alone and in combination for various situations to determine whether a distant well is within or just beyond the chemical influence of a water source. A reasonable chance of success requires the use of all applicable methods. Specific examples will illustrate the potential of the various techniques.

Included in the section on chemical methods is a discussion of what to test for and the factors to be considered when making this decision: native (background) water quality; substances that interfere with analyses; and the problems of detection limits.

The statistical section discusses the limitations of the Student's t-test for determining whether water quality at two points is significantly different. Also described is the use of [illegible] analysis as a means of determining whether a well is coming under the influence of a waste [illegible] as reflected by significantly increasing concentrations with time.

H11-03

Heat Flow Beneath Arctic Streams

A. WANKIEWICZ (National Hydrology Research Institute, Ottawa, Canada, K1A [illegible])

Perennially unfrozen ground (river talik) exists beneath Rengleng River and Caribou Creek near Inuvik, Northwest Territories. Sub-channel ground temperature observations to 13 metres depth were obtained in April, August and November. Riverbed thermal-diffusion parameters were determined from heat transfer simulations of the summer and autumn profiles. It was found that while conduction is the dominant heat-transfer process in the talik beneath Caribou Creek, macrodispersion of heat by flowing ground water is the dominant process beneath Rengleng River. The latter increases apparent conductivity by an order of magnitude over simple conduction and can result in 10°C of summer heating, 7 metres beneath the channel. Ground water flow along a talik is shown by flow-net analysis to vary periodically in both time and space when the surface-water profile in the channel follows a

ool-and-reffle sequence. After the streams cease flowing in mid-winter, a frost layer up to two metres thick develops beneath the centre of the channels. Temperature recordings in 1978 showed that frost did not begin to thaw until the runoff peak of June 8, remaining partially frozen at deeper levels over 16 additional days.

H11-04

Correction of Measured Heads for Temperature Effects

BENJAMIN ROSS (GeoTrans, Inc., 209 Elden Street, Herndon, Virginia 22070)

The usual definition of hydraulic head assumes the density of water is constant. In deep formations, temperature and pressure may cause significant changes in water density. Such density variations complicate computations relating pressures to the height of a column of water in a piezometer. They also obscure the interpretation of ground-water flow in terms of either type of measurement.

Head measurements in aquifers with varying temperatures may be interpreted by analyzing the weight of water in a hypothetical U-tube consisting of two piezometers and the flow units connecting their open intervals. This method was first introduced for the study of saline aquifers by Jorgensen, Gogel, and Signor.

The U-tube analysis demonstrates that heads measured by observing the height of static water columns in a nest of piezometers may be used without correction to determine vertical flows. Horizontal flows in aquifers with no dip may be determined by correcting measured water levels or pressures to "cold water heads" representing the height of a column of water at any arbitrary reference temperature. In dipping aquifers with nonuniform temperature patterns, flow cannot always be determined from a "cold water head" and sometimes must be calculated directly from pressures.

H11-05

A Model of the Temperature Dependence of Hysteretic Soil-Moisture Characteristics

J. R. NIMMO (USGS, Menlo Park, CA 94025)
E. E. MILLER (Dept. of Physics and Dept. of Soil Science, University of Wisconsin-Madison, WI 53706)

A model has been developed to represent temperature dependence as well as hysteresis of static soil-moisture characteristics (water content θ vs. matric potential ψ). It combines a quantification of temperature dependence called the "gain factor" with an independent-domain hysteresis model of Mualem. A function of θ only, the gain factor is the ratio of the actual variation in ψ with temperature to the prediction of the commonly applied surface-tension, viscous-flow (STVF) concept. For a given medium, this combined model represents all hysteretic θ vs. ψ curves at all temperatures with three functions, two of ψ and one of θ. Two important physical assumptions are implicit in the model: the gain factor is taken as independent of temperature and equal for drying and wetting.

This model has been applied to measurements for glass beads, a sand, and an undisturbed silt-loam core sample in the range 4°-50°C. The resulting fits to the data points are mostly well within experimental error, while a comparable STVF treatment produces very poor fits. Besides permitting calculation of moisture characteristics at arbitrary temperatures, the gain-factor values are useful in judging the possible significance of suggested temperature-dependence mechanisms.

H11-06

An Inverse Approach of Estimating Groundwater Transport Parameters

A. G. BOBBA (National Water Research Institute, Burlington, Ontario, Canada L7R 4A6)

Contaminant transport through groundwater flow system is dominated by convection and hydrodynamic dispersion. The hydrodynamic dispersion coefficients in groundwater system can be determined from observed values of contaminant concentrations. This is achieved in two steps. The first step is to compute the concentrations by a two dimensional finite element transport model with dispersion coefficients which are prescribed in increments using the approach of Pectorrezzo (1967). From these computed concentrations, a double interpolation scheme using Newton's binomial formula can be constructed. This binomial equation represents the concentration-dispersivity relationship.

The second step is to use this relationship for estimating the dispersivities at observation site from observed values of concentrations. If there are exactly two such values, the Newton's method is used to solve uniquely for the two unknown dispersivities (longitudinal and transverse). Otherwise, a least squares optimization procedure will be used.

Examples from a low level radioactive disposal site will be given.

H11-07

Some Flow Parameters of Partly Saturated Soils and Their Spatial Variability

B. A. COOKE (U. S. Nuclear Regulatory Commission, Division of Waste Management, Washington, D.C. 20555)

W. BRUTSAERT (School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853)

The infiltration properties of a loam soil were determined in the laboratory by means of a capillary rise apparatus on 186 disturbed field samples. Measured and determined for each sample were the rate of advance of the wetting front, three forms of sorptivity and three forms of diffusivity as functions of water content. Calculations utilized a concise exponential wetting front curve fit with the associated exact diffusivity, and the quasi-steady-state solution with the exponential diffusivity. The latter was slightly more accurate than the former, but not as stable. The results obtained for the sorption parameters were similar to those reported previously for horizontal flow experiments. The value of $\beta=8$ in the exponential diffusivity was not contradicted. A significant difference between topsoil and subsoil parameters was discovered. Topsoil sorptivities with a mean of 0.051 $cm/s^{1/2}$ were about half those of the subsoil, with a mean of 0.098 $cm/s^{1/2}$. Values of diffusivity near saturation showed approximately the same ratio. The semivariogram and autocorrelogram analysis showed a range of approximately 150m for subsoil sorptivity.

H11-08

Effects of Spatial Variability of Soil Properties on Three-Dimensional Unsteady Unsaturated Flow

A. MANTOGLOU (Department of Civil Engineering, MIT, Cambridge, MA 02139)
L. W. GELHAR (Department of Civil Engineering, MIT, Cambridge, MA 02139)

The effects of spatial variability of soil properties on three-dimensional unsteady unsaturated flow are investigated and effective large scale parameters are evaluated. A Richards type equation is used in order to describe the local flow. The spatial variability of the hydraulic properties of the soil (saturated hydraulic conductivity, pore size distribution parameter and specific moisture capacity), is realistically described in terms of three-dimensional statistically anisotropic random fields. The local governing equation is perturbed and linearized. Assuming local stationarity and using a wave number representation, effective parameters and their dependence on key statistics of the soil properties (mean, variance, correlation lengths, etc.) were evaluated.

The most important findings are:

(1) The effective hydraulic conductivity tensor shows a hysteresis effect, due to spatial variability. For a one-dimensional vertical mean flow, the effective hydraulic conductivity shows hysteresis similar to that observed in the laboratory.

(2) The effective hydraulic conductivity tensor is anisotropic with degree of anisotropy depending on the flow conditions. In the case of drying the anisotropy is relatively small, while in the case of wetting the anisotropy is large.

These effects seem to be of importance and should be considered in numerical studies of large scale unsaturated flow systems.

H11-09

Designing Aquifer Restoration Schemes Using Contaminant Transport Simulation and Nonlinear Programming

S. M. GORELICK (U.S. Geological Survey, Menlo Park, Calif. 94025)
C. I. VOSS (U.S. Geological Survey, Reston, VA 22092)

A management modeling methodology is presented for designing and evaluating aquifer restoration schemes. Finite-element groundwater flow and contaminant transport simulation are combined with nonlinear optimization. The management model can determine optimal well locations plus pumping and injection rates for groundwater quality control. Examples demonstrate linear or nonlinear objective functions subject to linear and nonlinear simulation and water management constraints. Local restrictions can be placed on hydraulic heads, pumping and recharge rates, hydraulic gradients, and contaminant concentrations. Three design strategies are compared for an aquifer that is contaminated by a steady and constant contaminant source. They are: pumping for contaminant removal; water injection for in-ground dilution; and a pumping, treatment, and injection cycle. Finally, contaminant plume interception and in-ground dilution strategies are compared for a transient-case example. The methodology is very general and can be applied to the management of many types of nonlinear distributed parameter systems.

H11-10

Relationship Between Organic and Inorganic Species Concentrations in Contaminated Groundwaters

J. E. BARBASH (Dept. of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1)
J. F. BARKER (Dept. of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1)

Investigations of groundwater contamination by organic compounds often incorporate geophysical surveys or the monitoring of inorganic parameters in order to delineate the aerial extent of the contaminant plume. This approach is usually based upon the assumption that the distribution of organic compounds within an impacted hydrogeologic system should, in a general sense, mimic that of any inorganic contaminants which may also be present within the affected zone(s). To evaluate this assumption, we tested the significance of a series of simple linear regressions between the concentrations of organic species (Total Identified Volatile Organic Compounds [TIVOC] and Total Identified Extractable Organic Compounds [TIXOC]) and inorganic species (chloride, sulfate and specific conductance) using chemical data from three landfill sites in Southern Ontario.

Using a Type-I error rate of 0.01, none of five organic-vs.-inorganic regressions were found to be statistically significant ($.22<P<.74$). In addition, the relationship between TIVOC and TIXOC at one site was also found to be non-significant ($P=.61$). However, regressions of chloride against sulfate and against specific conductance at another site were both found to be significant ($P<.0003$). Based upon these results, inorganic contaminant distributions or geophysical surveys would therefore appear to be inappropriate as indirect indicators of organic species distributions in contaminated groundwaters.

H11-11

An In Situ Column for Determining Groundwater Transport Parameters of Trace Organic Solutes

STEVEN L. WINTERS (Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1)
DAVID ROBERT LEE (Environmental Research Branch, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada K0J 1J0)

Model predictions of contaminant retardation in groundwater were compared with results from an in situ column technique. The method, also appropriate for inorganic solutes, was as follows: Stainless steel cylinders (20cm diameter, 30cm long) were inserted vertically into a streambed known to be receiving groundwater. A tracer mixture (e.g., tritium and ^{14}C-labeled naphthalene) was injected as a slug into a porous screened disc at the column base. Groundwater samples were taken over a period of 2 to 3 days through a small screened sampling point about 20cm above the porous disc. Results showed that it is practical using in situ columns to determine (1) natural changes in groundwater during the final 30cm of flow and (2) retardation factors for selected trace organics at their point of entry to surface water.

Three ^{14}C-labeled compounds were used as organic tracers: chlorobenzene, naphthalene and 4-chlorobiphenyl. All tracers were at 10^{-8} to 10^{-7} per cent of their water solubilities. Field results show that chlorobenzene was not retarded, although a retardation factor of about 2 was predicted from its n-octanol/water partitioning coefficient and a sedimentary TOC of about 0.1%. In addition, naphthalene was observed about 3 times more mobile than predicted by the model. Four-chlorobiphenyl, however, was not observed to move within the column.

H11-12

Adsorption Characteristics of Trichloroethylene - A Comparative Analysis

MOHSEN MEHRAN and ROGER L. OLSEN (D'Appolonia Waste Management Services, 17500 Redhill Avenue, Irvine, California 92714)

Trichloroethylene (TCE), because of its widespread use, is one of the most common organic solvents found in aquifers and has been studied more extensively than other compounds. The geochemical interactions of TCE between the solution phase and the solid phase in the soil-water system are usually lumped into one single parameter known as the distribution or partition coefficient (K_d). This paper presents field measured distribution coefficients over a 1-acre area. These K_d values are also compared with K_d values obtained from three other sources: laboratory experiments, theoretical formulas and literature data. From concentrations of TCE in the soil and the water in contact with the soil, based on 22 field observations, the average distribution coefficient was estimated to be 0.187 ml/g. Leaching of a representa-

tive sample of the soil in the laboratory resulted in a K_d of 0.17 ml/g. The average K_d obtained from the literature was 0.15 ml/g. Theoretical calculations considering the organic carbon content of the soil resulted in an average K_d of 0.155 ml/g. The large number of field measured K_d values, in satisfactory agreement with values obtained from other methods, strongly indicate that results of laboratory column studies and theoretical approaches could reliably be used for calculating the retardation factors in predicting the transport of TCE in soil-water systems.

H11-13

A Field Example of Measuring Hydrodynamic Dispersion in a Single Fracture

K.S. NOVAKOWSKI, (Atomic Energy of Canada Ltd., attached to Environment Canada, Ottawa, K1A 0E7)
G.V. EVANS, (Atomic Energy Research Establishment, Harwell, U.K. OX11 0RA)

A single fracture in monzonitic gneiss, hydraulically connected between two boreholes over an interborehole distance of 10.6 metres, was selected for two dual-well injection-withdrawal type tracer experiments. The fracture was isolated in each borehole with double packer spacings designed to minimize the injection and withdrawal mixing volumes. ^{82}-Br tracer was introduced over a ten minute pulse into a "steady-state" flow regime established between the boreholes. Tracer arrival at the withdrawal well was monitored by sampling the withdrawal water directly. The experiments were conducted at injection-withdrawal flowrates of 0.170 L/min and 0.205 L/min.

The breakthrough curves obtained from both experiments show excellent reproducibility with only a minor variation which is likely due to the difference in flowrates. The smooth shape of the curves is indicative of transport within a single flow plane. A mathematical model which describes the injection-withdrawal geometry and hydrodynamic dispersion was used to fit the field data. A good fit over the entire length of the breakthrough curves was obtained with a dispersivity of 1.35 metres. Dispersion induced by the injection-withdrawal and the monitoring apparatus was found to be small compared to dispersion within the fracture plane.

H11-14

Transport Experiments in Fractured Tuffs at Yucca Mountain, Nevada Test Site

RICHARD E. WADDELL (U.S. Geological Survey, Lakewood, Co. 80225)
JAMES R. ERICKSON (U.S. Geolological Survey, Lakewood, Co. 80225)

Field tests to determine hydrologic and geochemical transport parameters in fractured tuffs at a potential repository site for high-level nuclear waste (Yucca Mountain, Nevada Test Site) are being performed in cooperation with the U.S. Department of Energy. Fractures at well-bore surfaces have been characterized by pumping and packer tests, borehole-flow surveys, and televiewer and television logs. Single-well, drift-pumpback experiments will be conducted, using conservative tracers in 2 to 4 test holes, to collect information about flow velocity and effective porosity. Downhole concentration of ^{131}I will be monitored during the drift phase with four gamma-detectors. The tracers will be pumped back and monitored at the land surface after about 2 months.

Downgradient from Yucca Mountain, a triangular array of 914-meter-deep test holes is being constructed so that hydraulic and transport tests can be performed along directions parallel to and across regional-fracture sets. Field tests will include multiple-well (convergent flow and recirculating) and single-well tests to determine: (1) Characteristics of the fractures away from the boreholes; (2) whether results from laboratory experiments on tracer/rock interactions (being performed by Los Alamos National Laboratory) can be extended into field tests; and (3) comparability of different configurations to measure aquifer parameters. Tracers under consideration include conservative (Br^-, I^-, $^{36}SO_4$, fluorocarbons, HTO, $^{99}TcO_4$); nonconservative (Cs^+, Ce^+, Fe-II/III, other redox couples); and perhaps nondiffusing (Au-colloid, virus) tracers.

H11-15

Estimating Pore Water Velocity p.d.f. Parameters Using Solute Tracer Data

K. W. WATSON (Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831)
R. E. PHILLIPS (Agronomy Department, University of Kentucky, Lexington, KY 40506)
(Sponsor: G. T. Yeh)

Pore water velocity distribution parameters for tilled and undisturbed treatments on the Maury silt loam soil were estimated using solute tracer data. Chloride concentrations with depth were measured in the field following a 5 cm square pulse input of chloride solution to double ring infiltrometers. Breakthrough concentrations were determined on intact soil columns. Optimum means and variances of a lognormal p.d.f. were determined by a least-squares fitting procedure of the appropriate cumulative p.d.f. to experimental data. R-square values in excess of 0.98 were observed for all of the fitted data.

Coefficient of variation values of pore water velocity ranged from 379 to 1090 and 462 to 3550 for the tilled and undisturbed field treatments, respectively. The CV values for the laboratory study were similar for the undisturbed treatment and slightly lower for the tilled treatment when compared to the field study. The laboratory cores were collected following two years of tillage while the field study was conducted during the first tillage year. Tillage appears to reduce pore water velocity variability and deep movement of surface-applied water.

Field Methods for Supporting Ground-Water Chemical Transport Models

Room 13–14 Mon PM

Presider, F.J. Molz, Auburn University

M.P. Anderson University of Wisconsin

H12-01 INVITED

A Thermal Well Test Method

Chin-Fu Tsang (Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720)

A new well test procedure has been proposed that involves the injection and subsequent production of water at a different temperature from that of the aquifer. Temperature measurements are made at the end of injection at different depths in two or more observation wells. By the study and analysis of the temperature data, using analytical solutions and numerical models, we may determine the permeability anisotropy, layering characteristics, and in-situ thermal properties of an aquifer.

This thermal well test procedure has been successfully applied to data from the ATES field experiments carried out by Auburn University in Mobile, Alabama. The first cycle of the 1978-1979 experiment was used to calculate aquifer heat capacity, effective thermal conductivity, and permeability anisotropy. The first cycle of the 1981-1982 experiment was used to determine the relative permeability of a three-layered aquifer. Results are consistent with earlier information on the aquifer and demonstrate the usefulness of the method in estimating permeability anisotropy and layering characteristics.

H12-02

Field Studies of Dispersion in Porous Media: Methods

R.W.D. KILLEY
D.L. MOLTYANER (Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, Chalk River, Ontario K0J 1J0)

Two non-reactive tracer tests have been performed in an unconfined aquifer. In both cases, a volume of water labelled with ^{131}I sufficient to generate a cylinder approximately 1.5 m in diameter was injected into a well that was screened over the saturated thickness of the aquifer. Movement and dispersion of the labelled slug were monitored in an array of dry access tubes extending initially 20 m and subsequently 40 m downgradient of the injection well. Measurements of ^{131}I concentration by gamma counting in the dry tubes were made by both i) collecting continuous profiles of tracer distribution with depth at discrete points in time and ii) collecting continuous records of tracer distribution with time at discrete points in space.

Use of the radiotracer has provided a tremendous increase in spatial resolution over that possible with any other tracer and similar manpower. In the 40-metre experiment, the equivalent of 0.75 million point measurements of ^{131}I concentration were collected. The dry access tube technique causes no perturbation to the flow system other than the inevitable disturbance caused by drilling. With the technique, we were able to define the presence of strata several tens of centimetres thick and several tens of metres in lateral extent within the fluvial sand. Dispersivities within these strata were within a factor of two of the values measured in laboratory columns.

H12-03 INVITED

Field Experiment to Evaluate Dispersion in Unsaturated Media

D.B. STEPHENS (New Mexico Institute of Mining and Technology, Socorro, NM 87801)
L.W. GELHAR (Massachusetts Institute of Technology, Cambridge, MA 02139)
S. YOUNG (Tennessee Valley Authority, Norris, TN 37828)

A field experiment was designed to collect data for studying the three-dimensional nature of the water transport and solute dispersion processes in unsaturated media at a scale representative of utility waste seepage problems. The data will provide a means to validate various predictive models, including recent stochastic theories.

A site has been selected at Socorro, NM, on the basis of preliminary drilling and analyses of hydraulic properties. The depth to the water table is approximately 40m, and the overlying material is sandy. Saturated hydraulic conductivity, K_s, is on the order of 10^{-3}cm/sec.

The experimental design requires pulsed application of water and tracer over a 900m^2 area using an automated drip-irrigation system. The water flux across the surface is expected to be controlled at rates of approximately $0.01K_s$ and $0.1K_s$. Water application will be continuous for at least two years. Conservative tracers, injected over periods of a week or more, may include calcium bromide, pentafluorobenzoicacid, O-trifluromethylbenzoicacid, M-trifluoromethylbenzoicacid, and fluorescent compounds.

A 2m-diameter caisson will be constructed in the center of the plot for monitoring and sampling to a depth of about 30m. Neutron moisture logging access tubes, porous cup samplers, tensiometers and thermistors will be installed horizontally through the caisson at 30cm depth intervals. At 32 locations within and outside the wetted area, water content will be monitored by neutron logging, and nests of solute samplers will be installed. Solute samples will also be obtained from field cores.

The site will be characterized extensively by laboratory and field tests for unsaturated hydraulic properties to give a three-dimensional perspective of spatial variability.

H12-04

Non-Equilibrium Desorption of Volatile Organics During Field Test of Aquifer Decontamination

J. M. BAHR (Dept. of Applied Earth Sciences, Stanford University, Stanford CA 94305)
J. F. PICKENS (GTC Geologic Testing Consultants, Ottawa, Ontario K1S 5H4)
R. E. JACKSON (NHRI Environment Canada, Ottawa, Ontario K1A 0E7)
R. B. WHIFFIN (GTC Geologic Testing Consultants, Ottawa, Ontario K1S 5H4)

A two-well injection-withdrawal experiment was conducted at a hazardous waste disposal site near Ottawa, Canada to assess the feasibility of aquifer restoration by means of a purge well network. The six-day test involved injecting clean water in one well while withdrawing contaminated water from a well located 5 m away. Two tracers, I^- and m-TFMBA, were added to the injection water. Samples taken from multilevel sampling points located along flow lines between the two wells were analyzed to determine the concentrations of tracers and of volatile organic contaminants. Tracer breakthrough data were fitted to an approximate analytic solution to determine average linear velocities and dispersivities. The desorption curves obtained for three organic compounds indicate a departure from transport controlled by local chemical equilibrium. Evidence for non-equilibrium transport includes spreading of desorption curves, "tailing", and an observed increase in concentration following a step decrease in flow rate. Comparison with results of a one-dimensional numerical model of non-equilibrium reactive solute transport demonstrates that the observed desorption behavior of these compounds closely approximates that expected for a linear reversible reaction with rate constants which are small relative to the ground water velocity.

H12-05 INVITED

Estimating Advection and Dispersion Parameters of an Experimental Plume Using Spatial Moments

DAVID L. FREYBERG (Dept. of Civil Engineering, Stanford University, Stanford, CA 94305)

Using detailed data from an ongoing field-scale experiment in a shallow glaciofluvial aquifer at Borden, Ontario, spatial moment estimation techniques are used to estimate the advective and dispersive parameters of experimental plumes of a salt tracer and five organic compounds. Such moment estimates provide model-independent information, integrated over space and time, that is consistent with modern theories of dispersive transport in spatially variable media. Thus, theory and model structures can be tested and quantitative parameter estimates can be obtained.

Application of these techniques to the Borden data collected to date (about 400 days of travel) reveals a plume development consistent with modern theory. In addition, the moment estimates provide insight into the chemical and biological processes leading to the retardation and transformation of the organic compounds.

H12-06

A comparison of methods for determining the retardation of trace organic solutes in hydrogeologic regimes

C.J. PTACEK (Groundwater Research Institute, University of Waterloo, Waterloo, ONT. N2L 3G1)
R.W. GILLHAM (Groundwater Research Institute, University of Waterloo, Waterloo, ONT. N2L 3G1)

To assess the reliability of different techniques for predicting the geochemical retardation of halogenated organic solutes, two laboratory methods and one field method were evaluated and the results compared with a large-scale field tracer test. The laboratory methods included equilibrium batch experiments and miscible displacement column experiments. The field method involved the use of a recently-developed in-situ column technique designed to maintain geochemical and physical conditions representative of the groundwater environment. Both the in-situ column technique and the natural-gradient tracer test were conducted in an unconfined sandy aquifer at Borden, Ontario, and the laboratory tests were conducted using soil materials collected from the same site. Five compounds, carbon tetrachloride, tetrachloroethylene, bromoform, 1,2-dichlorobenzene and hexachloroethane, were used in the study. Results from the batch experiments indicated that temperature and soil heterogeneities were important variables affecting the adsorption characteristics. The column experiments showed the degree of retardation to be sensitive to changes in velocity, suggesting the presence of nonequilibrium processes. Recognizing the above factors, it was found that all three methods gave results that were in close agreement with the migration characteristics exhibited by the large-scale tracer test.

H12-07 INVITED

HYDROGEOLOGIC STUDIES AT A HAZARDOUS WASTE SITE USING AN ITERATIVE DATA COLLECTION SCHEME, GEOSTATISTICAL EVALUATION, AND FLOW AND TRANSPORT SIMULATION

R. Schalla (Battelle-OHWM, Richland, WA 99352)
G. L. McKown (Battelle-OHWM, Richland, WA 99352)
J. L. Devary (Battelle-OHWM, Richland, WA 99352)
F. W. Bond (Battelle-OHWM, Richland, WA 99352)

Methods for optimizing data collection at a hazardous waste site were put to a practical test. Geostatistical analysis and model simulation provided feedback to guide monitor well placement during this multi-phased study.

During early phases of the project, the objectives were to determine the hydrogeologic characteristics of the multi-layered system and the vertical and horizontal extent of migration from three contaminant sources. The first two of four monitor well installation phases emphasized near-source contaminant characterization which resulted in an irregular distribution of monitor wells. Subsequently, additional monitor wells were installed and a three-dimensional flow and transport model was developed to define transport pathways and evaluate the feasibility of remedial strategies at the site.

Kriging was used to interprete the data and determine uncertainty for guiding monitor well placement in the later phases. After data errors were resolved, uncertainty distributions for hydraulic potentials were kriged. These uncertainty contour maps were used as a criterion in selecting monitor well locations where the degree of uncertainty was considered intolerable. Also, a few significant differences between subjective and kriged versions of the flow field indicated the need for monitor wells in areas previously not considered important.

The results of this study emphasize the need for objective as well as subjective evaluation; kriging and preliminary model runs can provide essential feedback in planning data collection efforts.

H12-08

Groundwater Velocity Measurements Using an Electrical Conductance-Borehole Dilution Device

D. W. Belanger (Department of Earth Science, University of Waterloo, Waterloo, Ontario. Presently with GTC Geologic Testing Consultants, Ottawa, Ontario.)
R. E. Jackson (National Hydrology Research Institute, Environment Canada, Ottawa, Ontario.)

An electrical conductance electrode in a flow cell located downhole is used to measure the dilution of a salt tracer in a newly developed borehole dilution apparatus. The borehole dilution apparatus, which was tested in a laboratory, does not cause density induced flow and is capable of measuring groundwater velocities as low as a diffusion velocity of 1.2×10^{-7} m/s.

The device has been employed at two hydrogeologically different sites to illustrate its application. At the first site, the Borden Landfill, Canadian Forces Base (C.F.B.) Borden, Ontario there is a shallow groundwater aquifer consisting of glacio-fluvial sands while the second, the Gloucester Landfill, near Ottawa, Ontario is characterized by a deep confined aquifer of glacial outwash. Groundwater velocities of 5.8×10^{-7} to 2.1×10^{-6} m/s determined by borehole dilution at C.F.B. Borden compare favourably with velocities determined by natural gradient tracer tests and other methods. A zone of high groundwater flow has been identified in one of the tracer test sites. At the Gloucester Landfill, borehole dilution tests were used to produce a velocity cross section along a path of contaminant migration. The confined aquifer is found to have an average groundwater velocity of 7.5×10^{-7} m/s and velocities range from 1.2×10^{-7} to 2.3×10^{-6} m/s.

The electrical conductance-borehole dilution method is shown to be a reliable method of measuring insitu groundwater velocities and is suitable for routine application in many groundwater studies.

H12-09 INVITED

Field Preparation, Preliminary Aquifer Evaluation, and Injection-Recovery Tracer Test Results and Analysis at the Auburn University Site

JOEL G. MELVILLE, FRED J. MOLZ, OKTAY GÜVEN (Civil Engineering Department, Auburn University, Alabama, 36849)

Field studies designed to measure the vertical and lateral variations of horizontal hydraulic conductivity are being conducted in cooperation with the Robert S. Kerr Laboratory of the U.S. Environmental Protection Agency. The experiments are being performed in a confined aquifer near Mobile, AL. Standard pumping tests at several locations have indicated vertically averaged conductivities ranging from 40m/d to 55m/d. Information concerning the actual distribution of hydraulic conductivity will be obtained by measuring the vertical variation of horizontal seepage velocities in the vicinity of fully penetrating injection wells operating at approximately 15 l/s. Velocities will be determined using several methods including measurement of tracer travel time between the injection and observation wells, borehole dilution, and if possible, direct velocity measurement using the flowmeter system manufactured by K-V Associates. The observation wells were constructed so that the various measurements could be made at seven locations isolated hydraulically along each wellbore. To date, extensive laboratory testing of the K-V Flowmeter indicates that the velocity-measurement principle is valid, but the apparatus is difficult to utilize successfully in the field. A preliminary tracer test involving 3000 m^3 of bromide solution is planned. Results will be presented and correlated with grain size distributions obtained from core samples. The long term objective of the experiments is to develop field methods and related interpretative techniques which are designed to quantify the major convective aspects of dispersion which seem to be the dominant dispersing mechanism in many natural aquifers.

H12-10

Evaluation of Solute Transport Parameters from a Natural Gradient Groundwater Tracer Experiment

J. C. PARKER, Agronomy Department, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061
T. G. NAYMIK and M. E. SIEVERS, Illinois State Water Survey, Champaign, IL 61820

A natural gradient groundwater tracer experiment was conducted in an unconfined stratified glacio-fluvial aquifer by injecting concentrated fluorescent dye via a partially penetrating well and monitoring the tracer plume at observation wells 3, 6 and 12 m downstream. Breakthrough curves for the 3 wells were fit to analytical solutions to the convection-dispersion equation for 3-dimensional transport in a planar velocity field subject to pulse-type or exponentially decaying inlet boundary conditions. Parameter estimation was carried out by nonlinear regression methods. Estimated mean pore water velocities (v) and longitudinal dispersivities (D) were insensitive to inlet boundary condition assumptions owing to the relatively high Peclet number of the formation. Essentially identical estimates of v and D were obtained for both decaying and pulse injection solutions to the 3-dimensional model as well as for a 1-dimensional pulse model if pulse durations in the latter were arbitrarily adjusted to allow for mass depletion at downstream wells due to lateral dispersion. Accurate estimates of transverse dispersivity could not be obtained owing to uncertainties in the inlet boundary conditions and the velocity field direction which was observed to shift slightly during the experiment. Between the 3 and 12 m downsteam observation wells v was observed to increase from 43 to 61 cm/day while D increased from 17 to 33 cm when constant aquifer properties were invoked to describe each breakthrough curve. Employing a spatially unique temporal dispersion function was unsuccessful in eliminating this apparent scale dependence of parameter values.

H12-11

Field Measurement and Geochemical Interpretation of ^{90}Sr Adsorption in a Contaminated Aquifer

R.E. JACKSON, K.J. INCH, R.J. PATTERSON (NHRI, Environment Canada, Ottawa, K1A 0E7, Canada)
R.W.D. KILLEY, (CRNL, Atomic Energy of Canada Ltd., Chalk River, K0J 1J0, Canada).

Adsorption of ^{90}Sr from radioactively-contaminated ground waters is occurring in a shallow sand aquifer at the Chalk River Nuclear Laboratories. Results of analyses of cored contaminated aquifer sands and associated interstitial waters show that adsorption of ^{90}Sr is dependent on the concentration of the principal competing cations (Ca(II) and stable Sr(II)) and the abundance of mineral adsorbents (e.g. vermiculite) with high specific surface area. The range of measured K_d^{Sr} (i.e. Serne's R_d parameter) values is from 3 to 13 ml/g. The larger values are correlated with low competing cation concentrations (Sr(II) < 2.0 μeq/L, Ca(II) < 0.4 meq/L) and vice versa. If the data are divided into two groups on the basis of these concentrations, adsorption isotherms show a linear dependence between adsorbed and dissolved ^{90}Sr and evidence of heterogeneity in the surface of the adsorbents. A partition model indicates that approximately 90% of adsorbed ^{90}Sr is associated with just two adsorbents comprising only 40% of all aquifer grains. Results of desorption experiments suggest that a significant fraction of the ^{90}Sr (~20%) is irreversibly adsorbed due to specific adsorption by metal oxides. The relationships defined indicate that contaminant transport models should take into account the dependence of solute adsorption on competing cation concentrations and adsorbent abundances and the errors which may result from assuming reversible adsorption.

H12-12

Use of Geochemical Modeling to Calculate Source Terms for Solute Transport Modeling

KATHRYN J. BUSH (GECR, Inc., Rapid City, SD 57709)

Chemical reaction parameters as input to groundwater chemical transport models must accurately represent the geochemical system within which the transport is being modeled. Chemical reactions occur in response to chemical disequilibrium and affect the concentrations of contaminants in solution. The degree of disequilibrium is the greatest as two unlike media are mixed. Reactions proceed upon mixing until equilibrium is attained. Reaction rates are relatively rapid with respect to flow rates, and therefore major changes in concentrations of contaminants occur over short distances. Calculation of chemical reaction parameters for solute transport models are simplified by considering the chemical reactions only at major geochemical discontinuities. Use of the thermodynamic geochemical model, PHREEQE, is useful in defining the chemical reaction parameters needed for the transport model by evaluating the chemical equilibria along the flow path. Calculations of the mixing of two or more unlike solutions will provide predictions of the source terms for components exiting the disequilibrium zone. Control of the concentrations of contaminants by precipitation can be distinguished from adsorption by comparison of the predicted concentrations with the measured values. This approach has been successfully applied to the determination of contamination in seepage from uranium mill tailings. Source concentrations were calculated by PHREEQE for all of the major contaminants.

H12-13

An Analysis of Single-Well Tracer Dispersion Tests in Stratified Aquifers

R. W. FALTA, O. GÜVEN, F. J. MOLZ, AND J. G. MELVILLE (Civil Engineering Department, Auburn University, Alabama 36849)

A numerical study of various factors affecting the results of a single-well conservative tracer test in a stratified aquifer is presented based on a radially symmetric three-dimensional steady flow numerical model. The primary factors considered are the differential radial advection among the stratified layers, the radial and vertical local dispersion coefficients, the scale of the test, and the steadiness of the input concentration. In the computer program, the advective and dispersive terms in the advection-dispersion equation are uncoupled and the effects of advection and local dispersion are computed separately during each time step effectively eliminating numerical dispersion as a computational problem. Using a given radial hydraulic conductivity distribution in the vertical, a constant porosity, constant radial and vertical local dispersivities (on the order of those measured in laboratory tests), and a constant molecular diffusion coefficient, the concentration field is calculated for every time step. The model is verified in part by comparisons

with available one-dimensional analytical solutions for the concentration in radial flow in a homogeneous medium, and in part by comparisons with the actual experimental field data of Pickens and Grisak (1981), obtained in a locally stratified aquifer. The analysis indicates that the withdrawal concentration versus time data measured at the injection-withdrawal well reflects primarily the effects of local dispersion which has taken place during the test, while the full-aquifer concentration breakthrough curves from nearby observation wells reflect mainly the effects of the nonuniform hydraulic conductivity profile.

Miscible and Immiscible Transport in Ground Water I

Room 23 Tues AM

Presider, L.F. Konikow, U.S. Geological Survey

J.W. Mercer Geo Trans, Inc.

H21A-01

Miscible Displacement in Nonuniform Porous Media

J. E. Houseworth (Environmental Engineering Science, Caltech, Pasadena, Ca. 91125)
(Sponsor: N. H. Brooks)

This work concerns the transport of passive solutes through relatively coarse (0.1mm-1mm) uniform and nonuniform natural sand media at high Peclet numbers, where nonuniformity refers to variations in pore structure at the grain scale. The investigation is limited to one dimensional (longitudinal) transport in macroscopically homogeneous, isotropic porous media. A theoretical model for permeability and dispersion based on a random, interconnected, three dimensional capillary tube network is developed. A comparison of experimental results and theoretical calculations show that the permeability is relatively insensitive to the variance of the pore radius distribution. Longitudinal dispersion is found to be controlled in large part by variations in residence time for transport through the capillary tubes, making the pore length distribution important in the dispersion process. Miscible displacement experiments were carried out on uniform and nonuniform sand media at a variety of Peclet numbers in which both the permeability and longitudinal dispersion were measured. Simple methods relating the pore radius distribution to the capillary drainage curve and pore length distribution to the grain size distribution are developed. These distributions are used in model calculations which are compared with measured results. Long breakthrough curve "tails" are observed experimentally, which cannot be modeled with advective-diffusion theory. The tails are thought to be due to molecular diffusion-limited mass transfer in slowly flowing zones.

H21A-02

DEVIATIONS FROM LOCAL EQUILIBRIUM IN TRANSPORT OF SORBING SOLUTES

M. N. Goltz
P. V. Roberts (both at: Environmental Engineering and Science, Dept. of Civil Engineering, Stanford, CA 94305)

In a field experiment conducted by a group of investigators from Stanford University and the University of Waterloo, a known mass of inorganic tracers and organic solutes was injected into an unconfined sand aquifer. Breakthrough curves were obtained at several points downstream of the injection zone. These field observations are compared with solutions of two models of solute transport in sorbing porous media. One model uses the advection/dispersion equation, combined with assumptions of linear/reversible sorption of the solute on the media, and local equilibrium. The second model incorporates a mass transfer term to allow for deviations from the local equilibrium assumption. The general form of the observed breakthrough curves indicates that the equilibrium model may not adequately describe solute transport in the field experiment. The most pronounced anomaly is the apparent excess tailing of the observed breakthrough response in some instances. Presently available models will be assessed from the viewpoint of interpreting the results of a medium-scale, natural gradient field experiment.

H21A-03

Validity of the Local Chemical Equilibrium Assumption for Describing Sorbing Solute Transport Through Homogeneous Soils

A. J. VALOCCHI (Civil Engineering, Univ. of Illinois, Urbana, IL 61801)

Adsorption reactions are important processes governing the fate of dissolved hazardous substances in groundwater. Sorption processes can be modeled using either an equilibrium or kinetic approach; however, the former has been most widely utilized because of its conceptual and mathematical simplicity. Although many laboratory experiments have been conducted to test the local equilibrium hypothesis, their results have been generally inconclusive. A theoretical study has thus been conducted in order to examine the conditions under which the equilibrium assumption is valid.

Transport models have been formulated based upon several nonequilibrium submodels. For example, one model assumes instantaneous sorption onto the surface of a spherical sorbent particle followed by molecular diffusion within the particle. Work to date has focused upon one-dimensional uniform flow, although some results have also been obtained for radially diverging flow fields. Closed-form model solutions are not generally available, however a technique is used to find analytical expressions for the time moments of the solute breakthrough curves. By comparing the time moment formulas for the kinetic and equilibrium models, it is possible to derive criteria for local equilibrium to be valid. These criteria explicitly show that basic system parameters (e.g. dispersion coefficient, retardation factor, seepage velocity, boundary conditions) have an important influence on the attainment of local equilibrium. For example, the results indicate that increasing the dispersion coefficient tends to enhance the attainment of equilibrium; this observation is in conflict with the commonly held belief that chemical equilibrium is valid when hydrodynamic dispersion is on the order of molecular diffusion.

H21A-04 INVITED

A Moving Boundary Problem in the Transport of Reacting Solutes

D. M. WILLIS (USGS, Menlo Park, CA 94025)
J. RUBIN (USGS, Menlo Park, CA 94025)

In solute transport through a porous medium, where the solute is affected by equilibrium-controlled precipitation and dissolution, Class III reactions in Rubin, Water Resour. Res., 19, 1231-1252, 1983), appropriate boundary conditions bring about chemically distinct zones. A zone from which a given solid phase is absent, Zone I), is separated by a moving boundary from a zone in which this phase is present (Zone II). In Zone II, the system of simultaneous partial differential and algebraic equations describing solute transport may be transformed to a more easily solved system where the only simultaneous equations are algebraic. Zone I is described by a single phase Stefan problem: the convection-dispersion equation is defined on a changing domain and is coupled with an equation for the velocity of the moving boundary. We have taken two approaches for solving this problem for a model, one dimensional transport system. The first is based on an integral formulation of the equations. The second uses the Crank-Nicholson method to solve the partial differential equation in a given interval and iterates to determine the precise time when the moving boundary arrives at the end of the interval. Both methods have been numerically tested for accuracy, stability and convergence and their results show excellent agreement. Our numerical experiments clearly show the dependence of the speed of the boundary on such factors as the flux and dispersion coefficient.

H21A-05

TRANQL: A Groundwater Mass Transport and Equilibrium Chemistry Model for Multicomponent Systems

SAIL A. CEDERBERG
ROBERT L. STREET
JAMES O. LECKIE (all at Department of Civil Engineering Stanford University, Stanford, CA 94305)

A general mass transport model, TRANQL, for a multicomponent solution system has been developed. The equilibrium interaction chemistry is posed independently of the mass transport equations which leads to a set of algebraic equations for the chemistry coupled to a set of differential equations for the mass transport. A solution is found by iterating between the two equation sets. All significant equilibrium chemical reactions such as complexation, ion exchange, simultaneous adsorption, precipitation/dissolution, and dissociation of water may be included in TRANQL. TRANQL was initially used to simulate the transport of Cd in a one-dimensional groundwater flow system, accounting for both Cd solution speciation and adsorption. Binding constants for Cd at the solid/solution interface were determined from experimental data for a range of conditions. Results show the transport and adsorption of Cd is a strong function of the solution composition and varies significantly with relatively small changes is solution parameters. It follows, for example, that use of the classical constant distribution coefficient, K_d, for such a trace metal would introduce considerable error in transport estimates because K_d depends on the solution parameters, thus being in fact truly spatially and temporally variant. TRANQL is found to be a very versatile model for the prediction and description of solute transport in a multicomponent groundwater flow system.

H21A-06

Analysis of Contaminant Time Series at Waste Disposal Sites: A Multi-Well Inverse Method

C. J. DUFFY (Utah State University, Logan, UT. 84322)
J. HARRISON (Utah State University, Logan, UT. 84322)

This research deals with the development of an analytic technique and field methodology for interpretation of water quality time series from observation wells at waste disposal sites. We would emphasize here, that application of the technique as described below is particularly appropriate where long term monitoring is practiced, as is becoming standard at waste disposal facilities. The theory is based on solutions to the classical convection-dispersion equation in both the time and frequency domain. The frequency domain solution is represented by the frequency response function, from the theory of linear systems, and is related to the time domain solution, the impulse response function, via the Fourier transform. Field equations are presented for pairs of observation wells, located along flow lines and down gradient from the disposal site. It is assumed that the observed solute response in observation wells can be divided into two types: (1) a slowly varying solute response, for which a time domain solution to the convection-dispersion equation would apply, using a discrete form of the convolution equation and the impulse response function; and (2) a stochastic variation in solute response, for which the frequency response function (or the transfer function and phase spectrum) is appropriate. The analysis generalizes analytic solutions of the convection-dispersion model to include complex time variations in contamination. The approach is presently being applied to field data supplied by the USGS, for thirty years of groundwater monitoring at the Idaho National Engineering Laboratory.

H21A-07

A New Continuum Approach for Modeling Dispersion in Fractured Media

F.W. SCHWARTZ (Dept. of Geology, Univ. of Alberta Edmonton, Canada, T6G 2E1)
L. SMITH (Dept. of Geological Sciences, Univ. of British Columbia, Vancouver, Canada, V6T 2B4)

Continuum models in general provide the only practical approach to modeling dispersion in large, fractured rock systems. However, the conventional approaches based on a simple diffusion model of dispersion suffer from important limitations in representing the dispersion process. A new continuum approach has been developed that more realistically accounts for the influence of fractures and fracture geometries on the pattern of dispersion. The technique involves particle tracking where the particular motion of a large number of reference particles in the continuum is determined by the statistical characteristics of the network and specific features of flow velocities in fractures. Detailed information on the pattern of directed random motion of particles requires the use of a discrete-fracture, sub-model with a fracture geometry similar to that envisioned for the continuum model. In practice, the domain for the discrete model would be much smaller in size and contain many fewer intersections than the continuum model. By comparing breakthrough curves for discrete models and continuum models of the same system we have been able to demonstrate the validity and usefulness of this modeling procedure. The most important application of this approach will be to evaluate the character of contaminant plumes that develop in complex, three-dimensional systems.

H21A-08 INVITED

Some Recent Results on the Nature of Scale-Dependent Dispersion Coefficients with Implications for Modeling of Contaminant Migration in Aquifers

O. GUVEN, F. J. MOLZ, and J. G. MELVILLE
(Civil Engineering Department, Auburn University, Alabama 36849)

Some recent studies related to the transport of conservative solutes in saturated unconsolidated deposits are reviewed. These studies imply that scale dependent dispersion coefficients are not in general unique physical properties of any one part or the whole of an aquifer, but they depend on the imposed flow system and on the complete three-dimensional spatial distribution of the aquifer seepage velocities. Furthermore, they also depend on the particular averaging process (space average or flow-weighted average) used to define the average concentrations.

behavior supports several questions raised previ-
ly about the validity and practical utility of scale-
endent dispersion coefficients in modeling contami-
t migration and also supports several suggestions
e earlier about the need to reevaluate the applica-
ity of some current areal advection-dispersion
dels which make use of either field-measured or model-
librated scale-dependent dispersivities. In light of
e recent and previous studies, it appears that more
phasis should be placed on the direct field determi-
tion of the three-dimensional hydraulic conductivity
d porosity variations and of local field dispersion
efficients for use in physically based models if
etter predictions of contamination distribution in a
iven aquifer are to be made. This approach seems
o be particularly relevant and necessary if major
arge-scale heterogeneity trends exist in the aquifer.
uch detailed theoretical studies and large-scale field
xperiments are obviously needed to test these ideas
nd to advance the present incomplete understanding
f solute transport.

H21A-09

Field Studies of Dispersion in Porous Media: Analysis of Experimental Data

G.L. MOLTYANER
R.W.D. KILLEY (Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, Chalk River, Ontario K0J 1J0)

Monitoring of the ^{131}I distribution in a natural gradient tracer test showed the formation of separate plumes. Within each plume, the observed continuous curves of radioactivity versus time were simulated using one- and three-dimensional advection-dispersion models. The aquifer longitudinal dispersivities calculated within individual plumes were 0.0044, 0.0049 and 0.0132 m with the arithmetic average 0.0075 m.

The vertical continuous profiles of radioactivity versus depth were simulated using the three-dimensional analytical model. The results of simulations based on a statistical averaging approach show that within each distinguishable textural feature of the tracer site aquifer the vertical dispersivities are 0.0005, 0.001 and 0.0065 m with the arithmetic average 0.0007 m.

Eight laboratory and field column experiments yielded an average longitudinal dispersivity half that observed in the natural gradient test (0.0035 m). These results showed that the advection-dispersion model can be successfully applied for analysis of field-scale experiments.

H21A-10

Finite-element simulation of potential radionuclide migration from a potential nuclear-waste repository at the Nevada Test Site

John B. Czarnecki (USGS, Denver, CO 80225) (Sponsor: R.K. Waddell)

A finite-element transport model has been developed to examine the potential transport of radionuclides downgradient from a proposed nuclear-waste repository at Yucca Mountain at the Nevada Test Site. Flow conditions were obtained using a two-dimensional, finite-element inverse model to provide flux and transmissivity data for the transport model. Coefficients of variation for transmissivity parameters ranged between 0.3 and 2.4 percent; residuals obtained from the difference between simulated and historic hydraulic-head data indicated a good match between simulated and historic data. The effect of potential changes in recharge resulting from future climatic changes on recharge-boundary conditions and the subsequent effect on transmissivities and saturated thicknesses within the model were examined.

Radionuclide migration was simulated using a finite-element model for tracing specific members of the Actinide series. Sensitivity analyses were made for changes in longitudinal and transverse dispersivities, porosity, and boundary fluxes resulting from climatic changes. Simulations of radionuclide concentrations and travel times for as much as 20,000 years in the future were made for a 3,000-square-kilometer area.

H21A-11

Coupled Modeling of Flow and Chemical Reactions for U-Mill Tailings Solutions Percolating Through Sediments

R. J. SERNE, S. R. PETERSON, and C. J. HOSTETLER (Battelle, Pacific Northwest Laboratory, P.O. Box 999, Richland, WA 99352)

The effluents from column experiments in which U-mill tailings solution was percolated through sediments were measured and compared to model predictions. The code used, MINICUP, couples the chemical code MINTEQ and its thermodynamic data base with a one-dimensional flow model. MINICUP considers the following processes: hydrodynamic dispersion, advection, dissolution-precipitation of minerals and amorphous compounds, surface adsorption, soluble complex formation and redox reactions. Presently, MINICUP does not consider kinetics and assumes equilibrium is reached within each time step.

MINICUP requires the user to input the initial concentration of all major cations, anions and trace metals, amounts and types of solid compounds within the sediment that are considered to be reactive, the total adsorption or cation-exchange capacity and water velocity. The user may also specify adsorption, stability or solubility constants for components not present in the standard data base.

Results for both clay-rich and coarse sediments contacted with acidic U-mill tailings solutions will be presented. For selected major cations/anions the solids that control the observed effluent solution concentrations will be identified. Trace metal effluent concentration predictions both considering adsorption and ignoring adsorption will be compared with observed column data.

A discretization error occurs as the sediment column is modeled as a finite number of reaction cells. The ability of this error to mimic hydrodynamic dispersion will be discussed. Finally, the modeling results and laboratory observations will be compared to contaminant migration and mineralogic changes actually observed at U-mill tailings disposal sites.

Investigations on Mesoscale Precipitation Fields I

Room 13–14 Tues AM

Presider, V.K. Gupta, University of Mississippi

H. R. Cho University of Toronto

H21B-01 INVITED

Variations in precipitation structure of mesoscale convective systems with differing environmental conditions

W. A. LYONS (Atmospheric Science Group, Texas Tech University, Lubbock, TX 79409)

Mesoscale convective systems form in a wide variety of environmental conditions. These include variations in vertical profiles of wind, temperature and humidity, variations in horizontal wind fields and the presence or absence of topographic features. While most mesoscale convective systems possess common features like intense convective cells along the leading edge and a large precipitating anvil cloud to the rear, no two mesoscale convective systems are identical. This paper describes an attempt to interpret the variations in precipitation structure of a number of well-studied mesoscale convective systems in terms of differing environmental conditions.

H21B-02 INVITED

Quasi-Stationary Mesoscale Convective Systems and Excessive Precipitation Events

C. F. CHAPPELL (Weather Research Program, NOAA/ERL, Boulder, CO 80303)

Recent studies of several flash flood events have shown that quasi-stationary mesoscale convective systems are frequently responsible for producing the excessive rainfall. A requirement for producing quasi-stationary mesoscale convective systems is for the propagation velocity to be equal in magnitude but opposite to the direction of the mean cell velocity. The propagation velocity is mainly controlled by the rate at which new cells discretely develop upstream of the mean cell motion vector and also by the rate of dissipation of older cells downstream. Certain meteorological conditions are necessary to generate new convective cells at the appropriate rate, and in the correct location, so that an equilibrium between propagation and mean cell velocities can exist for a few hours. At least two forms of mesoscale forcing can help to focus the required convection if the appropriate thermodynamic conditions are presented over the area.

H21B-03 INVITED

Mesoscale Precipitation Systems and Their Environment: Control and Feedback Mechanisms

RICHARD H. JOHNSON (Department of Atmospheric Science, Colorado State University, Fort Collins, 80523)

During the past decade there has been a considerable improvement in our understanding of the structure, properties and life cycle characteristics of mesoscale convective systems in some areas. It remains true that there is a lack of understanding of the processes that control the development of mesoscale convective systems. In addition, the way in which these systems feed back to alter the large-scale flow is not well known.

In the tropics there appears to be a wide variety of mechanisms which may control the development and organization of mesoscale convection: the intertropical convergence zone, monsoon circulations, easterly waves, land-sea breeze circulations, conditional instabilities of the "second kind", convective outflow boundary intersections, radiative processes and others. Similar mechanisms, along with baroclinic processes, serve to influence the development of mesoscale precipitation systems at midlatitudes.

Feedbacks from mesoscale precipitation systems to the large-scale atmospheric circulation are often pronounced. While modifications of the large-scale circulation are frequently concentrated at the storm outflow level (in the upper troposphere) and in the planetary boundary layer, effects on the mid-troposphere flow have also been observed. Better understanding of the control and feedback loops is needed for improved forecasting of mesoscale convective systems.

H21B-04 INVITED

Dynamics of Mesoscale Precipitation Fields

H. R. CHO (Department of Physics, University of Toronto, Toronto, Ontario, Canada, M5S 1A7) (Sponsor: V. K. Gupta)

Atmospheric dynamic processes leading to mesoscale irregularities in the precipitation fields associated with synoptic scale weather systems are illustrated by specific examples. It is shown that during the development of a midlatitude cyclone, small perturbations at the mesoscale in the initial temperature field may lead to regions of significantly enhanced precipitation. Since these mesoscale temperature perturbations are difficult to observe, the resultant distributions of precipitation may appear to behave randomly. The statistics of the precipitation field may be determined from a set of deterministic dynamic equations subject to random initial conditions, if the effects of latent heating due to condensation on the dynamic processes are ignored.

On the other hand, if the feedback effects of latent heating are included, random initial conditions will lead to stochastic forcing on the dynamic processes. The precipitation field will be determined by a set of stochastic dynamic equations.

H21B-05 INVITED

SMALL SCALE APPROXIMATIONS OF TEMPORAL RAINFALL FROM A MULTIDIMENSIONAL FIELD: A NUMERICAL STUDY.

J. B. VALDES, (Coordinacion de Recursos Hidricos, Universidad Simon Bolivar, Caracas, Venezuela.
I. RODRIGUEZ-ITURBE, (Coordinacion de Recursos Hidricos, Universidad Simon Bolivar, Caracas, Venezuela.
V. K. GUPTA, (Dept. of Civil Engineering, University of Mississippi, University, MS 38677

A physically based multidimensional dynamic simulation model for precipitation was developed which is based on the theory proposed by Waymire et al. (1984). The model produces a moving storm with realistic meso-scale meteorological features such as cell, clusters, intensity attenuation in time and space, etc. Rainfall traces at fixed gage stations were taken as real world values and then aggregated at different time scales ranging from 15 min. to 24 hrs. Second order statistics were evaluated from the simulated series at each level of aggregation and were employed for estimating the parameters of three different one-dimensional models of temporal rainfall at a point, 1) Poisson model 2) rectangular pulses model and 3) Neyman-Scott model. This served to analyze the feasibility of approximating the temporal rainfall traces at different scales with simpler stochastic models and investigating the range of variability in their parameters with respect to these time scales. The estimated parameters in the Neyman-Scott model proved to be quite stable at almost all the scales of aggregation and coincided quite well with some of the parameters of the multidimensional model. The Poisson model provided good approximation only at very high levels of aggregation. The rectangular pulses model was also found to be inadequate for most of the scales considered. Extreme value analysis was also carried out and again the Neyman-Scott model provided the best approximations of the three to the multidimensional model.

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Miscible and Immiscible Transport in Ground Water II

Room 23 Tues PM

Presider, J.W. Mercer, Geo Trans, Inc.

L.F. Konikow U.S. Geological Survey

H22A-01 INVITED

The Importance of the Interface in Modeling Multiphase Flow

L.M. Abriola and W.G. Gray (both at the Department of Civil Engineering, Princeton University, Princeton, NJ 08544)

In previous developments of equations which govern the multiphase flow of fluids in a porous medium, the surface properties of the interfaces between the phases have generally been neglected. The importance of surface effects to the determination of fluid/matrix properties such as relative permeability or capillary pressure-saturation relations, however, is a widely recognized if not well understood phenomena.

A system of macroscopic balance equations which explicitly incorporates the surface properties of the interfaces can be derived by the use of averaging theory. The starting point of this derivation is the examination of the local jump condition for a given property at an interface. Each jump condition is written to account for all possible surface effects and then averaged over some representative volume and finally over the entire domain to obtain a macroscopic constraint on the balance equations.

Explicit incorporation of surface properties into the macroscopic equations gives insight into the effects of specific surface terms on the behavior of a multiphase system. Surface properties can be shown to account for differences in pressure or temperature between phases. Manipulation of the momentum balance equations reveals that the macroscopic fluid stress tensor is not necessarily symmetric for systems in which surface tension is of importance. In addition, both the fluid stress tensor and the fluid heat flux can be shown to have some interphase dependence if surface effects are considered.

H22A-02

Correlating Micro and Macro Scales

J. H. CUSHMAN (Dept. of Agronomy, Purdue University, W. Lafayette, IN. 47907)

There has been considerable interest over the last two decades in developing averaging methods to increase the scales of motion in multiphase transport theory. Most recently, these averaging methods have been related to instrumentation windows. In our discussion we relate averaging theory to impulse-response filter theory. We perform a Fourier analysis in frequency space to indicate how the filters should attenuate low and high frequency noise when natural length scales exist. We also present a method for correlating the micro to macro scale changes associated with averaging the transport equations. Finally, the results are generalized to the space of compact distributions - the natural space for the Fourier analysis of the transport equations.

H22A-03

Immiscible Contaminant Transport in Soil and Groundwater with an Emphasis on Gasoline Hydrocarbons

A. Baehr (Dept. of Civil Engineering, University of Delaware, Newark, DE 19716)
M. Y. Corapcioglu (Dept. of Civil Engineering University of Delaware, Newark, DE 19716)

Soil and groundwater contamination resulting from leaks of petroleum products from faulty storage tanks and pipelines has become a recent environmental concern. Petroleum products such as gasoline are almost entirely a mixture of various hydrocarbons which includes known hazardous substances such as benzene, toluene, xylene and cyclohexane. A generalized mathematical model, incorporating the physical, chemical and biological processes which collectively describe the transport of a reactive and immiscible contaminant in soils and groundwater will be presented. The problem is one of multiphase transport, that is, the contaminant can be transported as solutes in water, vapors in air and as unreacted constituents in an immiscible phase. Conservation principles lead to a system of nonlinear partial differential equations governing the phenomenon.

The model has been applied to study the fate and transport of hydrocarbons found in petroleum products such as gasoline trapped in an unsaturated zone. This particular application can help assess the long term threat to underlying water resources posed by the fraction of the petroleum product which remains after remedial efforts have ceased. Thermodynamic equilibrium principles and the role played by oxygen in the biodegradation of hydrocarbons are incorporated into the model. The resulting system of equations is then solved using a finite difference scheme. The results predict the concentrations of each hydrocarbon in all phases (water, air, immiscible, adsorbed) in space and time allowing the user to estimate the amounts of hydrocarbons which enter the underlying aquifer or which leave the soil via volatilization into the atmosphere. Such predictions will be presented for selected cases.

H22A-04

Ground-Water Model of Two-Phase Immiscible Flow in Coarse Material

D. P. HOCHMUTH (Resource Consultants, Inc., P. O. Box O, Fort Collins, CO 80522) (Sponsor: Jonathan Purkoff)

D. K. SUNADA (Dept. of Civil Engineering, Colo. State Univ., Fort Collins, CO 80523)

A numerical model was developed to simulate the behavior of two-phase immiscible fluids in ground-water systems for specific application to hydrocarbon spills and leaks. The model is a two-dimensional areal flow model using the finite element method. A verification of the numerical model was performed using both an approximate analytical solution and a laboratory investigation. The results show that the numerical model adequately describes the behavior of immiscible two-phase flow within the limitation of a coarse porous material imposed by the assumptions used to develop it.

H22A-05

A Numerical Model of Flow of Water and an Immiscible Fluid Under Saturated and Unsaturated Conditions

FAUST, CHARLES R., GeoTrans, Inc. 209 Elden Street, Herndon VA 22070

A numerical model is developed that describes the simultaneous flow of water and a second immiscible fluid under saturated and unsaturated conditions in porous media. The governing equations are a simplified subset of the three-phase flow equations commonly used in petroleum reservoir simulation. The simplification is analogous to that used to derive the Richards equation for flow of water in the unsaturated zone. The assumption that pressure gradients in the air phase are negligible leads to two partial differential equations. The proposed formulation is posed in term of volumetric water saturation and fluid pressure in the immiscible fluid. The two dimensional equations for flow in a vertical plane are approximated by finite-differences. The fully implicit equations are solved by a direct matrix technique and Newton-Raphson iteration on nonlinear terms.

The resulting numerical model has potentially wide application to hazardous waste contamination of groundwater. Unfortunately data such as relative permeabilities and capillary pressures are not readily available for the types of fluids and porous materials present in hazardous waste sites. As this type of data becomes available and field-investigation techniques improve, the application of this type of model will become more practical. Examples are used to demonstrate the potential application of the proposed model.

H22A-06

Application of Multi-phase Flow Models to the S-Area Landfill, Niagara Falls, New York

GUSWA, JOHN H., (Arthur D. Little, 25 Acorn Park, Cambridge, MA. 02140)
FAUST, CHARLES R., (GeoTrans, Inc. 209 Elden Street, Herndon, Virginia 22070)

Numerical models of two-phase flow in porous media have been applied at the S-Area landfill in Niagara Falls, New York. Two-phase models were necessary because dense organic chemicals exist as an immiscible fluid phase at this site. The two-phase model results were analyzed to identify various hydrogeologic conditions which could be an effective barrier to the downward migration of a heavier than water, non-aqueous phase liquid from unconsolidated glacial deposits to the underlying bedrock. These results indicate that even under a downward hydraulic gradient, natural differences in capillary pressure relationships for different lithologies would prevent downward movement of the organic fluid. Where these lithologic barriers are not present, remedial measures creating a strong upward hydraulic gradient can reverse the downward migration of the organic fluid. Simulations of both one-dimensional (vertical) and two-dimensional (vertical section) flow fields were evaluated.

Investigations on Mesoscale Precipitation Fields II

Room 13–14 Tues PM

Presider, H. R. Cho, University of Toronto

V.K. Gupta University of Mississippi

H22B-01 INVITED

Scaling Limits for the Precipitation Field

ED WAYMIRE (Department of Mathematics, Oregon State University, Corvallis, OR 97331)

Point process and point random field representations of the temporal and space-time, respectively, rainfall process are briefly reviewed. For such representations the practical problem of calculating probabilities of the form $\mathrm{Prob}(X(B) \leq K)$, where $X(B)$ is the number of occurrences in a temporal or spatial-temporal region B (or some smoothed version of it) is discussed and some new results are given in the case when B is "large". Applications to the product density statistical estimation problem are then indicated.

H22B-02 INVITED

Scale Invariance in the Atmosphere and a Fractal Model of Rain

S. Lovejoy (CNRM/C[illegible], Météorologie Nationale, 2 Ave. Rapp, Paris 75007, France)
D. Schertzer

A fractal is an unsmooth shape that is scaling, that is, their shape appears unchanged when examined at varying magnifications. Scaling, or scale invariance is a basic symmetry principle known to hold widely in nature. Fractal analysis [illegible] the atmosphere [illegible] by the fact that the basic equations of fluid motion of Navier-Stokes are scale invariant down to very small size ruled by viscosity.

Evidence is presented confirming that scaling holds over a very wide range of meteorologically significant time and space scales. We show how to construct a fractal model of rain (Lovejoy and Mandelbrot 1984) which depends on only one basic order determined parameter. The model is visually realistic and exhibits the following other characteristics:

a) Horizontal [illegible]: The model displays a scale hierarchy of fronts, clusters, cells and other [illegible] of which had been put in by design.

b) Temporal evolution: The model involves in the simply and consistent kinetic manner intermittent [illegible] of rain, [illegible] blocking phenomena.

c) Vertical structure: Vertical cross-sections are modelled using the concept of "stochastic stratification" and "elliptical dimension" (Schertzer and Lovejoy 1984). The small scale exhibits shafts or intense vertically [illegible] cores, while the very large scale is horizontally stratified.

Finally, we mention the effect of the Coriolis force may be taken into account ("stochastic geostrophy").

This model is [illegible] for [illegible] between [illegible] and for modelling [illegible] contexts.

H22B-03 INVITED

Maximum Likelihood Estimation for Point Processes

R.N. CHATTOPADHYAY (Department of Mathematics, Indiana University, Bloomington, IN 47405)
M.L. PURI (Department of Mathematics, Indiana University, Bloomington, IN 47405)
(Sponsor: V.K. Gupta)

Let $N(t)$ be a stationary ergodic point process. Under very general conditions one

In the stream, concentrations of nitrate, chloride, and potassium increased with increasing discharge, which reflects an increase in soil-water contribution during high streamflow. Highest concentrations of these constituents were in soil water from the organic horizon.

H31A-07

A Simple Model of Dissolved Sulfate Dynamics in Soils

B.J. Cosby (Department of Environmental Sciences, University of Virginia, Charlottesville, Va. 22903)
G.M. Hornberger, R.N. Wright, J.N. Galloway

Atmospheric deposition of sulfate results in the acidification of surface waters within a watershed. The rate of acidification is controlled by the rate of sulfate deposition and the ability of the watershed soils to adsorb sulfate. Those areas subject to large deposition rates in which surface water acidification has been slow (e.g. the southeastern U.S.) are characterized by watersheds that are accumulating sulfate. By contrast, areas whose surface waters have been acidified to a greater degree (e.g. the northeastern U.S.) are characterized by watersheds that are in steady state with the current sulfate deposition. Based simply on the observation of present day levels of surface water acidification, there has been a tendency to classify watersheds as one of two types; those that are affected by (and will respond to) sulfate deposition sequences and those that are not. The model demonstrates that these watershed responses need not be considered dichotomous but can be viewed as two points on a continuum of possible watershed responses to acidic deposition.

The model is based on a simple equilibrium relationship between dissolved sulfate in the soil water and sulfate adsorbed on soil particles (a Langmuir isotherm). The response time of sulfate concentration is a function of both the hydrologic response time of the watershed and the amount of sulfate adsorbed on the soil. Watersheds with a small adsorption capacity respond at a rate essentially determined by the hydrologic response. Watersheds with large adsorption capacities respond much more slowly. However, as these strongly adsorbing watersheds accumulate sulfate, the response time decreases. This can lead to "breakthrough" behavior and sudden changes in surface water acidification that cannot be predicted from knowledge of current conditions alone.

H31A-08

Solute Loading Mechanisms in the Colorado River Basin

R. L. RITTMASTER (US Bureau of Reclamation, Salt Lake City, Utah 84147)
D. K. MUELLER (US Bureau of Reclamation, Denver, Colorado 80225)

Water management planning for salinity control is often based on the assumption that a salinity reduction at one location is conserved along the flow path. This assumption was tested in a batch study designed to simulate differences in solute pick-up from sediments as a function of stream water quality.

Channel sediments and water samples were collected at five locations in a tributary basin of the Colorado River. Cation exchange capacity was measured on a composite sediment sample, and major minerals were identified by X-ray diffraction. Major ions were analyzed for each water sample.

Two waters ($I=6.9\times10^{-3}$ and 2.2×10^{-2}) were selected as contact media. Changes in solute concentration of the filtrates were compared after contact times ranging from 0.5 to 120 hours. Mineral reactions to identify the solute loading mechanisms in both field samples and filtrates were postulated using USGS computer models WATEQF and BALANCE. Using available hydrologic data, net change in solute load was calculated when a solute-reduced upstream water was routed down the channel. The upstream reduction was not totally conserved.

H31A-09

Experimental Observations of Transport and Sorption in the Subsurface Flow Beneath the Unwetted Channel of a Low-order Mountain Stream

K. E. BENCALA, V. C. KENNEDY, G. W. ZELLWEGER, R. J. AVANZINO (USGS, WRD, Menlo Park, CA 94025), and A. P. JACKMAN (Chem. Engr., Univ. of Calif., Davis, CA 95616)

Results of a field experiment show that after a entering a stream channel through subsurface flows, a solute may continue to interact with subsurface water and bed materials through surface-subsurface exchange flows.

Experiments were conducted in Little Lost Man Creek, Humboldt County, California, in a period of low-flow during which only a part of the bankfull channel held active surface flow. The tracers chloride, strontium, lithium, potassium, and sodium were injected into the stream for a period of 20 days. All tracers were subsequently present in shallow pits dug one to five meters from the wetted part of the channel. In the stream and in the subsurface zones, concentrations of chloride were increased three- to four-fold above the pre-experimental background level. (Chloride background was 6 mg/L.) In the stream, concentrations of strontium were increased up to thirty-fold; however, in some areas of the subsurface zone the increases were less than two-fold. (Strontium background was 0.07 mg/L.) Relative concentration increases of conservative and sorbing solutes further indicates that chemical alterations of stream water occurred in the subsurface zones. Intensive sampling of two apparent inflows to the stream suggests these are actually return flows of surface water temporarily passed through the subsurface. Preliminary simulation studies have been used to identify the relative importance of physical transport and chemical sorption processes in determining subsurface solute concentrations near the flowing channel.

The exchange flows will influence transport times through the system as well as the chemical composition of the water in areas of the catchment.

H31A-10

Hydrologic Storage and Biotic Utilization of Injected Solutes in the Wetted Channel and Adjacent Riparian Areas of a Small Mountain Stream

F. J. TRISKA (USGS, WRD, Menlo Park, CA 94025)
V. C. KENNEDY, K. E. BENCALA, R. J. AVANZINO,
G. W. ZELLWEGER (USGS)

A continuous coinjection of chloride (conservative) and nitrate (biologically reactive) was conducted in a 327 m reach of Little Lost Man Creek, CA at low flow (Cl/N = 40.4). The leading edge of the chloride injection traversed the study reach in 4 hours. Nitrate was rapidly removed; and even after 24 hours, a 50% concentration decrease in NO_3-N was observed through the reach. Assuming nitrate transport identical to chloride, 64% of the loss could be explained by transient storage and 36% by biotic uptake. Only after 7 days of continuous injection did the nitrate daily average concentration approach a plateau, indicating saturation of hydrologic storage sites. Transient storage away from the wetted channel was confirmed by the presence of injected chloride in shallow pits dug 1 to 5 meters from the stream. After the injection ended, Cl/N ratio (by atoms) decreased in most pits from approximately 48 to as low as 30, indicating a nitrogen source in adjacent gravels. In two pits Cl/N was consistently > 607, indicating a severe nitrate sink possibly due to subsurface denitrification. The results indicate that combined hydrologic storage and biotic factors can cause large concentration shifts in biologically nonconservative elements over short distances along a catchment channel.

General Ground Water II
Room 20 Wed AM
Presider, J. Robertson, U.S. Geological Survey

H31B-01

Land Treatment of Tannery Sludges: A Hydrologic Perspective

S.J. DREISS (Earth Sciences, Univ. of Calif., Santa Cruz, CA 95064)
L.D. ANDERSON (Earth Sciences, Univ. of Calif., Santa Cruz, CA 95064)

In September 1980, the EPA and Tanner's Council of America initiated a joint project to investigate the feasibility of land treatment for disposal of tannery sludges. The wastes of most concern contain high concentrations of total chromium (20,000-50,000ppm), total nitrogen (3.5-4.5% wet weight), and total organic carbon (20-40% wet weight). The project is unique in two ways. First, unlike many land-treatment projects, measured changes of soil matric suction and water content are used to estimate the vertical component of soil moisture movement. The highest flux rates over a weekly interval occur during prolonged periods of rainfall when soils are close to saturation. Secondly, the project involves monitoring, under both saturated and unsaturated conditions, of lower concentrations of metals than are usually studied at hazardous waste sites. Measured concentrations of total chromium, in the range of 10 to 43 ppb, are at a maximum during initial seasonal rains, decreasing rapidly within 3 months. Chromium may be mobilized as soluble Cr(VI) or as complexed Cr(III). Interpretation of temporal trends in measured concentrations is complicated by the chemical and physical heterogeneity of the soils and by the fact that chromium co-precipitates with iron in the soil water samplers during collection periods.

H31B-02

Charting the Contaminant History Beneath the Dade County Municipal Landfill

KAU-FUI VINCENT WONG (University of Miami, Department of Mechanical Engineering, Coral Gables, Fl. 33124
(Sponsor: James W. Mercer)

Abstract

Ground water management demands a priori information regarding contaminant transport. The capability to predict the movement of contaminants in ground water is needed for ground water quality impact assessment.

The area that is being studied is the Northwest 58th Street solid waste disposal facility located in Miami, Dade County, South Florida. The facility has operated since 1952 and is only 3 miles west of a major Dade County municipal water supply well field. This area is well suited for the study because (1) the geology and hydrology of the area are well known, (2) water quality data is available to calibrate the model.

A discrete, identifiable leachate plume has been recognized under and down gradient from the waste disposal facility. The concentrations of the contaminants decrease with depth beneath the disposal site and down gradient in response to the advective-corrective dispersion. The present paper deals with the charting of the history of this leachate plume. The work has shown that the movement of the contaminant plume beneath the landfill has been significant. The contaminants that have been studied include NH_3-N, TON, TKN, Dr, COD and phenol. The understanding and prediction of the movement of these contaminants are essential for ground water management.

H31B-03

Use of Geoelectrical Sounding For Evaluating Groundwater Pollution in Faridabad Area, India

A JEYRAM (Department of Civil Engineering, University of Roorkee, Roorkee 247667, India)
D.C. SINGHAL (Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada)
V.K.S. DAVE (Department of Earth Sciences, University of Roorkee, Roorkee 247667, India)
(Sponsor: E.A. McBean)

The Geoelectrical sounding method has been applied to delineate areas of groundwater pollution caused by the percolation of effluents released by factories in Faridabad area close to Delhi metropolis of India. It is observed that mostly untreated waste effluents are released into open streams in this area, thus allowing their percolation into the saturated zone. Accordingly, the groundwater in places further downstream shows a lowering of electrical resistivity when compared to that in the upstream areas. In such situations, the contrast in electrical resistivities of the aquifer at the two places is significant and the main areas of pollution can be demarcated by geoelectrical studies.

The results of geoelectrical soundings in Faridabad area along a local stream, Bhuria Nallah, indicate that groundwater is polluted in areas near Bhopani and Mahabarpur villages located towards northeastern parts, where aquifer resistivity as low as 7 ohm-m was recorded in downstream area of Bhuria Nallah as against 22-60 ohm-m in other areas where groundwater is of superior quality.

The above findings are supported by the maxima of isosalinity contours, observed near Bhopani-Kherikalan villages, for groundwater of shallow wells in the area.

H31B-04

Geochemical trends in the Sandstone Aquifer, eastern Wisconsin

K. E. FRANZ (Department of Geology, Syracuse University, Syracuse, New York 13210)
D.I. SIEGEL (Department of Geology, Syracuse University, Syracuse, New York 13210)

The geochemistry of the Sandstone Aquifer in eastern Wisconsin is being studied by the United States Geological Survey as part of the Northern Midwest Regional Aquifer System Analysis. Groundwater samples were collected and field measurements of pH, Eh and dissolved oxygen were made at 16 wells located on two east-west transects. These data were used to evaluate redox conditions in the aquifer and other geochemical controls on the groundwater chemistry.

Ground water changes from a Ca-Mg-HCO_3 type in the unconfined recharge area downgradient to a Ca-SO_4-HCO_3 type where the aquifer is confined by the Maquoketa Shale. Field pH varies little downgradient, ranging from 7.0 to 7.4, whereas Eh varies from about +400 to -30 millivolts. Dissolved oxygen decreases from about 1 mg/L in the recharge area to less than 0.1 mg/L, whereas dissolved iron generally increases from less than 0.1 to over 2 mg/L.

Saturation indices show that ground water is close to equilibrium with respect to calcite and quartz, undersaturated with respect to siderite, dolomite, anhydrite, and gypsum, and oversaturated with respect to goethite, hematite, and pyrite. Calculations of Eh using dissolved oxygen with Sato's relationship correspond relatively well to measurements of field Eh. However, the major redox reactions controlling environmental Eh are not yet known.

H31B-05

Field Observations of Spatial Variation of Soil Water Pressure in the Vadose Zone

T.-C. JIM YEH (Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22904
L. W. GELHAR (Department of Civil Engineering, MIT, Cambridge, MA 02139)
P. W. Wierenga (Department of Agronomy and Soils, New Mexico State University, Las Cruces, NM 88001)

Field variability of soil water pressure was observed along a 290 m transect through an alfalfa field near Socorro, NM. Pressures were measured using 94 individual tensiometers permanently installed at 3 m intervals along the transect and at a depth of 0.3 m. The tensiometers were monitored using a single, digital readout, pressure transducer which could be rapidly connected by inserting a hypodermic needle through the rubber stopper seal at the top of the tensiometer unit. With this monitoring system a series pressure measurements for the entire transect could be completed in 30 minutes. The transect was monitored several time during a two-week period following a 13 mm rainfall.

The observations show a gradual increase of soil water tension over time and a high degree of spatial variability; the tension ranged from 0.15 to 0.7 bars at a given time. Covariance analyses of the pressure data show that the variations are spatially correlated over distances of at least 6 m. The variance of pressure is observed to increase with mean tension; this trend is in agreement with predictions from stochastic theory.

H31B-06

Hydraulic Conductivity of Peat, Lost River Peatlands, Northern Minnesota

CHASON, D.B. (Department of Geology, Syracuse University, Syracuse NY 13210)
SIEGEL, D.I. (Department of Geology, Syracuse University, Syracuse NY 13210)

The hydraulic conductivity (K) of peat was determined as part of a larger study to evaluate the interrelationships among the hydrogeology, water chemistry, and ecology of a raised-bog complex in the Lost River Peatlands, northern Minnesota. Forty eight piezometers were installed at saturated depths ranging from 0.5 to 5.0 meters on a raised bog, adjacent fen, and large peat mound.

Field hydraulic conductivity was determined by time lag methods. K of Sphagnum peat on the bog ranges from 2.1 E-4 to 5.0 E-3 cm/s, whereas K of the fen peat ranges from 1.3 E-3 to 2.6 E-2 cm/s. K of interbedded Sphagnum and fen peat on the peat mound ranges from 9.7 E-4 to 1.6 E-2 cm/s. The K determined for decomposed peat deeper than 1 meter is 2 to 6 times greater than previously reported in the literature. K of calcareous silty-clay beneath the peat ranges from 7.7 E-5 to 1.3 E-4 cm/s, about 1 to 2 orders of magnitude less than that of the overlying peat. There appears to be little correlation of K with depth, as suggested by other workers who investigated only the uppermost "active" layer, about 1 meter deep.

The data suggests that highly decomposed peat can transmit ground water more rapidly than previously [illegible], and that the interaction between ground water in the peat and surface water [illegible] be significant.

H31B-07

Validation of the Integrated Continuum Approach for Flow in Macro-Micro Porous Systems

Nabil I. EL-KADI (Holcomb Research Institute, Butler Univ., Indianapolis, IN 46208)
WILFRIED BRUTSAERT (School of Civil & Env. Engrg., Cornell Univ., Ithaca, NY 14853)

Experimental evidence is used to validate the integrated continuum approach for flow in macro-micro porous systems. In this approach macro and micro are treated not as separate and distinct flows, but as differing elements of the same system. This is achieved through the definition of special characteristic functions which are obtained using the pore size distribution. The new model can be applied to different saturated-unsaturated ground-water problems by solving a single flow equation with no special attention given to the detailed structure of the medium (e.g., spacing and geometry of the macro-pores). Applications to drainage and infiltration problems showed that macro-pores, when they exist, are likely to affect to great extent the behavior of the system under consideration.

H31B-08

Sand Body Interconnectedness and Ground-Water Flow in a Thick Multiple Aquifer System[1]

GRAHAM E. FOGG and S. J. SENI, (Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78712-7508)

Many so-called sandstone aquifers are actually multiple aquifer systems consisting of discontinuous sand bodies distributed complexly in a matrix of lower permeability silts and clays. The arrangement and interconnectedness of these various lithofacies strongly influence spatial patterns of hydraulic conductivity (K). Such patterns can generally be estimated only through careful analysis of both subsurface geologic data and hydrologic (K and hydraulic head) data. In this study, a three-dimensional ground-water flow model was constructed for a 1,300 km^2 area of the Wilcox Group (Eocene), a complex, multiple aquifer system up to 820 m thick, in the East Texas Basin. Using K data from core samples and pumping tests and more than 100 geophysical logs, two hydrostratigraphic units were mapped in three dimensions: (1) dip-oriented, elongate fluvial-channel-fill sands having predictable values of K, generally from 1 to 10 m/day and (2) finer grained interchannel sediments that are lower in K by a factor of 10^1 to 10^3 in most cases. Results demonstrate that the degree of lateral and vertical interconnectedness of channel-fill sands is of pivotal importance to ground-water velocities computed by the model. Vertical interconnectedness is poor, as evidenced by the low ratio of vertical to horizontal equivalent hydraulic conductivity ($K_v/K_h = 10^{-4}$) needed to simulate observed vertical hydraulic gradients. Good horizontal interconnection is apparently restricted to distinct channel sand belts where frequency of channel-fill sands is high. These belts tend to be isolated from one another by large interchannel sections in which the channel-fill sands are too sparse to be interconnected. Simulated ground-water velocities are consequently lower in the interchannel sections than in the channel-fill sands by a factor of 10^{-3} to 10^{-4}.

H31B-09

LESSONS IN SIMULATING SALTWATER TRANSPORT IN A MULTI-LAYER GROUNDWATER SYSTEM

A. Das Gupta (Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand)

The degree of confidence with which the saltwater transport in aquifers can be simulated depends solely on the availability of historical information on hydraulic and salinity aspect; detailed geological information; and information on physical characteristics of various layers comprising the formation. In most of the application problem on regional scale, data needed to analyze the situation are inadequate and the modeller has to investigate all the possible alternatives not only to appraise the situation but also to enhance the necessity of a concentrated field investigation on specific aspects in specific areas.

A quasi-three-dimensional finite difference solute transport model is developed with the objective of obtaining a practical model that closely represents the hydrogeological situation in the multi-layer groundwater basin underlying the city of Bangkok, Thailand. The first two water bearing layers of sand and gravel below the ground surface namely Bangkok aquifer (50 m zone) and Phra Pradaeng aquifer (90 m zone) are considered for the analysis purpose. The saltwater transport process in the Phra Pradaeng aquifer is simulated considering three possibilities of the sources of contamination; namely, (a) downward seepage of brackish water from two rivers flowing through the basin to the first layer and subsequently to the Phra Pradaeng aquifer; (b) existance of connate water bodies in the Phra Pradaeng; and (c) both the existance of connate water bodies in the Phra Pradaeng aquifer and seeping of saltwater from the connate water bodies in the Bangkok aquifer through the interlinkage areas between the aquifers. The results obtained from these exercises emphasize the areas where detailed field investigation is needed. (Saltwater transport, multi-layer ground-water basin, models, simulation).

H31B-10

The Geostatistical Approach to the Inverse Problem in Ground-water Modeling: 2-D Simulation and a Case Study

P.J. HOEKSEMA (Iowa Inst. of Hydraulic Research, Iowa City, Iowa, 52242)
P.K. KITANIDIS (Iowa Inst. of Hydraulic Research, Iowa City, Iowa, 52242)

The geostatistical approach to the estimation of transmissivity from head and transmissivity measurements is developed for two-dimensional steady flow. The field of the logarithm of the transmissivity (log-transmissivity) is represented as a zero-order intrinsic random field; its spatial structure is described through a two term polynomial generalized covariance function which is linear in the parameters θ_1 and θ_2. Linearization of the discretized flow equations allows the construction of the joint covariance matrix of the head and log-transmissivity measurements as a linear function of θ_1 and θ_2 as well as additional parameters from measurements. Linear estimation theory (cokriging) then yields point or block-averaged estimates of transmissivity. The approach is first applied to a test case with favorable results. It is shown that the application of the methodology gives good estimates of transmissivities. It is also shown that when the transmissivities are used in a numerical model, they reproduce the head measurements quite well. Results from the application of the methodology to the Jordan aquifer in Iowa, are also presented.

H31B-11

Numerical Experiments on Artificially Generated, 3-Dimensional Fracture Networks

C. HUANG (Dept. of Hydrology and Water Resources Univ. of Arizona, Tucson, AZ. 85721)
D. D. EVANS and S.P. NEUMAN

Numerical experiments on artificially generated, three-dimensional fracture networks are described. The network is a random assembly of planar fractures having variable shapes. The location, orientation, size and aperture of each fracture are drawn from prescribed statistical distributions. Experiments have been conducted to investigate the effect of sample scale on steady state fluid flow under a range of boundary conditions, on the interpretation of point injection hydraulic tests, and on the transport of chemicals from a point source. The results provide insight into related scale effects and facilitate the design and interpretation of field tests.

H31B-12

The Development of Multiple Seepage Faces on Heterogeneous Hillsides

J.J. RULON (Center for Environmental Research, Cornell Univ., Ithaca, NY 14853)
R.A. FREEZE (Geological Sciences, U. of British Columbia, Vancouver, BC, Canada, V6T 2B4)

A study has been made to clarify the water-table configuration and hydraulic-head distribution in layered hillsides containing multiple seepage faces. A finite-element model was used to simulate two-dimensional, steady-state and transient flow through layered slopes. A laboratory sand-tank experiment was built to test the physical foundation of the mathematical model; the test met with success. Layered slopes were found to feature perched water tables and wedge-shaped unsaturated zones which, in some cases, can extend several kilometers into the flow region. The results demonstrate that the hydraulic-head distribution and the formation of multiple seepage faces are strongly dependent upon the position of the impeding layers, the hydraulic conductivity contrast, the rainfall rate, anisotropy, and the slope angle. Predictions of the groundwater conditions based on homogeneous, saturated analyses may be significantly in error when applied to problems in layered slopes. This study has implications with respect to slope stability, inflows into excavations, regional groundwater flow, the occurrence of perched flow systems, and hillslope processes involved in landform development.

H31B-13

Delineation of Aquifers in Alluvial and Hardrock Areas Of Banda District, India, Using Automatic Interpretation of Geoelectrical Data

D.C. SINGHAL (Department of Civil Engineering University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada)
SRI NIWAS (Department of Earth Sciences, University of Roorkee, Roorkee 247667, India)
B.B.S. SINGHAL
(Sponsor: E.A. McBean)

An area of approximately 3000 sq. km in the southeastern parts of Banda District, Uttarpradesh, India has been studied by means of 160 Schlumberger geoelectrical soundings supplemented by hydrogeological and photogeological studies. The aim of the study was to delineate shallow and deep aquifers in the northern, alluvial areas and in the southern, rocky terrain. The data of geoelectrical soundings was interpreted using a Computer Programme, which involved computations of theoretical and observed resistivity transforms and obtain their convergence by an iterative process, using Marquardt technique.

The study has indicated three main aquifers at shallow depths - a porous, sandy aquifer within the alluvium; fractured (and weathered) aquifer in the sandstone bedrock in eastern parts, and in the granite northwestern parts of the area. A deeper aquifer has been indicated in the cavernous dolomite occurring below the sandstone at depths ranging from 25 - 100 m below the ground surface. The dolomitic aquifer is likely to be highly productive at some localities, as indicated by relatively low electrical resistivities in the order of 38 - 150 ohm - m. However, its southward extension beyond a lineament, designated as Manikpur Shear Zone, could not be established.

H

H31B-14

An Alternative Numerical Method for Solution of the Transient Groundwater Flow Equation

JAMES Y. TRACY (S. S. Papadopulos & Associates, Inc., Rockville, MD 20852)
GARY R. CHIRLIN (S. S. Papadopulos & Assoc., Inc.)

The steady groundwater flow equation is frequently solved by finite difference or finite element methods, which can accomodate spatially varying hydraulic parameters and boundary conditions and geometries. At the subdomain level (e.g., a grid cell or element) these numerical methods rely on a simple (typically linear) functional representation of the solution. When the transient flow equation is solved the same methods of spatial discretization are used. Hence the solution surface at the subdomain level is effectively a quasi-steady one. A change in conditions at any node of a subdomain is immediately propagated to adjacent nodes.

Here a methodology is proposed for the transient flow equation which decomposes the functional representation over a single subdomain into a steady and a transient component. These terms are developed from the analytical solution of the transient flow equation over a homogeneous subdomain with simple boundary conditions. The steady term produces the conventional quasi-steady surface. The transient term modifies this surface to effect the timing of propagating storage changes.

The method was originally developed to consider the transient response of thick, or layered, sediments abutting a pumped formation, where timing and quantity of contributions of flow from storage are significant (e.g., delayed yield).

Economy of discretization and accuracy of approximation are considered for this method, and are compared with standard numerical methods for a class of simple, analytically solvable, problems.

H31B-15

ogress on Radiometric Dating of Deep Brines in The alo Duro Basin, Texas Using ^{4}He, ^{21}Ne and ^{40}Ar

A. ZAIKOWSKI and B. J. KOSANKE (Bendix Field Engineering Corp.), Grand Junction, Colorado 81502
N. WUBBARD (Battelle Memorial Institute), Columbus, Ohio 43201

Ground water samples from deep wells in the Palo Duro Basin, Texas are being analysed for noble gases in an attempt to obtain radiometric ages for the waters in the Wolfcamp, Pennsylvanian Carbonate and Granite Wash aquifer. These ground waters are brines and contain radiogenic ^{4}He and ^{40}Ar produced from the radioactive decay of U, Th and K. Excess ^{21}Ne is found and ascribed to alpha-neutron reactions on ^{18}O. The ^{4}He and ^{40}Ar data are used to estimate the age of the Wolfcamp brines as about 130 million years at two wells. At two other wells interaquifer mixing is indicated by other isotopic data. Unless the mixing hypothesis is replaced by a better hypothesis, it may never be possible to calculate a meaningful age for the Wolfcamp brines at these two wells. Data to date for excess ^{21}Ne/^{4}He ratios are constant within a factor of two and agree with the excess ^{21}Ne/^{4}He ratios expected from theoretical calculations of ^{21}Ne production rates for the alpha-neutron reactions on ^{18}O, where the alphas are from U and Th. The similarity of the observed and theoretical excess ^{21}Ne/^{4}He ratios indicates no significant loss of ^{4}He from the ground water and that the ground water ages calculated from the ^{4}He data are basically correct.

General Hydrology
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H32-01

Optimizing Water Quality Under Uncertainty

D. H. Burn (Department of Civil Engineering, University of Waterloo, Waterloo, Ontario Canada, N2L 3G1)
E. A. McBean

Methodologies are presented for including stochastic considerations within a screening model for water quality management plan determinations. The motivation for the research is to enhance the agreement between the results obtained from a screening model, suitable for use at the planning stage, and those results obtained from a more detailed simulation of the physical system. To accomplish this, screening models must incorporate improved reflection of the stochastic nature of water quality phenomena.

A chance-constrained programming formulation is utilized to include probabilistic constraints in the dual formulation. To determine the degree of randomness in the transfer coefficients due to the variability of their constituent elements, first order uncertainty analysis is employed. In the case study application presented, the optimal treatment levels to maximize water quality, subject to a budgetary constraint, are determined.

H32-02

Application of a Linked Water Quality-Stream Network Screening Model

R.M. CLARK (Drinking Water Research Division, USEPA, Cincinnati, Ohio)
W.M. GRAYMAN (W.M. Grayman Consulting Engineer, Cincinnati, Ohio)

This paper describes the application of the Routing and Graphical Display System developed by USEPA to illustrate how computer based water quality modelling in conjunction with geographically based network data base systems may be utilized to assess the types and concentrations of contaminants that may be found in a river. The method is applied to the Lower Mississippi River.

The USEPA Reach File System, Industrial Facilities Discharge File, and matrices representing average pollutant loadings by industrial type are used in conjunction with a first order decay model to determine pollutant loadings and to route the pollutants through the river system. Twelve organic contaminants are simulated and the resulting pollutant concentrations compared to measured values in the New Orleans area (Jefferson Parish, Louisiana). Computer generated profile plots illustrate the longitudinal variation in pollutant concentrations. Observed and predicted concentrations show reasonable order of magnitude agreement in most cases.

The methodology applied in this study may be used as a screening procedure to identify the types and levels of contaminants likely to be found within a raw water supply derived from surface water sources. Research is continuing in the refinement and application of this methodology.

H32-03

Average Dilution in Rivers

RICHARD CODELL (U.S. Nuclear Regulatory Commission, Washington D.C. 20555)

The hazard of low levels of chemical or radioactive waste is often quantified on the basis of annual, or longer, average exposure (e.g., 10CFR20 for radionuclides). The average concentration $\langle C \rangle$ for a nondecaying pollutant has been frequently, but mistakenly, calculated as:
$\langle C \rangle = \langle W \rangle \times 1/\langle Q \rangle$ (Eq.1), where $\langle W \rangle$ and $\langle Q \rangle$ are the expected values of pollutant and river discharges respectively. It is demonstrated that if W is not correlated to Q, then $\langle C \rangle$ is usually more accurately calculated:
$\langle C \rangle = \langle W \rangle \times \langle 1/Q \rangle$ (Eq.2). The concentration calculated by Eq.1 is always less than that calculated by Eq.2, because the former is weighted by floods, while the latter is weighted by droughts. It is shown that close to the point of release, where river flowrate and concentration are highly correlated, Eq.2 would hold, but far from the source $\langle C \rangle$ tends toward Eq. 1. This phenomenon is dubbed the Concentration-Distance (CD) effect, and is caused by the decay of the correlation between concentration and river velocity with distance from the source. This phenomenon has nothing to do with the actual decay of the material, which is considered in this case to be a nondecaying tracer. It can further be shown that longitudinal dispersion in the river would generally have no measurable effect on $\langle C \rangle$ because a much larger effective dispersion is introduced by the averaging procedure. The theory is tested using real data on two free-flowing, undammed segments of the Yampa and Missouri Rivers. In both cases, the CD effect was shown to be unimportant. Furthermore, measured values of dispersion for these rivers had no noticeable effect on the calculated value of $\langle C \rangle$. The ratio of $\langle C \rangle$ calculated by Eq.2 to that calculated by Eq. 1 ranged from about 3.7 in the smaller and unregulated Yampa River, to about 1.3 in the larger and extensively regulated Missouri River. The effects of the increased level of regulation in the Missouri River over a period of time can be clearly seen. The CD effect is predicted to be much more important in extensively dammed rivers such as the Tennessee River. The techniques presented are being used for the evaluation of the effects of normal and accidental releases of liquid effluent from nuclear power plants

H32-04

Mathematical Model of Vertical Stratification in a Lake Receiving Acid Mine Drainage

E. B. Pastetter (Department of Environmental Sciences, University of Virginia, Charlottesville, Va. 22903)
S. M. Hornberger, A. D. Mills, and A. Herlihy

Contrary Creek, an acid mine stream, flows into Lake Anna, Virginia, with a sulfate concentration ranging between 2,000 and 10,000 micro-molar. Bacterial sulfate reduction in the sediments effectively removes most of the sulfur before the water leaves the arm of the lake into which Contrary Creek flows. The hydrology of the lake, especially the degree of mixing and the level of insertion of Contrary Creek water into the lake, is very important to the process of sulfate removal since it controls the access of sulfate to the sediments. High sulfate concentrations are frequently observed in the bottom waters of this arm of the lake which lead us to hypothesize that the lake may be salt stratified.

A modified version of DYRESM-6 (a computer simulation model for predicting the vertical temperature and salt structure of medium sized lakes) was used to predict the sulfate distribution in the lake in the absence of biological removal. Results of the simulations indicate that thermal stratification in the lake is much stronger than salt stratification, however, a strong thermal stratification effectively traps the sulfate plume in the hypolimnion and weak salt stratification develops when temperatures are homogeneous top to bottom. These results, in conjunction with measured sulfate reduction rates in the sediments, suggest that the sediments are most effective at sulfate removal during calm summer days when thermal stratification is strong.

H32-05

Sediment Load During Flood Events

MISGANAW DEMISSIE (Associate Professional Scientist, Illinois State Water Survey, Champaign, IL 61820)

A large percentage of the annual sediment yield from a watershed is transported by a stream during a small number of floods that occur for a relatively short period of time in any year. The correct determination of the total sediment yield from a watershed therefore depends largely on the accuracy of sediment load measurements during flood events. Furthermore, the development of a relation between the annual sediment yield and the sediment load during flood events will provide a simple procedure for estimating the total sediment yield based on the sediment load during a few high floods in a year. Such a procedure will result in significant savings of effort and money for agencies responsible in monitoring and evaluating watershed erosion, reservoir sedimentation and conservation practices.

Relationships between the annual sediment yield and the sediment load during the highest and second highest floods in a given year were developed based on available stream sediment load data from five midwestern states. On the average, it was found that the two highest floods in a year transport about 40 percent of the annual sediment yield from a watershed. The combined duration of the two floods was generally less than 30 days.

H32-06

Effects of Unremoved Periodicity in Parameters on Stochastic Dependence

JAYANTHA OBEYSEKERA
VUJICA YEVJEVICH (both at: International Water Resources Institute, George Washington University, Washington, D.C. 20052)

The modeling of seasonal hydrologic time series often involves the identification of periodic functions of its basic parameters (mean, standard deviation, skewness, autocorrelation, etc.). A common practice is to single out a stationary stochastic model of a time series, after making it non-periodic by using the inferred periodic functions. This presentation deals with consequences in case of an incorrect inference on harmonics of underlying basic periodic parameters in the subsequent identification of characteristics of stochastic dependence.

The individual and joint effects of unremoved periodicities in the mean, the standard deviation, and the autocorrelation are treated. In general, the unremoved periodicities significantly distort the autocorrelation function of the inferred deseasonalized time series, requiring the modeler to use complex models such as the higher order ARMA, when in reality the true autocorrelation function does not follow such models.

H32-07

ABSTRACT

A Linear Regression Approach to Spectral Analysis of Hydrologic Time Series

G. Padmanabhan (Dept. of Civil Engineering, North Dakota State University, Fargo, ND 58105
A Ramachandra Rao (School of Civil Engineering, Purdue University, West Lafayette, IN 47907)

The traditionally used Blackman and Tukey (BT) and Fast Fourier Transform (FFT) methods of spectral analysis suffer from disadvantages such as artificial extension of data series (padding) with zeros and subjective choice of window functions. Also spectra can be estimated only at certain frequencies depending on the number of data points or maximum lag up to which autocorrelation estimates are available. Actual dominant frequencies in the data may lie between these frequencies and may pass undetected. In hydrological applications, the details of spectra in the low frequency range which are important may be completely missed. Power in the actual dominant frequencies may also erroneously show up in the adjacent harmonic frequencies. As an alternative to the traditional methods, in this paper, a linear regression approach is used to estimate power spectra of some hydrologic time series. Spectral estimate can be obtained at any desired frequency and no window smoothing is required in this method. Results are compared with those obtained from traditional methods.

Average Dilution in Rivers

RICHARD CODELL (U.S. Nuclear Regulatory Commission, Washington D.C. 20555)

The hazard of low levels of chemical or radioactive waste is often quantified on the basis of annual, or longer, average exposure (e.g., 10CFR20 for radionuclides). The average concentration $\langle C \rangle$ for a nondecaying pollutant has been frequently, but mistakenly, calculated as: $\langle C \rangle = \langle W \rangle \times 1/\langle Q \rangle$ (Eq.1), where $\langle W \rangle$ and $\langle Q \rangle$ are the expected values of pollutant and river discharges respectively. It is demonstrated that if W is not correlated to Q, then $\langle C \rangle$ is usually more accurately calculated: $\langle C \rangle = \langle W \rangle \times \langle 1/Q \rangle$ (Eq.2). The concentration calculated by Eq.1 is always less than that calculated by Eq.2, because the former is weighted by floods, while the latter is weighted by droughts. It is shown that close to the point of release, where river flowrate and concentration are highly correlated, Eq.2 would hold, but far from the source $\langle C \rangle$ tends toward Eq. 1. This phenomenon is dubbed the Concentration-Distance (CD) effect, and is caused by the decay of the correlation between concentration and river velocity with distance from the source. This phenomenon has nothing to do with the actual decay of the material, which is considered in this case to be a nondecaying tracer. It can further be shown that longitudinal dispersion in the river would generally have no measurable effect on $\langle C \rangle$ because a much larger effective dispersion is introduced by the averaging procedure. The theory is tested using real data on two free-flowing, undammed segments of the Yampa and Missouri Rivers. In both cases, the CD effect was shown to be unimportant. Furthermore, measured values of dispersion for these rivers had no noticeable effect on the calculated value of $\langle C \rangle$. The ratio of $\langle C \rangle$ calculated by Eq.2 to that calculated by Eq. 1 ranged from about 3.7 in the smaller and unregulated Yampa River, to about 1.3 in the larger and extensively regulated Missouri River. The effects of the increased level of regulation in the Missouri River over a period of time can be clearly seen. The CD effect is predicted to be much more important in extensively dammed rivers such as the Tennessee River. The techniques presented are being used for the evaluation of the effects of normal and accidental releases of liquid effluent from nuclear power plants.

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4. H (hydrology)
5. Special Session: none
6. 0
7. Zero Percent
8. Prepaid - $30.00
9. C

'Average Dilution in Rivers'
By Richard Codell

Narrative Description of Slides Presented at AGU Meeting
Cincinatti, Ohio, May 16, 1984

Slide 1

Pipe flow representation of a river.

a. Pollutant W(t) released at x=0 uniformly across river. Conservative non-decaying tracer.

b. Flowrate Q(t) in river. Cross section area A.

c. Pollutant concentration for low-level chronic discharges frequently evaluated on long-term basis. Therefore, we want to know what average dilution (e.g., 10 CFR 20 Standards for Radionuclides)

d. There are complicated, time-dependent models for dilution, but simplified models usually suffice.

e. Criteria for using simplified models for average dilution calculations.

Slide 2 Dilution Formulas

a. For one dimensional plug flow at source, x=0, C = W/Q

b. Expected value $\langle C \rangle = \langle W/Q \rangle$

c. If W and Q are uncorrelated,

$\langle C \rangle = \langle W \rangle \langle 1/Q \rangle$

or $\bar{C}^R = \frac{\langle W \rangle}{\bar{Q}^R}$ (Eq. 1)

where $\bar{Q}^R = \langle Q \rangle^{-1}$ (reciprocal av. or harmonic mean)

d. Dilution frequently but mistakenly calculated

$$\overline{C} = \frac{\langle W \rangle}{\overline{Q}} \qquad \text{(Eq. 2)}$$

where $\overline{Q} = \langle Q \rangle$ (arithmetic mean)

e. Eq. 1 correctly weights flowrate, (including low flows) but Eq. 2 overemphasizes importance of floods.

Slide 3 Artificial flowrate used in pipe flow model

a. Period of change is P time units

b. Velocity chosen from a uniform random distribution between UMAX and UMIN, with mean <U>

c. Aspect ratio $a = \frac{UMAX}{UMIN}$

Slide 4

Ratio $\overline{Q}^R / \overline{Q}$ as function of aspect ratio a.

$$\frac{\overline{Q}^R}{\overline{Q}} = \frac{2(a-1)}{(a+1)\ln a}$$

Shows that effective average dilution at source decreases for flows with larger deviation from mean.

Slide 5

The effect of flow variability on the effective dilution can be shown on data from Missouri River at Sioux City, Iowa.

a. Ratio $\overline{Q}/\overline{Q}^R$ plotted for each year of record.

b. $\overline{Q}/\overline{Q}^R$ after about 1960 shows marked decrease.

c. Several large reservoirs formed in upper Missouri River Valley which had the effect of regulatory flow, and reducing deviation from mean, thus making $\overline{Q}^R$ approach $\overline{Q}$.

Slide 6

Slide shows <C> normalized to $\overline{C}$

where $\overline{C} = \langle W \rangle / \langle Q \rangle$

as a function of aspect ratio and distance from source:

a. Calculated with finite difference pipe-flow model and artificial flow rate. No longitudinal dispersion and no numerical dispersion.

b. L is distance traveled at <U> for period of flow oscillation P

c. Demonstrates that close to source, average concentration is predicted by Eq. 1,

$\langle C \rangle = \langle W \rangle / \overline{Q}^R$

but far from source, $\langle C \rangle \rightarrow \langle W \rangle / \overline{Q}$

Slide 7

Effect of longitudinal dispersion on average concentration

a. Calculated with finite difference pipe flow model using artificial random flow rate

b. Boundary conditions were

$$W = \epsilon \frac{\partial C}{\partial z} + \frac{U}{\langle U \rangle} C \qquad \text{at } z = 0$$

$$\frac{\partial^2 C}{\partial z^2} = 0 \qquad \text{at } z = \infty$$

$$z = x/L$$

c. Slide shows that increased dispersion parameter makes average concentration approach $\overline{C} = \langle W \rangle / \langle Q \rangle$

Slide 8 Example rivers to try out theory

a. Yampa River in Colorado

$\overline{Q}$ between 448 and 1017 ft^3/sec

b. $\overline{Q}^{R}$ between 187 and 275 ft^3/sec

c. Subject of USGS study on dye tracer dispersion

d. Typical of medium size free-flowing river with wide variations in flowrate (high aspect ratio).

Slide 9

Missouri River between Sioux City and Omaha

a. $\overline{Q}$ = 28900 ft^3/sec

b. $\overline{Q}^{R}$ = 21125 ft^3/sec

c. Also subject of USGS dye dispersion study

d. Typical of large free-flowing river, but with regulation by tributary reservoirs. Relatively small variations in flowrate (low aspect ratio).

Slide 10

Tennessee River from Watts Bar Dam to Guntersville Dam

a. Typical of large river with mainstem dams

Slide 11 Delaware River from Trenton to Wilmington

a. Typical east-coast drowned river estuary

b. subject of modeling studies for BOD transport

c. Considered in this case as a river with small scale dispersion caused by tidal oscillations, with large scale transport by fresh-water flow superimposed.

d. Had no flow data for Delaware case, so assumed that the flow variability (aspect ratio) was similar to Missouri River

Slide 12 Power Spectra for Q and Q^{-1} in Yampa River

a. Since phenomena are frequency dependent, analyzed the frequency content of flowrates using spectral methods.

b. demonstrates that most of power in Q and Q^{-1} is for periods longer than 100 days.

c. The average velocity in the Yampa River is 2-3 feet/sec;

If $L = \langle U \rangle P$ and P is said to be represented by periods greater than 100 days, then L is about 3000-5000 miles.

d. so x/L over the 10 mile study reach is very small, about 0.002.

e. Ratio of $\overline{Q}/\overline{Q^{-k}} =$ 2.4 from approximately 3 years of data, suggesting that a = 100 if flow can be related to the synthetic flow used in finite difference model experiments.

f. Dispersion parameter $\epsilon = \frac{E}{\langle U \rangle L}$ using measured values also very small, about 0.0001.

Slide 13

a. Power Spectra for Missouri also suggest that dominant periods greater than 100 days.

b. $\langle U \rangle \doteq 4$ feet/sec.

L = $\langle U \rangle$ and P is said to be represented by periods greater than 100 days,

so L is about 7000 miles

c. x/L over the 130 mile study reach is about 0.02

d. Ratio of $\bar{Q}/\bar{Q}^{R}$ is about 1.4, suggestions that flow is similar to a = 10.

e. Dispersion Parameter ϵ = 0.0001 based on measured values

Slide 14 Pipe Flow Model

a Yampa and Missouri River flow rate data used in a finite difference model for one-dimensional transport which included longitudinal dispersion.

b. Model considered that cross-sectional area of river was related to the river flowrate using open-channel flow relationships.

c. $\langle C \rangle$ at end of study reach calculated for case of a steady injection rate W.

Slide 15 Concentration as a function of $\frac{x}{L}$ and a

a. Results of $\langle C \rangle$ at end of study reach plotted on this figure

b. Both Yampa and Missouri River cases plot on the left side of figure in region where average concentration is predicted by $\langle C \rangle = \langle W \rangle / \bar{Q}^{R}$

c. For Tennessee River, velocity is very much smaller than in Yampa and Missouri case. Therefore, over 200 mile reach, x/L = 150. The average concentration in this case is clearly in the region where $\langle C \rangle = \langle W \rangle / \bar{Q}$ (Eq. 2)

d. Delaware estuary case - Assuming that flow is characterized by a = 10, and P = 100 days (no data actually used). x/L = 0.07 at Philadelphia and about 0.18 at Wilmington. Therefore, <C> is predicted to be intermediately between that predicted $\langle W\rangle/\overline{Q}^{A}$ and $\langle W\rangle/\overline{Q}$, as shown on slide.

Slide 16 Effect of Longitudinal Dispersion

a. The dispersion parameter in the Missouri, Yampa and Delaware cases would al be in the range where there would not be any predicted effect on <C>.

b. Finite Difference model runs with Yampa and Missouri River data shown no effect of putting in or taking out measured value of dispersion.

c. Consistent with Molyneaux and Witten 1979 WRR paper which showed a large effective dispersion added because of flowrate variations.

Slide 17 - Conclusions

On basis of some simple numeral models, can state the following principals for calculating the expected value for concentration of conservative substances, if W and Q are uncorrelated.

a. for undammed rivers over stretches of up to several hundred miles, $\langle C\rangle = \langle W\rangle \langle 1/Q\rangle$

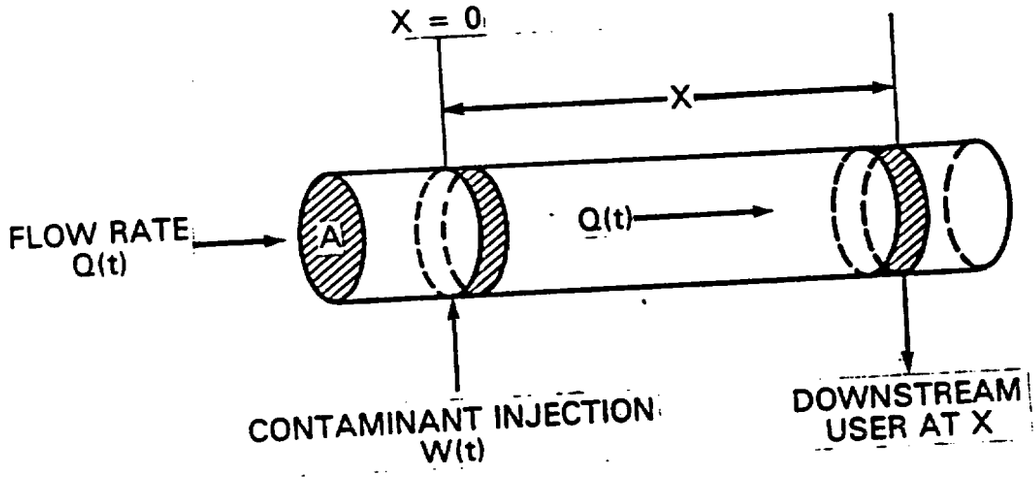
b. Biggest error in using $\langle C\rangle = \langle W\rangle/\langle Q\rangle$ is small flashy rivers with up to several hundred percent error possible.

c. For rivers with large mainstem dams, use $\langle C\rangle = \langle W\rangle/\langle Q\rangle$

d. Estuaries fall between $\langle C\rangle = \langle W\rangle/\langle Q\rangle$ and $\langle C\rangle = \langle W\rangle \langle 1/Q\rangle$

Slide 1, Slide 14

PIPE MODEL FOR RIVER



Slide 2

FOR A CONSERVATIVE TRACER

IN ONE DIMENSIONAL PLUG FLOW

$C = W/Q$ AT SOURCE

$\langle C \rangle = \langle W / Q \rangle$

$\bar{C}^R = \langle W \rangle \langle 1/Q \rangle$ if W AND Q UNCORRELATED (Eq 1)

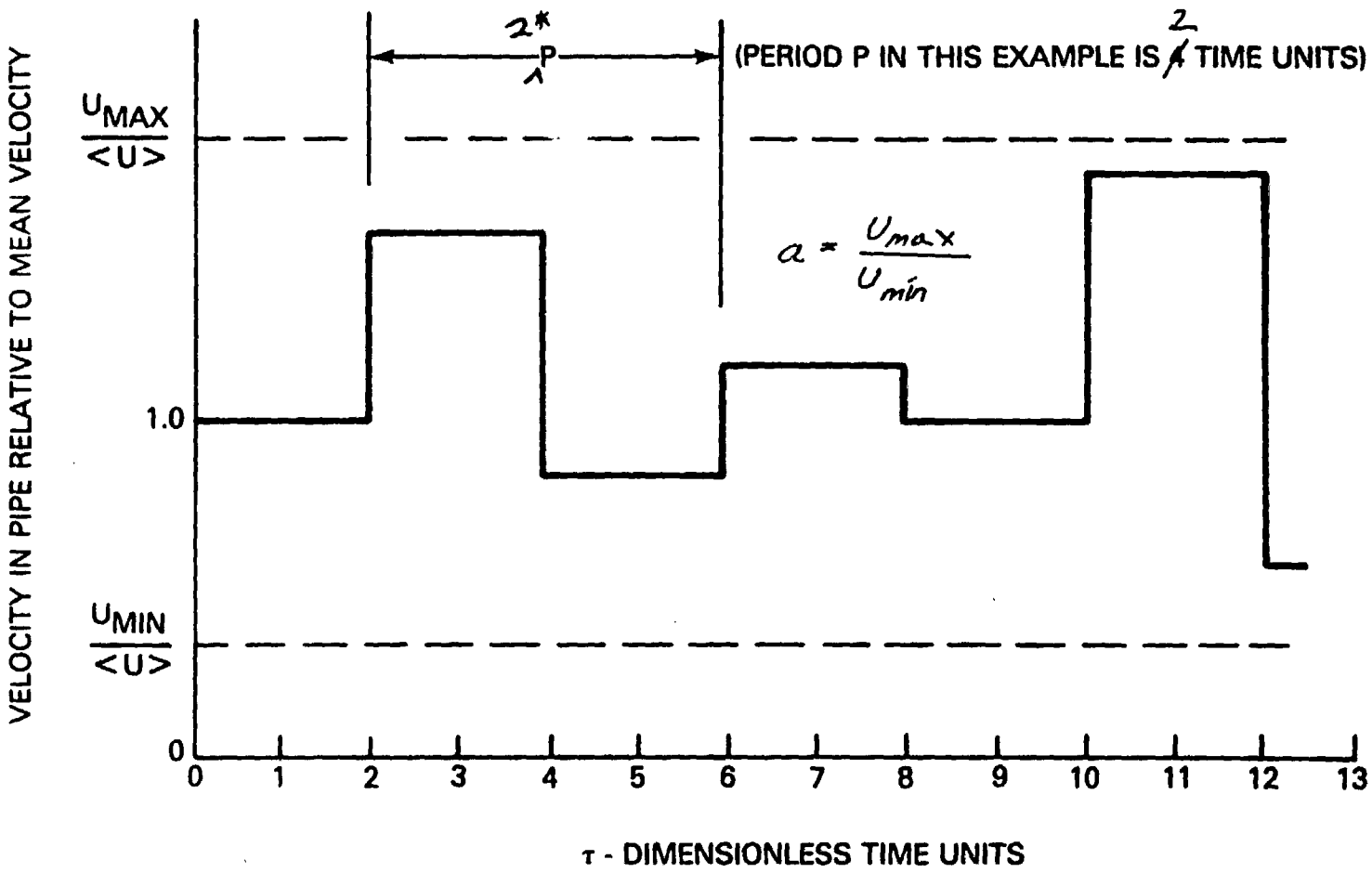
$\bar{C} = \langle W \rangle / \langle Q \rangle$ (Eq 2)

$\bar{Q}^R = \langle 1/Q \rangle^{-1}$

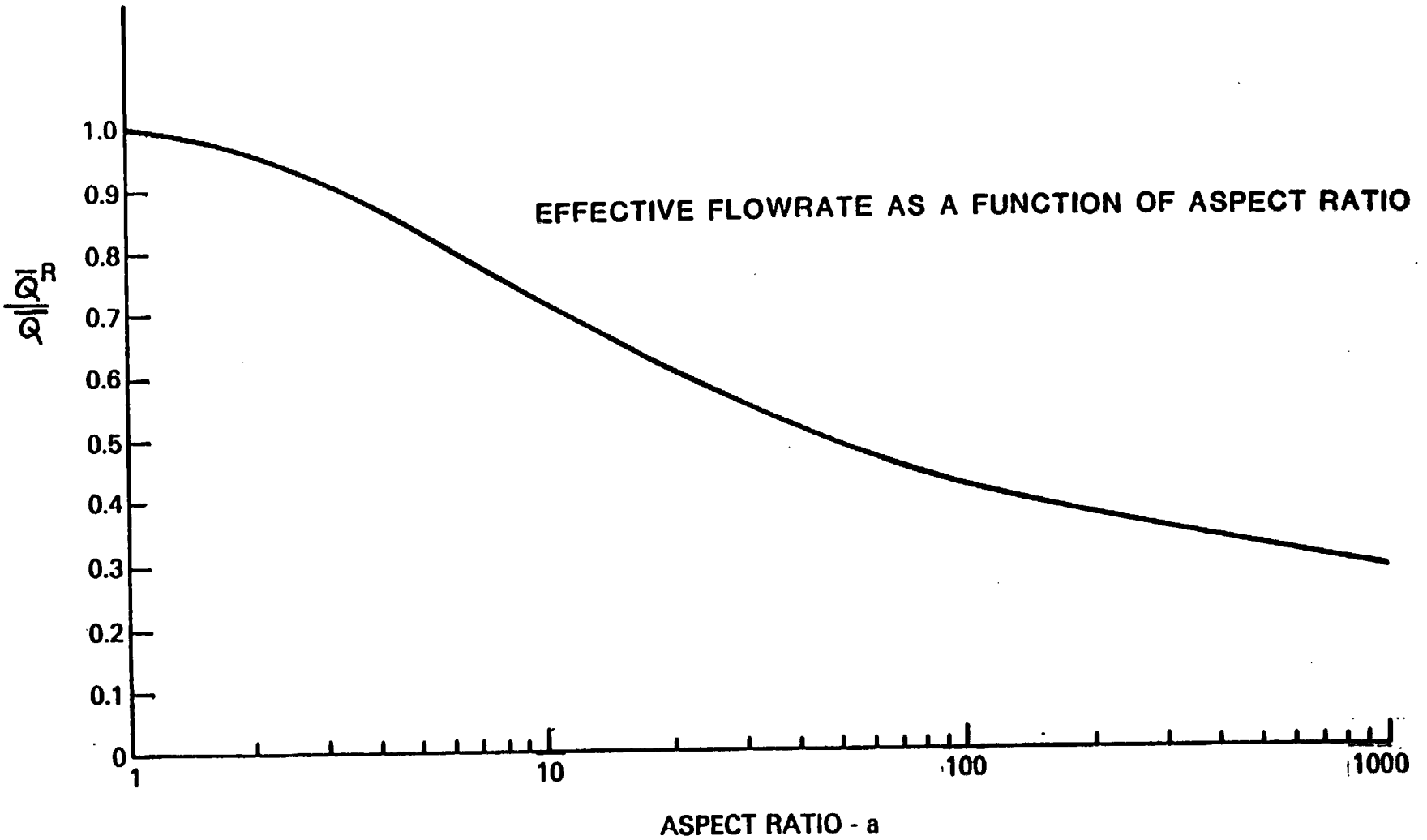
$\bar{Q} = \langle Q \rangle$

Slide 3

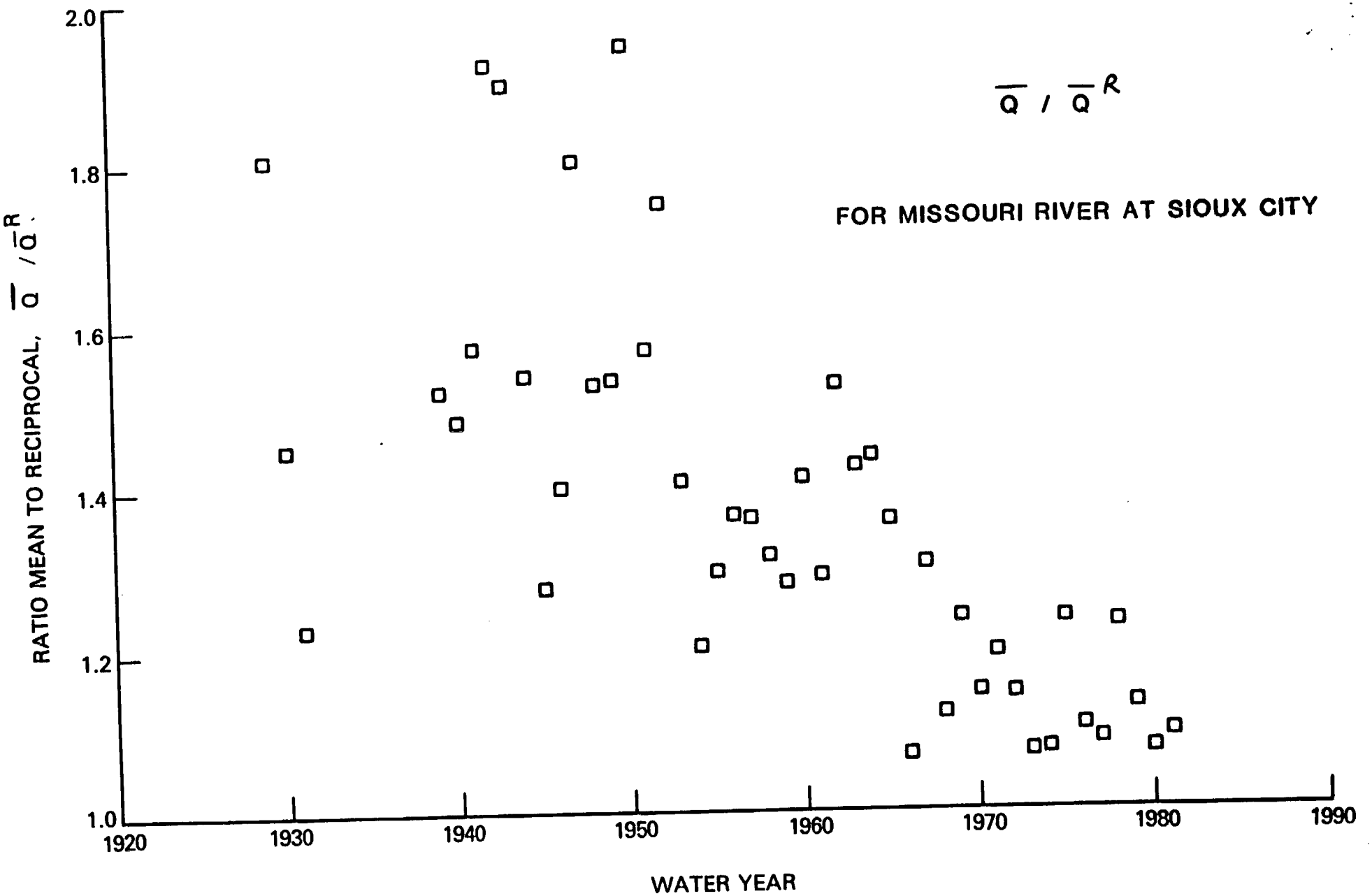
SYNTHETIC STREAMFLOW FOR RIVER



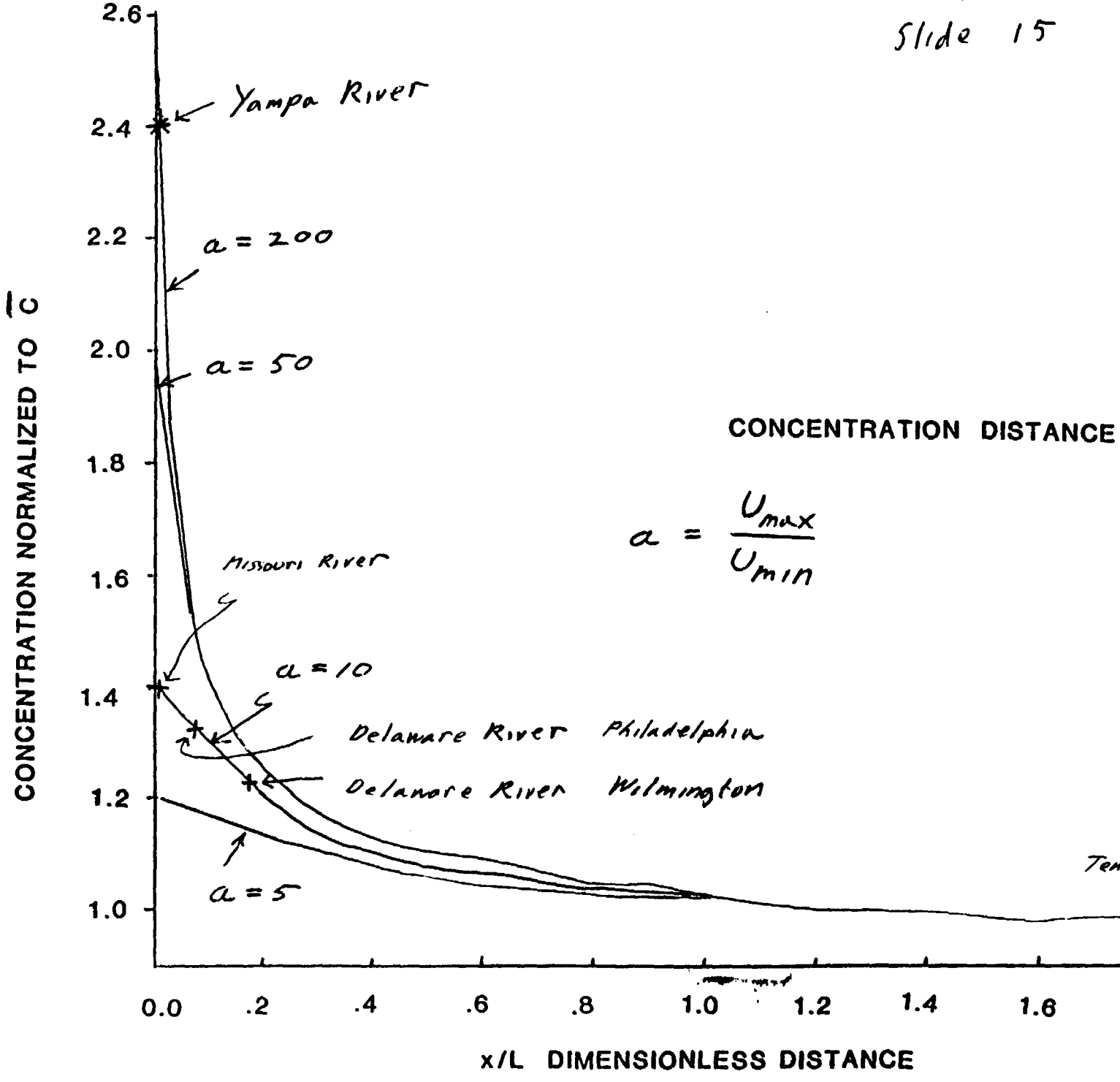
Slide 4


EFFECTIVE FLOWRATE AS A FUNCTION OF ASPECT RATIO
$\frac{Q}{Q^R}$
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
ASPECT RATIO - a

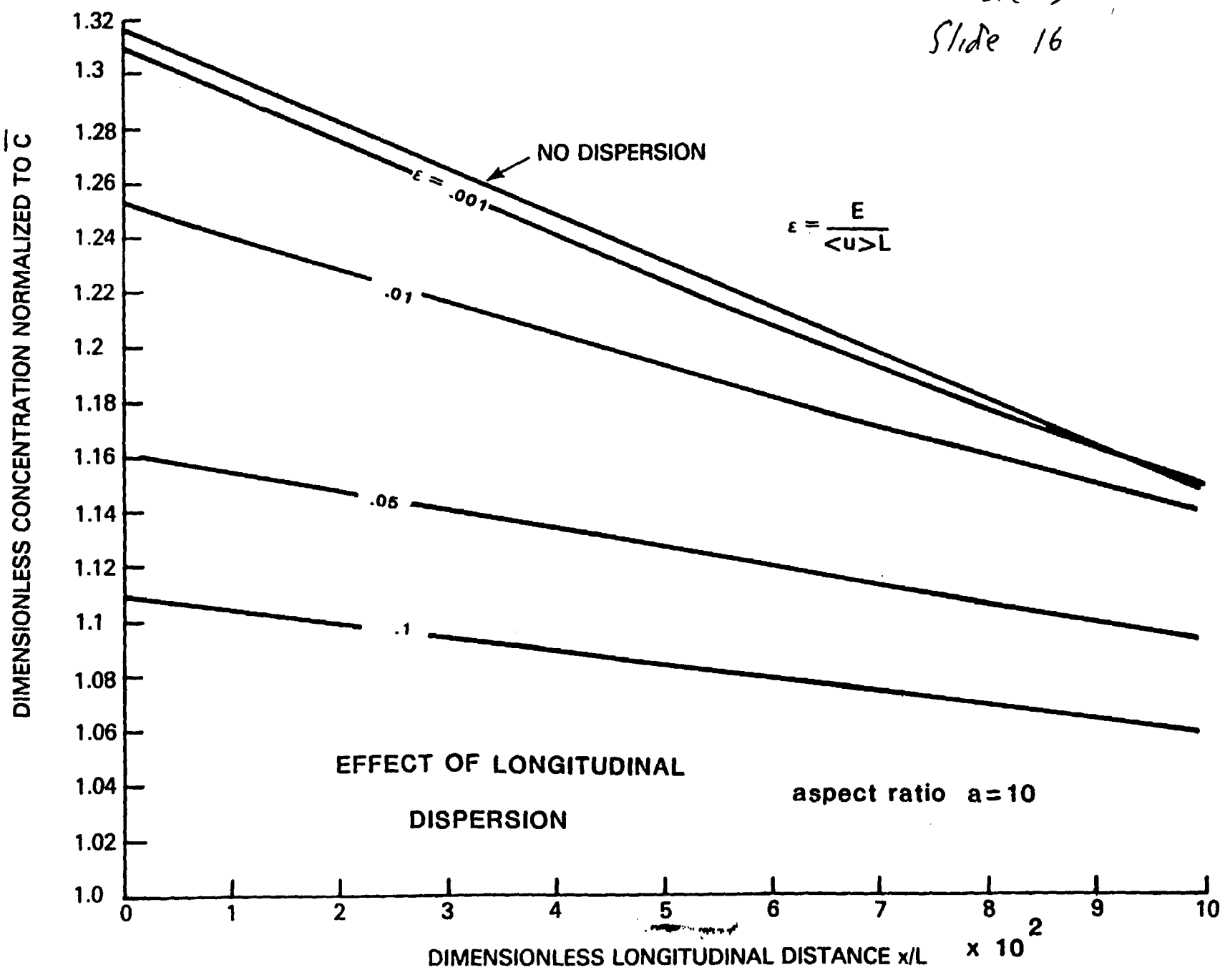
(Slide 5


$\bar{Q} / \bar{Q}^R$
FOR MISSOURI RIVER AT SIOUX CITY
RATIO MEAN TO RECIPROCAL, $\bar{Q} / \bar{Q}^R$
2.0
1.8
1.6
1.4
1.2
1.0
1920
1930
1940
1950
1960
1970
1980
1990
WATER YEAR

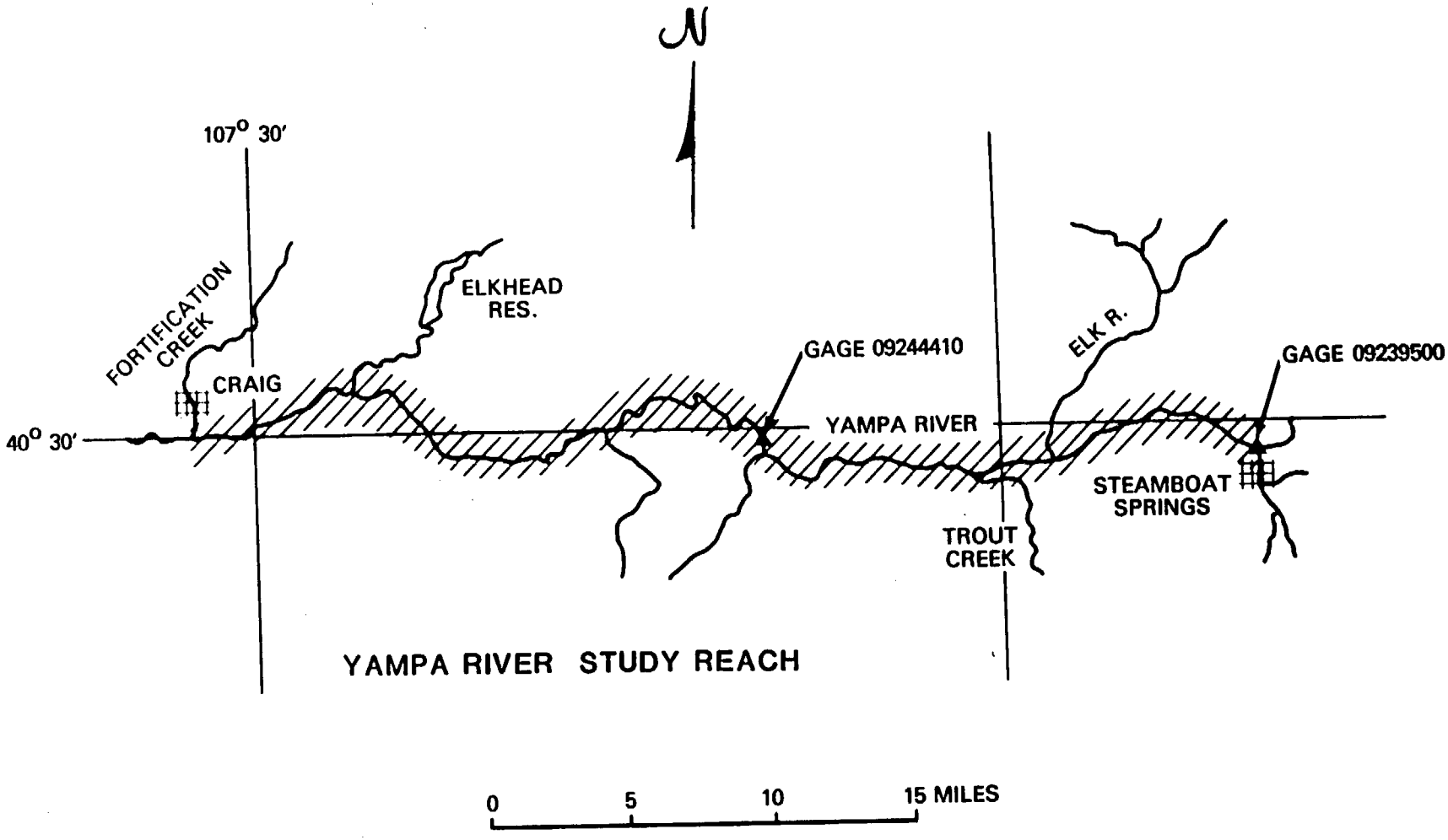
(Slide 6
Slide 15



Slide 7
Slide 16

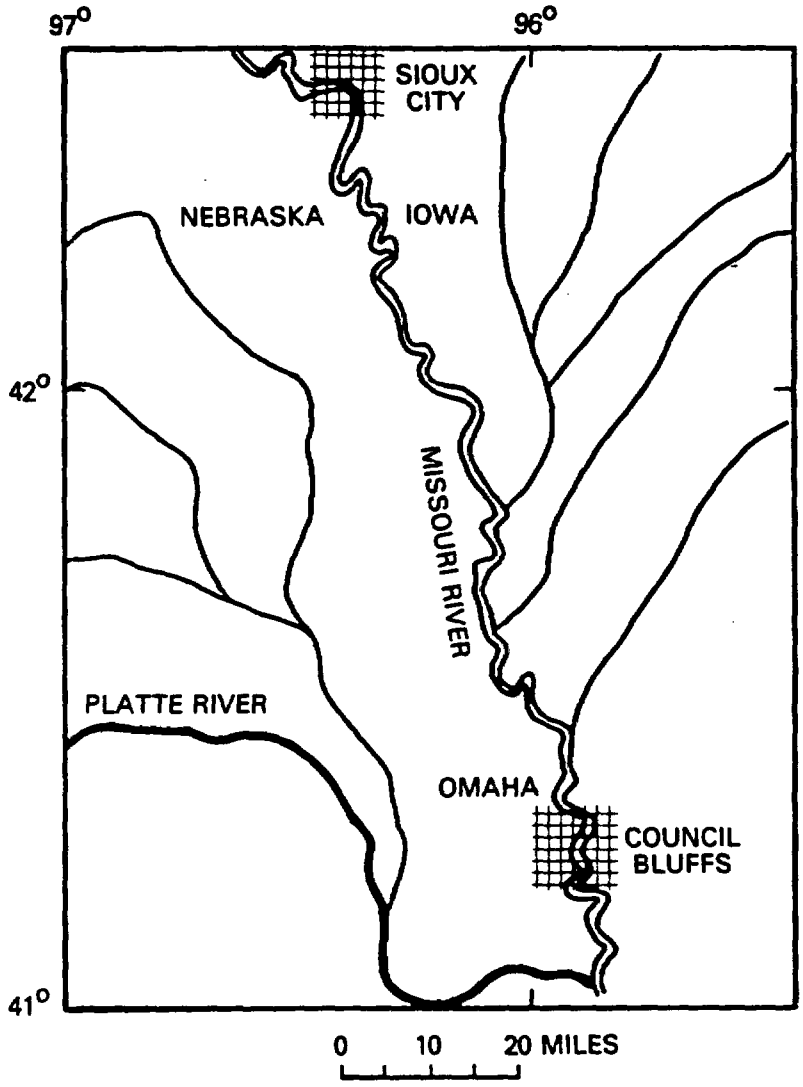


Slide 8



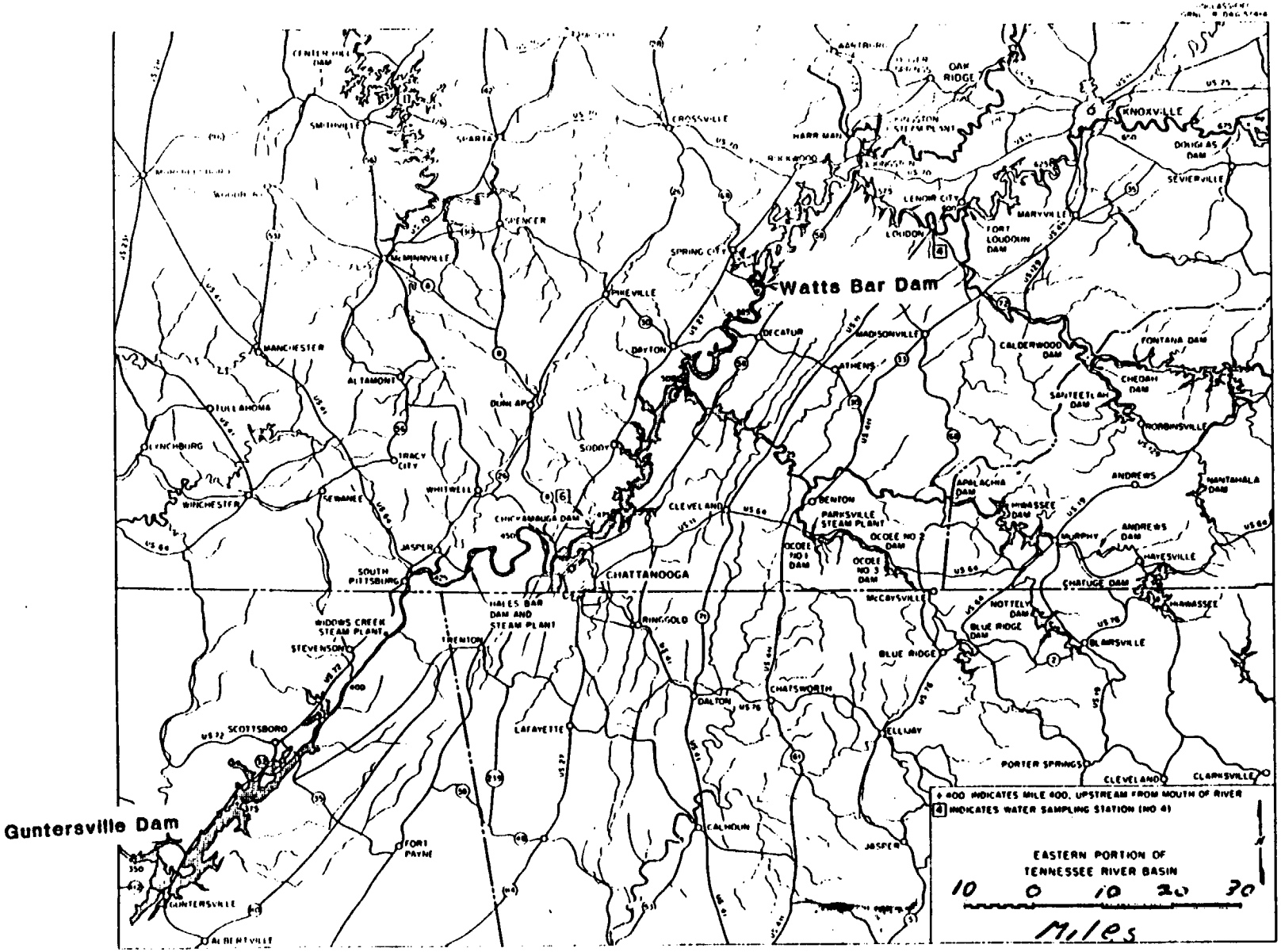
YAMPA RIVER STUDY REACH

Slide 9



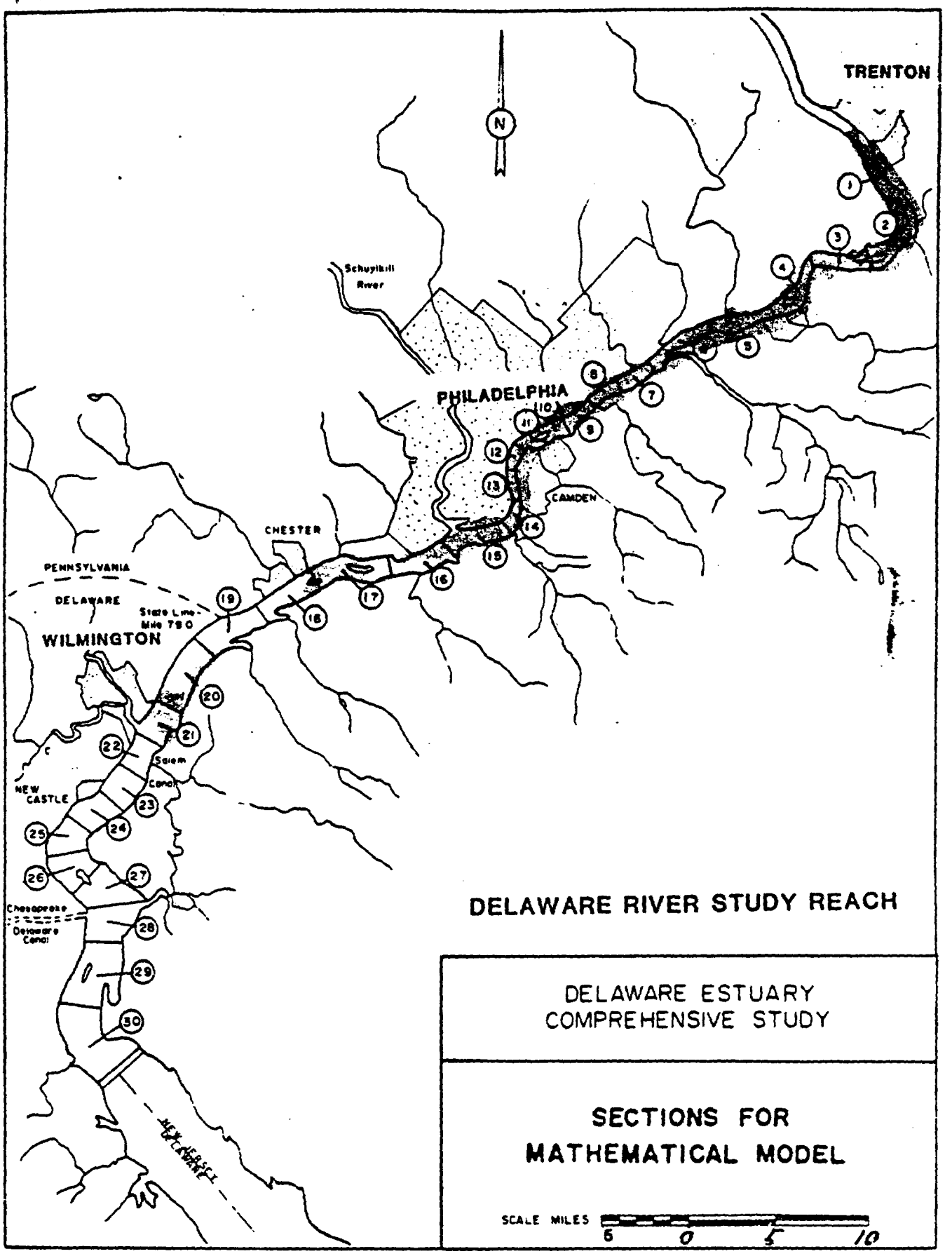
MISSOURI RIVER STUDY REACH

Slide 10



TENNESSEE RIVER STUDY REACH

Slide 11


TRENTON
N
Schuylkill River
PHILADELPHIA
CAMDEN
CHESTER
PENNSYLVANIA
DELAWARE
State Line - Mile 78.0
WILMINGTON
Salem Canal
NEW CASTLE
Chesapeake Delaware Canal
NEW JERSEY
DELAWARE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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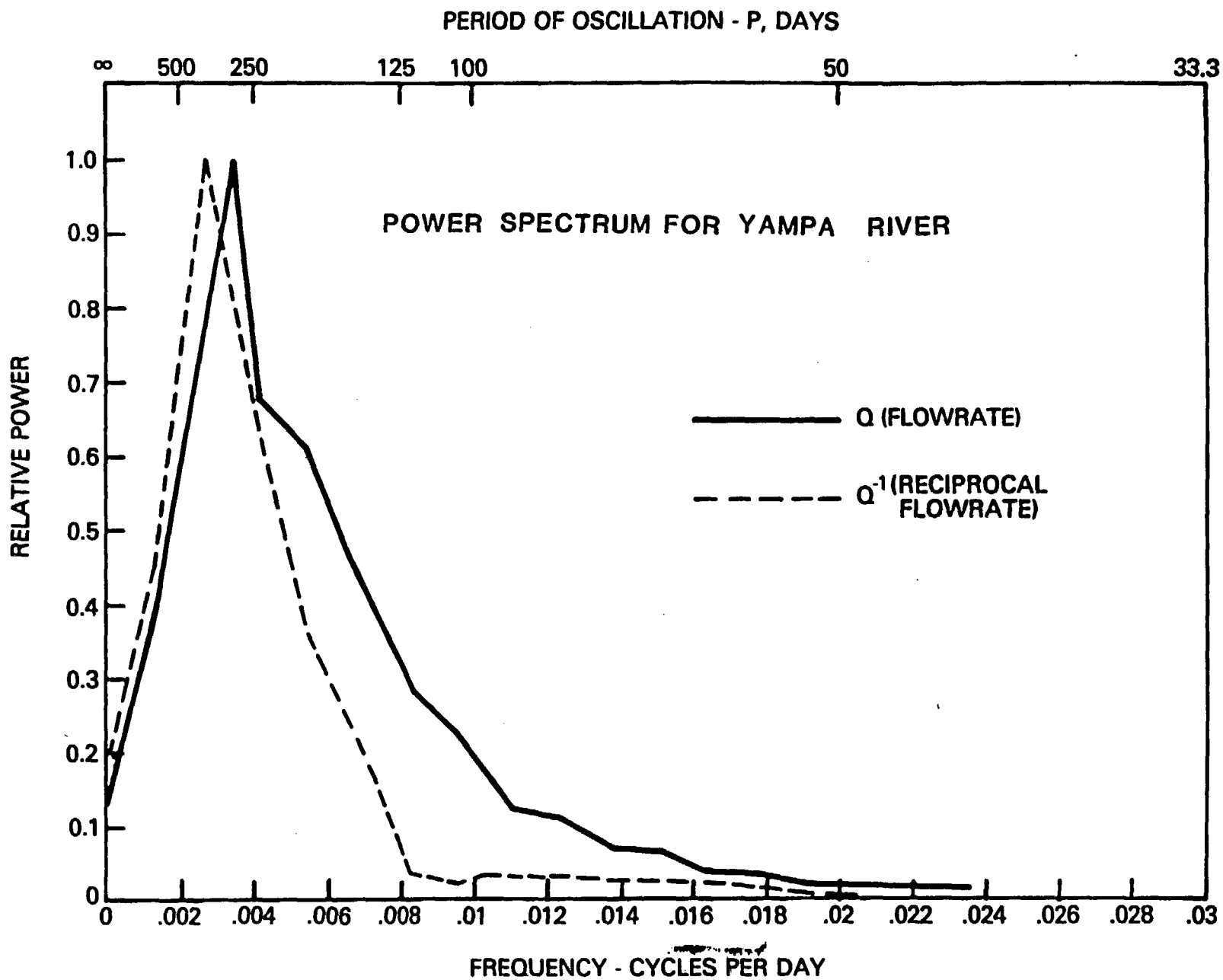
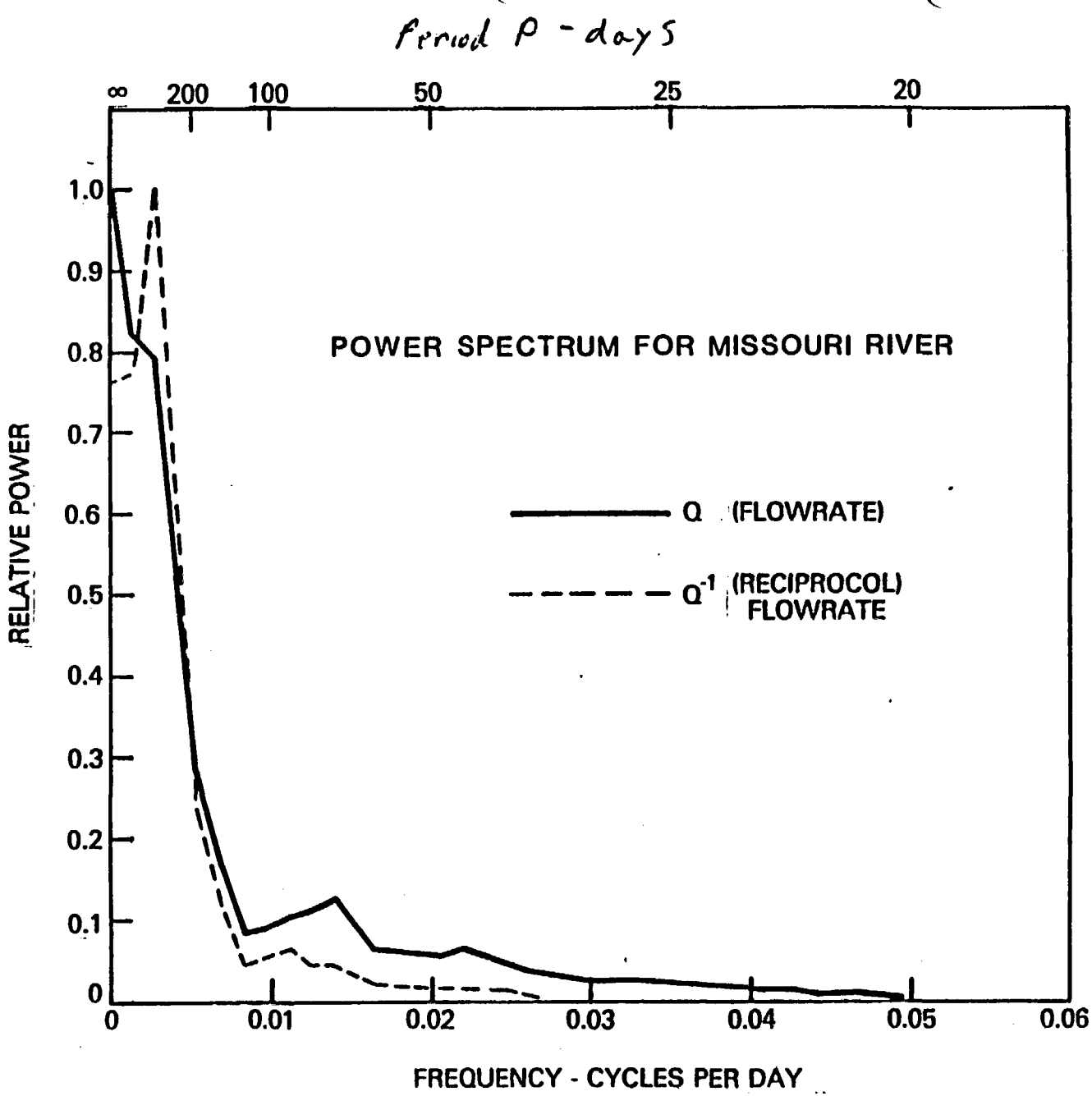
30
DELAWARE RIVER STUDY REACH
DELAWARE ESTUARY
COMPREHENSIVE STUDY
SECTIONS FOR
MATHEMATICAL MODEL
SCALE MILES
5 0 5 10

Slide 12


PERIOD OF OSCILLATION - P, DAYS
∞
500
250
125
100
50
33.3
POWER SPECTRUM FOR YAMPA RIVER
Q (FLOWRATE)
Q-1 (RECIPROCAL FLOWRATE)
RELATIVE POWER
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
.002
.004
.006
.008
.01
.012
.014
.016
.018
.02
.022
.024
.026
.028
.03
FREQUENCY - CYCLES PER DAY


Period P - days
∞
200
100
50
25
20
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RELATIVE POWER
POWER SPECTRUM FOR MISSOURI RIVER
Q (FLOWRATE)
Q-1 (RECIPROCOL) FLOWRATE
0
0.01
0.02
0.03
0.04
0.05
0.06
FREQUENCY - CYCLES PER DAY

Slide 17

CONCLUSIONS

1. FOR UNDAMMED RIVERS, USE $\langle 1/Q \rangle^{-1} = \overline{Q}^{R}$

   a. BIGGEST ERROR FOR SMALL, FLASHY RIVERS

2. FOR EXTENSIVELY DAMMED RIVERS , USE $\langle Q \rangle = \overline{Q}$

3. ESTUARIES BETWEEN $\langle 1/Q \rangle^{-1}$ and $\langle Q \rangle$

4. LONGITUDINAL DISPERSION NOT IMPORTANT