International Seminar on ENVIRONMENT MODELLING

was held in Jurmala, Latvia, 9-12 October, 1995.

The Seminar was organized and sponsored by:

Latvian Council of Science;
Riga Technical University, Environment Modelling Centre;
Geological Survey of Denmark and Greenland;
State Geological Surrvey of Latvia;
State Company "Latvijas Ģeoloģija"
Poznan University of Technology , Poland

Scientists from 7 countries participated in the Seminar and 45 communications have been presented of which 40 are included in the Proceedings.

The aim of the Seminar has been to provide a floor for discussion of theoretical and applied environment modelling. Experience was exchanged about various computer models used to solve hydrological, hydrogeological, contaminant transport, ecological and other problems related to computing boundary field equations. Numerical methods for solving the non-linear and inverse systems have been discussed.

We believe that the goal of the Seminar has been achieved and the contacts established will be beneficial for all the specialists involved.

Proceedings:

Boundary Fields Problems and Computers. Proceedings of International Seminar on "Environment Modelling".- Riga - Copenhagen: Published jointly by Riga Technical University and Geological Survey of Denmark and Greenland, 1995.-358p. ISBN 9984-552-02-0.

This collection (in two volumes) contains the current 36-th issue of the Riga Technical University annual collection of scientific articles "Boundary fields problems and computers". Predominantly papers from the International Seminar on "Environment Modelling" (October 9-12, 1995, Jurmala, Latvia) are included.

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Volume 1: pages 3 - 228; Volume 2: pages 229 – 358

PLENARY SESSION

Segals G. THE HISTORY OF HYDRAULIC MODELLING IN LATVIA

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Summary: The first hydraulic model in Latvia was built and investigated as far back as in the 1920. Hydraulic modelling of water objects has become regular starting from the 1960. Various problems were solved, but more often they concerned ecology and hydrotechnics. Almost all the results of modelling were reflected in the project documentation and erected structures. About 40 models were built in total. Joint hydraulic and mathematics modelling was carried out in two cases. (pp 5-14)

Oziabkin V.N. MODELLING THE TRANSPORT OF CONTAMINANTS THROUGH GROUNDWATER FLOW SYSTEMS : REACTIVE CHEMICAL TRANSPORT

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Summary: The simulation of contaminant transport in the underground environment is done with the help of two-steps algorithms. Mass transport and chemical changes are simulated in their turns in different equation systems. During the simulation of masstransfer the traditional numerical way is used; chemical processes are described by kinetic balance differential equation systems. The program realization has led to a lot of users' computer models (simulators) that are created by SOFDEC group for different types of problems and objects. (pp 15-32)

Demenko A. FINITE ELEMENT SIMULATION OF FIELD PROBLEMS WITH MOVEMENT

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Summary: The methods of movement simulation in the finite element analysis of field problems are presented. The applications of different methods are discussed. Special attention has been paid to the analysis of movement in electromagnetic field. The new approach to the formulation of the stiffness matrix as a function of the moving part position in proposed. The matrix for the moving part is expressed by the interpolating polynomial which is based on the matrices for discrete positions. (pp 33-44)

Gregorauskas M. and A.Klimas GROUNDWATER QUALITY MAPPING AND DATA PROCESSING FOR ENVIRONMENTAL MODELLING

Vilnius Hydrogeology

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Summary: Groundwater chemistry data contains data about conditions and factors causing them. The methodology proposed for a shallow groundwater quality mapping is a specific variant of GIS technologies. It is based on evaluation of groundwater chemistry formation regularities and application of statistical analysis for hydrochemical data. (pp 45-56)

Traszka Z. MODELLING OF MECHANISMS FOR NEUROBEHAVIOURAL EFFECTS OF ELECTROMAGNETIC EXPOSURES

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Summary: In this paper we are concerned with reactions of bioorganisms exposured to high level magnetic fields. The primary objective of the paper is to identify the reaction mechanisms of simple elements in the nervous systems on electromagnetic excitations. These studies have

been conducted to determine measurable behavioural and physiological effects excited by the exposure to natural earth and/or strong artificial magnetic fields. Many lines of evidence have resulted which indicate that a variety of live organisms are clearly affected by geomagnetic cues and especially by strong magnetic fields generated artificially by the present highly technological civilisation. (pp 57-64)

GROUNDWATER QUALITY

Voronov A.N. and A.A. Shvarts USE OF HYDROGEOCHEMICAL SIMULATION FOR THE EVALUATION AND MANAGEMENT OF THE QUALITY OF UNDERGROUND WATERS

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Summary: The necessity of taking into account not only total concentrations of elements but also forms of their presence in solutions during the ground water quality estimation is considered. A method of hydrogeochemical simulation is recommended. Some examples of the use of hydrochemical simulation for monitoring and forecast of ground water quality are included. (pp 65-70)

Miciudiene V. and R. Griciute PROCESSING OF HYDROCHEMICAL DATA OF SHALLOW GROUNDWATER

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Summary: Shallow groundwater in Lithuania occurs in the Quaternary deposits of two lithogenetic types: sandy fluvioglacial and alluvial, as well as clayey glacial and limonoglacial deposits. Due to different conditions of occurrence, groundwater of different chemical composition and quality is formed. Obvious qualitative differences are determined in the water sampled from dug wells, drilled wells and springs. (pp 71-78)

Sennov A.S. HE SIMULATION OF HEAVY METALS AND RADIONUCLIDES CONTAMINANT TRANSPORT THROUGH UNSATURATED ZONE

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Summary: Using the example of the program simulator SONEV1, the possibilities of the creation of analogous program systems aimed at the solution of the real problems of contaminants transport are shown. A preliminary forecast of radioactive contaminant transport out of a storage of liquid waste is made and the necessity of chemical influence over their composition in order to prevent some negative consequences in case of their leakage out of the storage is shown. (pp 79-84)

Oziabkin S.V. COMPUTER - AIDED PROGRAMMING AND SOME ASPECTS OF PROGRAM ORGANIZATION OF COMPLEX CHEMICAL - MIGRATION MODELS

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Summary:The settlement of the basis of hydrogeology simulation problems is given - computer-aided programming and the system organization of the complex program systems that simulate the transport of contaminants through subsurface environment. These problems are connected with each other and originate from the internal complexity and from a lot of variety of the simulation objects, which require the adequate complication of the simulation program systems - THE SIMULATORS. This article deals with some results in this field, shows some ways of their development and implementation. (pp 85-88)

Voronov A.N., O.V. Kuzmitskaya OME INFORMATION MAINTENANCE PROBLEMS OF ECOLOGO - ECONOMIC MODELS OF WATER RESOURCES

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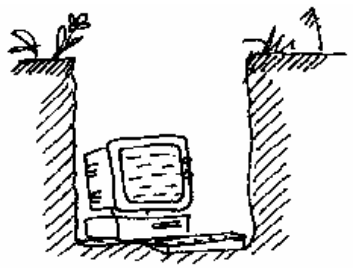
Summary: It is necessary to pay serious attention to information maintenance of ecologo-economic models of water resources. Most of hydrogeological and hydrochemical data for models are not quite correct. (pp 89-94)



GROUNDWATER MODELLING

Grikevich E. and V. Kuznetsov TEMPERATURE FRONT PROGRESSION DURING THE OPERATION OF A GEOTHERMAL WELL DOUBLET

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Summary: A computer programme has been produced for the calculation of the temperature field in the specified filtering zone and the water temperature in the production well for any moment of the operation of a doublet with a variable flow. (pp 95-104)

Bajkiewicz-Grabowska E. and M. Kochman THE USE OF THE DIGITAL TERRAIN MODEL FOR THE ESTIMATION OF THE FLOOD EXTENT IN ALLUVIAL VALLEY

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Summary: Considering water circulation in the river valley, based on the example of the Vistula near Plock, one of the most important problems is the estimation of the extent of the area that can be flooded during a flood event. The extent of the flood influence was determined using the digital terrain model (DTM). On this basis the extent of flooded areas and, in particular, segments of a alluvial valley was studied as a function of different water stages in a river. (pp 105-112)

Segals G. and A. Grosgalis MODELLED RESEARCHES WITH THE AIM TO WORK OUT MEASURES OF JEKABPILS PROTECTION FROM FLOODS

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Summary: The problem to be dealt with is not a new one but is still waiting for its final solution. We have carried out hydraulic modelling of the Daugava in the region of Jekabpils three times within the last 12 years (1983-84, 1991, 1992) and have given concrete answers to many questions. Nevertheless, it is not possible to state that everything is clear; too many different factors must be taken into account, the responsibility for the conclusions drawn from the results of investigations is too high, the expenditures to accomplish the measures forthe city protection are too high. (pp 113-122)

Graeber P.-W. PARALLEL SIMULATION OF GROUNDWATER STREAMS

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Extended abstract : In the soil and the groundwater zone, physical, chemical and biological processes take place. It is necessary to control and monitor these processes: at pumping wells in water works, drainage systems in mines and foundation pits, sanitation of deposits of industrial and agricultural contamination.

These processes are:

- very complex non-linear and bad conditioned for solving them,
- of great range of a time scale, and they have uncertain input parameters.

The original mathematical model consists of ordinary (ODE) and partial differential equations (PDE). The approximated one is the system of algebraic equations whose coefficients

are usually a function of space, time and of the solution. The model can be transformed into two joined non-linear second order partial differential equations:

-"the heat-conduction-equation" (elliptical PDE) for each phase (air, water and soil) and for each migrant;

- "the convection-diffusion-equation" (hyperbolic PDE) for describing water quality in a groundwater flow.

The above processes in the soil and in the groundwater zone have a large time scale and a high cost of monitoring. Therefore, the density of measurement points in the nature is low, resulting in the uncertainty of input data.

Parallelisation of the computer simulation is necessary to shorten the response time. Usually the area under investigation is divided into several parts which are simulated by traditional approaches of time-space approximation by a grid, for example: the finite-difference (FDM), finite-element (FEM), or the boundary-element (BEM) method.

The main limitation of these methods is data exchange between the gridded partitions. By using FDM, many information exchange lines in the discretisation grid need to be introduced. By applying FEM, this amount can be reduced, arranging large meshes in the border zones of each part. In the case of BEM, no data exchange between the processors is necessary. If it is possible to divide the area by equipotential lines then the necessary date exchange is also minimal for FDM and FEM. To solve the algebraic equation system produced by approximation, most time is spent by the specialised solver set. Traditional solvers are rather slow for a large number (e.g. one million and more) of equations to be processed. By using the conjugate gradient iterative method the solution time can be reduced. A special hierarchical preconditioning helps to achieve some additional acceleration. (pp 123-124)

Solnik W. and Z. Zajda COMPUTER SIMULATION IN DESIGN AND OPERATION OF PIT DRAIN SYSTEMS

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Summary: The paper presents a new approach to the pit draining problem. The computer simulation method proposed could be used not only in the design process but also during operation of pits. The model parameters are continually tuned and the results of draining pumps

control are forecast. The appropriate computer procedures for model parameters adjustment and introduction of irregular space shapes is presented. (pp 125-132)

Grikevich E. and V. Buzayev MODELLING OF HYDROGEOLOGICAL CONDITIONS FOR WATER SUPPLY PURPOSES

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Summary. The purpose of the model under discussion is to solve the problems of stationary and non-stationary filtering (9 hydraulically connected water-bearing layers, the total number of the nodes of the grid is 16000). The production of equipotential lines and streamlines, the calculation of protected zones and the determination of flow share in water intake of various sources are dealt with. (pp 133-144)

Spalvins A.1, R.Janbickis1, J. Slangens1, E.Gosk2, I.Lace1, Z.Viksne1, J.Atruskievics1, N.Levina3 and J.Tolstovs1 DEVELOPMENT OF REGIONAL HYDROGEOLOGICAL MODEL "LARGE RIGA"

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3) State Company "Latvijas Åeoloåija"
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Phone: 371 2 627662; Fax: 371 2 627518;

Symmary: Design principles of the three dimensional (3D) Regional Hydrogeological Model (HM) "Large Riga" are explained and the course of HM development is outlined. In HM the groundwater resources of the central part of Latvia are represented by a multiaquifer system.

Methods and software tools applied are described. First experimental results are reported. (pp 145-158)

Spalvins A. and J. Slangens LOCAL INTERPOLATION OF GEOLOGICAL ENVIRONMENT DATA

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Summary: A module of local interpolation and assembling of geological data on a uniform approximation mesh is considered. Advantages of using data search areas enclosed by hyperbolas are motivated. The interpolation coefficients are calculated based on hyperbolas as weighing functions. The module has been enclosed in an updated version of the Geological Data Interpolation (GDI) programme. (pp 159-174)

Spalvins A. and J. Slangens UPDATING OF GEOLOGICAL DATA INTERPOLATION PROGRAMME

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Summary: Algorithms for interpolating information of data lines and centres on a uniform approximation mesh are considered. Interference between these data is investigated. Modernization of Geological Data Interpolation (GDI) programme is discussed and achieved results reported. (pp 175-192)

Atruskievics J., Z.Viksne, A. Spalvins and I. Lace LAKES AND RIVERS ALGORITHMS IN THE HYDROGEOLOGICAL MODEL "LARGE RIGA"

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Summary: Data preprocessing technologies of hydrographic objects (rivers, lakes, hydrotechnical structures) included in the regional hydrogeological model (HM) "Large Riga" are considered. The data serve for obtaining the Quaternary watertable map that is applied as a boundary condition on the HM upper section. (pp 193-200)

Lace I., A.Spalvins and J.Slangens ALGORITHMS OF ACCOUNTING GROUNDWATER DISCHARGE IN THE REGIONAL HYDROGEOLOGICAL MODEL AND INTERPOLATION OF SIMULATION RESULTS AT OBSERVATION WELLS

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Summary: A theoretical basis is outlined for interpolating groundwater discharges on uniform approximation meshes of hydrogeologic models and for computing simulation results at irregularly sited observation wells. (pp 201-216)

Spalvins A. and R. Janbickis ALGORITHMS FOR CALIBRATING REGIONAL HYDROGEOLOGICAL MODEL "LARGE RIGA"

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Summary: A theoretical outlook for calibrating the regional hydrogeological model "Large Riga" is sketched. Algorithms for finding and correcting permeabilities of semipervious and water bearing layers are considered. Groundwater discharge rates are checked too. (pp 217-228)

NUMERICAL METHODS

Kaczorek T. SINGULAR TWO - DIMENSIONAL CONTINUOUS - DISCRETE LINEAR SYSTEMS

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Summary: A general 2-D continuous-discrete model and Roesser type continuous-discrete model of linear systems are defined. A solution and the general response formula to the regular 2-D model are derived. Necessary and sufficient conditions for the local reachability and the local controllability of the regular 2-D model are established. The minimum energy control of the regular 2-D model is solved. (pp 229-236)

Krasinski Z.1, A.Majewski1 and T.Hinata2 BOUNDARY VALUE PROBLEM FOR THE ELECTROMAGNETIC FIELDS IN ELLIPTICAL GEOMETRY

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Summary: The improved point-matching method for the analysis of the waveguides with elliptical geometry and the scattering problems by elliptical targets is proposed. The method is based on the boundary value problem where the electromagnetic fields are expanded in terms of one or more elliptical coordinate systems using the Mathieu functions. Numerical results are presented for the highly-birefringent W-type elliptical fibers and the plane wave scattering by an axially slotted conducting elliptical cylinder. (pp 237-248)

Majewski A. and A. Karczewski SOLUTION OF THE NONLINEAR SCHRDINGER EQUATION BY SPLIT - STEP FOURIER METHOD

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Summary: Numerical solution of the Nonlinear Schrdinger equation using split-step Fourier method, is based on physical mutual interaction of nonlinearity and dispersion, is described. The nonlinearity and dispersion are analysed separately within a very short piece of the guide.The split-step Fourier method can be applied to a solution of various sophisticated problems in the electromagnetic theory, particularly lossy optical guides with higher order effects.Some results of computation for ultra short pulses of selected shapes in picosecond and femtosecond range are also presented. (pp 249-256)

Majewski A.1 and S. Sujecki1,2 THE ANALYSIS OF THE RIB - LIGHTGUIDE STRUCTURES BY FINITE DIFFERENCE METHOD

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Summary: Two Semivectorial Finite Difference Methods have been applied to solve the wave equation in case of the rib waveguide; it is shown that they yield results, which are in excellent agreement. Two eigenvalue solvers were also applied and their features discussed. In order to generate the starting values of electromagnetic field, the Effective Index Method has been used which makes it easier and accelerates tedious finite difference computations in many cases. (pp 257-266)

Galar R. ADAPTIVE DYNAMICS OF POPULATIONS REPRODUCING IN A LIMITED ENVIRONMENT

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Summary: Available resources of the environment restrict the effective size of breeding populations. When populations become very small, it has a serious impact on the adaptation level and - more important - it enables large adaptive shifts. The appropriate results of computer simulations are presented. The usefulness of these effects in algorithms of adaptation is mentioned. (pp 267-274)

Maslowski A. THE USE OF INTELLIGENT MOBILE INSPECTION FOR ROBOTS' STATE IDENTIFICATION IN SPACE - TIME HAZARDOUS ENVIRONMENTAL SYSTEMS

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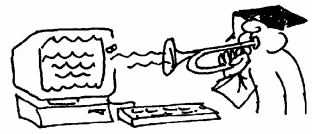
Extended abstract : One of the basic prerequisites for the design, modelling and analysis of the environment of robotized systems is the establishment of an adequate mathematical model. The derivation of such a model requires considerable physical insight. But in most practical

applications of autonomous mobile robots, especially, inspection machines discovering an hazardous environment, there does not exist enough determined information about the system, because the involved physical phenomena are so complicated for the human understanding, the presence of external disturbances, the measurement errors. During the last decade, considerable attention has been given to the development of an unified approach for state approximation of the environmental systems in the case of incomplete information about the system. This paper presents some investigation techniques of state identification for a class of space-time systems, such as the environment of robotic inspection machines. Disturbances are considered in the spatial domain and on its boundary but no statistical assumptions are made concerning their characteristics. The state identification quality index utilised is the functional in the classical least squares formulation. By using mathematical models of the system dynamics, of the observation results and the above index, the state identification is solved as the constrained functional extremalization problem.

Modelling and analysis of environmental systems are complex procedures which only recently have been subjected to a detailed analysis, that relying upon logic, abstraction and association skills. The mathematical model plays the central role in gaining sufficient understanding of the real world phenomena. In particular, transport of pollution in large-scale systems is an integral part of the overall environmental system. The fate of effluents depends on the physical, chemical, and biological influences. Not all transient effluents are adequately understood and modelled. The distributed parameter systems are most widely used in modelling various environmental systems. The uncertainties are quantified by variables with the deterministic structure description. The uncertainty inevitably leads to the state identification using advanced numerical techniques. The finite element method has been employed for approximating the state of the environment. The goal of our research has been to develop intelligent environmental systems of mobile inspection robots which exhibit various levels of intelligence. They will lead to a better understanding of environmental problems with the assistance of model analysis.

The objective of this paper is to show that the technique of state identification of deterministic parameter-bounding structure in the space-time systems is adequate with modelling approach. It is rather similar to the model parameter and the observation data processing by the non-linear least-squares method using the bounded constraints criteria. The nonlinearity of the objects' surfaces and the degree of feasible constraints lead to the choice of the Active Set method as optimal.

Algorithms of the state identification for some classes of systems are presented. An example of application is given: the solution of the water pollution concentration analysis problem supported by the idea of utilization of inspection mobile robots. (pp 275-276)



SIGNAL PROCESSING SYSTEMS AND PRACTICAL APLICATIONS

Lavendels J. and J. Ekmanis THE EFFECTIVE METHODOLOGY FOR DATA EXCHANGE IN MULTIPROCESSOR SYSTEMS OF SIGNAL PROCESSING

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Summary: The paper deals with the methodology of control data exchange between processors via dual port RAM. Described methodology minimizes the amount of data size transfered through semaphore protected dual port RAM part where collisions must be solved. (pp 275-282)

Solodov I. STABILITY OF CHAOTIC SYNCHRONIZATION PHENOMENA

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Summary: The influence of different factors (perturbations in the drive signal, its passage through the communication channel) on the stability of synchronization of chaotic systems is analysed.The concept of chaotic synchronization can be applied to guarantee secure communications. One of the possibilities is the chaotic masking principle where a message is added to the chaotic signal at the transmitter and then is recovered at the receiver using synchronization effect. The existence of an optimum value of chaos-to-message ratio providing the best quality of recovered message is shown.The possibility to use synchronized chaotic

systems for communications is based on the robustness of synchronization to perturbations in the drive signal. To provide a deeper understanding of the robustness phenomena a synchronized chaotic system is considered as a nonlinear state estimator and its performance is compared to an extended Kalman-Bucy filter. (pp 283-290)

Zavadska I. and N. Veselis REAL - TIME TESTING OF DIGITAL SIGNAL PROCESSING ALGORITHMS

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Summary: In this article are discussed problems connected with Digital Signal Processing Algorithms testing in real-time. There are showed technique of 2 DSP evaluation modules using for this task. Measurement method of algorithm execution time is work out on the digital signal processor TMS320C50 basis. (pp 291-296)

Bleiers J.1, N.Veselis1, A.Matveyev2 and A.Macans1 EVALUATION OF THE KINDS OF INTERPROCESSOR DATA EXCHANGE IN MULTI-DSP SYSTEM

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Summary: The paper deals with the efficiency of DSP multiprocessor systems. A global memory as interprocessor communication option is considered. Three kinds of data exchange organization are presented: sequential access to global memory, time-fixed access and access with arbitration. The timing analysis of these kinds should help select the optimum of interprocessor data exchange in the designed multiprocessor system. (pp 297-304)

Balodis G. SPREAD SPECTRUM TRANSMISSION CHANNEL

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Summary: This paper deals with the characteristics of spread spectrum signals making them advantageous for mobile communications. The parameters that determine both the performance and the processing gain are introduced. It is shown that despreading is conceded with losses in processing gain because of time delay and gain tolerances in broadband equipment. It is shown that the use of spread spectrum signal is limited by the transformation losses in the channel and receiver and frequency hopping signal is more efficient with narrower bandwidth. (pp 305-308)

Saulitis A. PRACTICAL INVESTIGATIONS OF CHAOS SYNCHRONIZATION

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Summary: This paper deals with experimental studies of possibilities to synchronize two chaos generators. Four ways of chaos synchronization are observed. Synchronization quality is measured without and with dispertion of parameters. Linear distortions of channel and white noise influence on synchronization are investigated. Finally, conclusions are drawn about the best way of synchronization. (pp 309-316)

Ziema M. SMALL PARTICLE RECOGNITION USING EXTENDED PHASE-DOPPLER ANEMOMETER

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Summary: Simultaneous measurements of diameter, velocity and concentration of particles is considered for the case of more than one dispersed phase in fluid. For high accuracy particle

recognition with different light scattering mechanisms, an extended phase-Doppler anemometer utilizing the sign of the signal phase shift in suggested. The possibility to distinguish two dispersed phases is verified with water, air bubbles and glass particles in a specially developed three phase flow channel. The technique is demonstrated for three phase flow measurements with different bubbles-glas loading. (pp 317-332)

THE LAST MOMENT PAPERS

Skibelis V. and V. Rode HIGH ACCURACY TECHNOLOGIES FOR PROCESSING CARTOGRAPHIC DATA

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Summary: An evaluation of the present status of cartographic materials, used for the modelling of hydrogeological processes, is given. Technologies of big-size cartographic material scanning, charakteristic errors during this process and ways of their correction using hard- and software are discussed. (pp 333-336)

Rode V., L. Niceckis and V. Skibelis DIGITIZATION OF GRAPHICAL DATA FOR GROUNDWATER FLOW MODELS

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Summary: The paper deals with the issues of further upgrading of graphic information input, and its digitization for the production of hydrogeological models. (pp 337-340)

Zajda Z. THE ADJUSTMENT OF THE TIME DISCRETIZATION STEP IN COMPUTER SIMULATION OF GROUNDWATER FLOWS

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Summary: A new approach to the finite differences method for computer simulation of processes with distributed parameters is presented. Usually the time discretization step and the space discretization step are kept constant during the calculation process. The idea is to connect the value of the time step and the rate of change of the state function. When the function

changes slower, the long time step is used, when the change is fast, the step is short. In this way, the simulation efficiency might increase without much loss of accuracy. The numerical algorithm is described and the choice of the function observation point is discussed. (pp 341-346)

Gosk E., B.Madsen and W.G.Harrar CONTAMINANT TRANSPORT MODELLING: PROBLEMS AND LIMITATIONS

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Summary: Rapid development and easy accessibility of software for processing of hydrogeological and geochemical information offers many advantages but often poses serious threat to "correctness" of the obtained results. Increased power of modern computers makes it possible to analyse complex situations with little computing effort. In addition, the cost of computer software and hardware is equivalent to the cost of a few water analyses. The paper highlights the problems and limitations which should be taken into account during computerized analysis of aquifer contamination situations. (pp 347-350)

Harrar W.G. and E.Gosk PARTICLE TRACKING TECHNIQUES: ALTERNATIVES TO SOLUTE TRANSPORT MODELLINTG

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Summary: An introduction to an attractive alternative to contaminant transport modelling, the particle tracking technique, is given. Different applications of this technique are discussed and guidelines for applications are presented. Advantages and shortcomings of this method, when compared to the contaminant transport modelling, are outlined. Contamination migration analysis, delineation of capture zones and evaluation of groundwater remedial alternatives are shown as examples of applicability of the particle tracking technique. (pp 351-356)