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Ground-water Policy-making Support:
USEM Optimization Modeling Plus GIS and Graphics

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A.M., Ali Gharbi¹, Mazibur Khan¹, Oscar Daza¹,
Douglas Ramsey² and Kurt Vest¹

Abstract

A support tool for ground-water management decision making involves integration of a multiobjective optimization model, GIS and graphics software. Two results are improved consideration of spatial data within the optimization model and improved conversion of optimal strategies to real-world application. Another result is improved visualization of the trade-offs involved between conflicting management goals.

Introduction

Assuring the sustained availability of groundwater of adequate quality and quantity requires integrating efforts of many agencies. This is so because contaminant movement is affected by ground-water pumping and vice versa. Contaminant movement can also be affected by use of approved site-specific water and chemical Best Management Practices, land uses or well-head protection regulations. Furthermore, in some locations, the legal right to use groundwater might be retained only to the extent that such use is sustainable and does not cause damage to others.

This paper demonstrates how a geographic information system (GIS) and graphics tools can be used to help integrate multiple agency goals for long-term ground-water management in the Salt Lake Valley. These tools facilitate use of the USEM (Utah State Embedding) model, which computes optimal sustained yield ground-water

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management strategies. The computed optimal strategies satisfy restrictions which reflect agency objectives, water flow and contaminant transport.

Computing Optimal Ground-water Management Strategies using USEM

USEM is a modified version of a model previously described by Gharbi et al. (1990) and Peralta et al. (1991). USEM is an operations research style of optimization model which includes an objective function, constraint equations, and limits on variables. The objective function includes either a single objective (i.e. maximizing ground-water pumping) or multiple objectives. At present, explicit multiple objectives include: (1) maximizing ground-water pumping and (2) minimizing future exceedance of target contaminant concentration values. Weighting coefficients are used to emphasize attaining one objective over another.

Constraints include representation, through embedded finite difference equations, of steady and transient flow processes. Represented are: ground-water flow, evapotranspiration, flow from drains, stream-aquifer interflow and boundary flows. Other constraints use embedded finite element equations to describe contaminant transport and future concentrations.

Utilized limits on variables (or sums of variables) most commonly include those on ground-water pumping, potentiometric and ground-water flow magnitudes and directions. These bounds (or constraints) reflect goals of several agencies. For example, agencies responsible for water supply or water rights agencies sometimes desire to prevent excessive drawdowns. Other agencies might want to prevent water tables from rising too near to the ground surface and contacting existing contamination. Another agency might wish to keep water levels high to maintain baseflow to streams.

Processing and Interpreting Optimal Strategies using GIS and Graphical Software

USEM computes optimal sustainable ground-water pumping (extraction) strategies and the future heads that will result within a study area. Figure 1 illustrates sample results for Salt Lake Valley (cells range in size from 1.3 to 2.6 sq km). It shows drawdowns in the potentiometric surface by the end of the planning horizon and shows whether optimal pumping values are greater or less than current pumping. Contours are developed using SURFER (GSI, 1990).

Figure 2 shows sample results of using ARC/INFO (ESRI, 1989) to process the optimal pumping values for the area. ARC/INFO is a vector based GIS that integrates a

data base management system (INFO) with a spatial mapping system (ARC). ARC/INFO is used for compatibility with other agencies in Utah, even though it does not deal with gridded data as easily as does a vector based system. Using ARC/INFO will also facilitate overlaying other vector based data available for Salt Lake Valley.

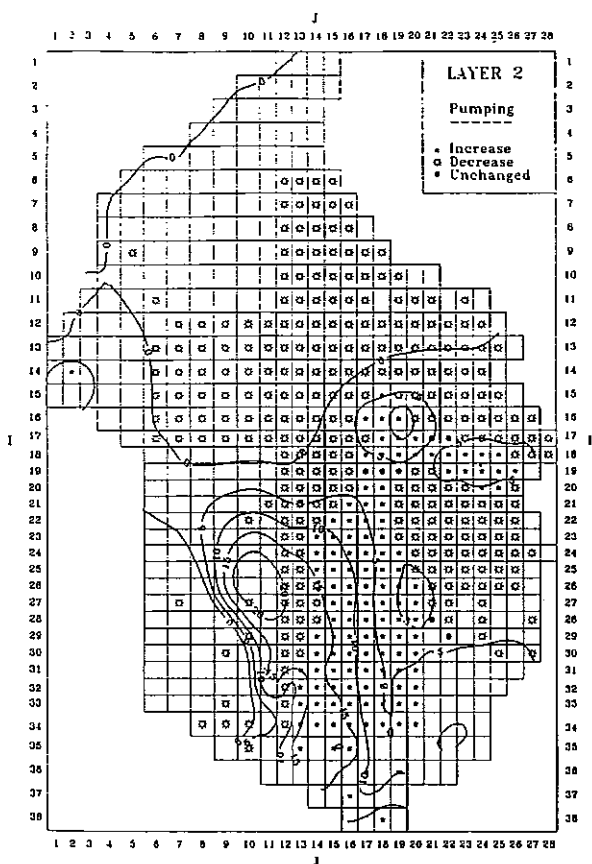


Fig. 1. Drawdown Contours in the Principal Aquifer after 20 Years of Optimal Ground-water Pumping (ft), and Comparison between Optimal Pumping and Current Pumping (To convert to meters multiply by 0.305.)

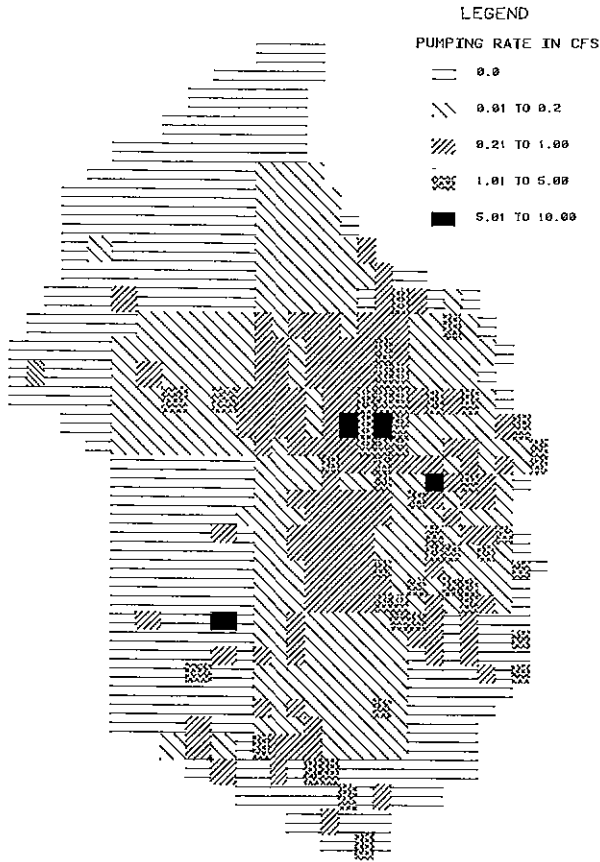


Fig. 2. Optimal Ground-water Pumping Values for Salt Lake Valley (To convert to cms multiply by 0.028.)

Figure 3 illustrates a type of graphic important for presentation to decision makers. It shows a hypothetical range of optimal solutions to the multiobjective optimization problem. This exaggerated figure demonstrates to managers a conflict between attempting to maximize sustainable ground-water extraction and preventing the increase in ground-water contamination at

specific locations. This problem occurs because maximizing pumping usually increases drawdowns and hydraulic gradients, speeding contaminant migration.

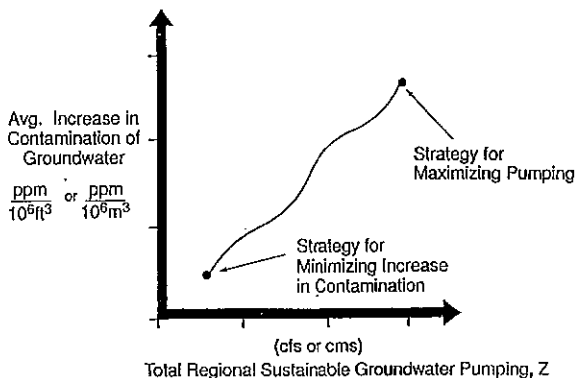


Fig. 3. Pareto Optimum of Conflicting Objectives for Maximizing Sustainable Ground-water Pumping and Minimizing Average Increase in Ground-water Contamination at Control Locations

Anticipated GIS Uses with USEM

In the future, ARC/INFO, or other GIS, will be used increasingly to formulate the optimization problems addressed by USEM. A GIS's unique ability to handle spatial and tabular data (soils, crops, water use, water rights, wells, land use, and others) in coverages that can be overlain, make it an ideal tool for generating input data for USEM. The same attributes will be increasingly utilized in producing products (such as maps) from USEM output.

These enhancements are important because the USEM discretization (cell grid), required for computational efficiency, is not ideal for real-world decision-making. For example, USEM output can help determine cells where a specific Best Management System (combination of irrigation efficiency and pesticide use) might be desired (to avoid ground-water contamination). However, one would probably not want to restrict water/chemical use in an entire cell. It is preferable to be able to adjust the boundaries of a restricted use area appropriately--within individual cells. That is where GIS capabilities can be very helpful.

Similarly, combining the abilities of USEM and GIS can aid water supply planning. USEM can help determine how much groundwater and surface water should be used in each cell. Ultimately however, water supply decisions should consider water service area pressure zones, which

are not generally described using a rectangular grid (Bishop et al. 1988). Converting cell-based optimal strategies into in-cell recommendations is important.

Summary

Long-term ground-water management is enhanced by use of optimization models, such as USEM, which consider both management goals and physical processes appropriately. However, the practical utility of such models is sometimes lessened because of the spatial discretization they use. To lessen computational difficulties, USEM uses a fairly regular or simplified spatial discretization scheme.

Linking USEM with other software can improve its utility. A GIS can process complex spatially variable data and prepare input in a discretization useful for USEM. Similarly, a GIS can help process optimal water use strategies (consisting of a separate value of groundwater or surface water use for each cell) into in-cell distributions more useful for practical water management.

Systematic decision making is aided by enhancing data development and presentation. Data development and presentation are enhanced by coupling optimization models, GIS, and graphics software. The result of these activities should be improved water management policies.

Acknowledgments

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Appendix I.-References

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Aerial View of Baltimore

Session 5/8:15-9:45am Con't.

Water Availability and Water Demand Study for the Citanduy River Basin, West Central Java, Indonesia: ED A. TOMS and R. JOSEPH BERGQUIST, ATC Engineering Consultants, Inc., Englewood, CO

Alternative Methods of Drainage Management in San Joaquin Valley, California: ALIREZA S. TAGHAVI, James M. Montgomery Consulting Engineers, Sacramento, CA, BEN EVERETT, Boyle Engineering Corporation, Sacramento, CA

SESSION: WR35 Convention Center 315 COMPUTER APPLICATIONS IN WATER RESOURCES

Presiding: JEFF WRIGHT, Purdue University, W. Lafayette, IN

Computer Modeling Responsibilities for Municipalities: MICHAEL L. DEAS, Los Angeles Dept. of Water & Power, Mono Lake, CA

Expert System for Operating a Treated Water Supply System: KENT K. MAO, HDR Engineering, Inc., Bellevue, WA

The Installation Water Resources Analysis and Planning Systems (IWRAP): J.F. LONGOWSKI and C.A. STRUS, Planning & Management Consultants, Ltd., Carbondale, IL

SESSION: WR18 Convention Center 316 WETLANDS: RESTORATION, MITIGATION, AND EVALUATION — I

Presiding: GLENN G. GREGORY, FHC Inc., Tulsa, OK

Engineering Aspects of Wetland Design: MIKE R. PALERMO, USAE Waterways Experiment Station, Vicksburg, MS, and DONALD F. HAYES, University of Nebraska-Lincoln, Omaha, NE

Innovative Wetlands Mitigation in the Yazoo Basin, Mississippi: KENNETH PARRISH and STEPHEN REED, U.S. Army Engineer District, Vicksburg, MS

Bodkin Island Restoration Project Design: JACK E. DAVIS, STEPHEN T. MAYNORD, JOHN MCCORMICK, MARY C. LANDIN and ROBERT A. EVANS, US Army Engineer Waterways Experiment Station, Vicksburg, MS

Savannah International Airport: Environmentally Minded Stormwater Master Planning: JAMES A. HARNED, ELLIOTT SILVERSTON and MARK EASLEY, Greiner, Inc., Tampa, FL

SESSION: WR17 Convention Center 318 TRADE-OFFS BETWEEN WATER RESOURCES AND INSTREAM FLOWS

Presiding: TERRY WADDLE, National Ecology Research Center, Ft. Collins, CO

Habitat Simulation in the United States, Great Britain and France: ROBERT T. MILHOUS, National Ecology Research Center, Ft. Collins, CO; IAN JOHNSON, Institute of Hydrology, Wallingford, UK; YVES SOUCHON and SYLVIE VALENTIN, CEMAGREF, Groupement de Lyon, Lyon, FRANCE

Is an Instream Flow Need a Beneficial Use?: ROBERT T. MILHOUS, National Ecology Research Center, Ft. Collins, CO

Are High and Low Flow Habitat Values Really the Same?: T.J. WADDLE, National Ecology Research Center, Ft. Collins, CO

River Basin Level Hydroelectric Development: Hydropower, Water Quality and Waste Discharge: SHOOM-YUH CHANG, North Carolina A&T University, Greensboro, NC; SHU-LIANG LIAW, Tamkang University, Tamsui, Taiwan, ROC; and STEVEN F. RAILSBACK and MICHAEL J. SALE, Oak Ridge National Laboratory, Oak Ridge TN

SESSION: ID11 Ballroom C IRRIGATION TECHNOLOGY TRANSFER IN DEVELOPING COUNTRIES: PART 1

Presiding: CHARLES BURT, California Polytechnic State University, San Luis Obispo, CA

The Debate Over Modernization: HERVE PLUSQUELLEC, The World Bank, Washington, DC, and CHARLES BURT, California Polytechnic State University, San Luis Obispo, CA

Technology Transfer Lessons From a U.S. Water District: DOUGLAS WELCH, Imperial Irrigation District, Imperial, CA

Technology Transfer For Projects In South America: JOSEPH B. SUMMERS, Summers Engineering, Inc., Hanford, CA

Intensive Irrigation Projects in Spain: ELIAS FERERES, CIDA, SPAIN

SESSION: ID02 Ballroom E DRAINAGE IN THE HUMID AREAS

Presiding: RICHARD D. WENBERG, Fairfax Station, VA

Environmental Impacts of Agricultural Drainage: R.W. SKAGGS, M.A. BREVE and J.W. GILLIAM, North Carolina State University, Raleigh, NC

Engineering of Controlled Drainage Systems: J.L. FOUSS, J.R. ROGERS and C.E. CARTER, USDA-ARS, Baton Rouge, LA

Optimizing Economic Returns in Drainage Design: LARRY D. GEOHRING, Cornell University, Ithaca, NY

Stochastic Analysis of Seasonal Hydraulic Conductivity: RAM K. GUPTA, RAMESH P. RUDRA and W. TREVOR DICKINSON, University of Guelph, Ontario, CANADA; NAVEEN K. PATNI, Agriculture Canada, Ottawa, CANADA; and GREG WALL, Agriculture Canada, Guelph, Ontario, CANADA

SESSION: ID07 Ballroom F GROUND WATER QUANTITY/QUALITY IN THE U.S.

Presiding: RICHARD C. PARALTA, Utah State University, Logan, UT

Ground Water Management in Southern Florida: MARK M. WILSNACK, South Florida Water Management District, West Palm Beach, FL

Ground Water Management in Arkansas: JONATHAN RAY SWEENEY, Arkansas Soil and Water Conservation Commission, Little Rock, AR, and A. MARK BENNETT III, University of Arkansas, Fayetteville, AR

Statistical Decision Analysis for Interception Wells: HEWA A. WIJEDASA and MARIAN W. KEMBLOWSKI, Utah State University, Logan, UT
³H and ¹⁴C As Tracers of Ground-Water Recharge: JOHN A. IZBICKI and ROBERT L. MICHEL, U.S. Geological Survey, San Diego, CA

SESSION: EE30 Columbia INDUSTRIAL WASTEWATER ISSUES

Presiding: IRA WHITMAN, Whitman Companies, East Brunswick, NJ

Identifying Promising Hazardous Waste Reduction Technologies: JAMES D. ENGLEHARDT, University of Miami, Coral Gables, FL

Baltimore's Industrial Pretreatment Program Has Successfully Reduced the Concentrations of Priority Pollutants Entering the Back River Waste Water Treatment Plant: GEORGE G. BALOG and RALPH O. CULLISON, III, City of Baltimore Dept. of Public Works, Baltimore, MD

Water Reduction Program as Justification for Permit Backsliding: GARY W. SIEGEL and MARGARET L. DWYER, Goldman Environmental Consultants, Randolph, MA

SESSION: EE04 Frederick ENVIRONMENTAL ASSESSMENT ISSUES

Presiding: AMY ZLOTSKY, EA Engineering, Science, and Technology, Lincoln, NE

Case Study: How Environmental Permits Take on a Life of Their Own: LEONARD A. CILLI, Earth Technology Group, Cherry Hill, NJ, and PAUL J. COTILLA, Cotilla Associates, Plainview, NY

Permitting Refinery Heater Modifications in the South Coast Air Quality Management District: R. SAHU, and T. HUNT, Engineering-Science, Pasadena, CA

Incineration — Panacea or Pandemic: HARVEY W. ROGERS, Agency for Toxic Substances and Disease Registry, Atlanta, GA

Mass Transfer and Exposure in Residential Showers: JOHN C. LITTLE, Lawrence Berkeley Laboratory, Berkeley, CA

SESSION: EE15 Annapolis TOXIC AND HAZARDOUS MATERIALS BIOREMEDIATION

Presiding: N. SHASHDIHARA, Ebasco Services, Lyndhurst, NJ

Development of a Protocol to Evaluate Volatilization and Biodegradability Characteristics of Turpene-Based Solvent Substitutes: BENERITO S. MARTINEZ, JR., RICARDO B. JAQUEZ, and WALTER H. ZACHRITZ II, New Mexico State University, Las Cruces, NM
Emerging In Situ Technologies for Addressing Contamination in the Saturated Zone: A Way to Reduce Cleanup Periods: SUTHAN S. SUTHERSAN, Geraghty & Miller, Plainview, NY

Session 5/8:15-9:45am Con't.

Use of Bioremediation as a Waste Minimization Process: SUTHAN S. SUTHERSAN, Geraghty & Miller, Plainview, NY

Process Design for Bioremediation of Nitrogen-Species Contamination of Soils and Ground Water: PAUL D. TURPIN, J. MICHAEL HENSON, and STEVEN L. MARTIN, RMT, Inc., Madison, WI

A Preliminary Evaluation of Transport Mechanisms for Multiple Substrates in a Laboratory Column System: ZHIHUI XUE and WILLIAM F. MCTERNAN, Oklahoma State University, Stillwater, OK

SESSION: EE11 Baltimore SOLID WASTE LANDFILL LINERS

Presiding: S. SAYED, Jamal & Associates, Winter Park, FL

Hydraulic Conductivity of Landfill Liners Containing Benzyltriethylammonium-Bentonite: JAMES A. SMITH, US Geological Survey, Trenton, NJ, PAMELA M. FRANKLIN, Stanford University, Stanford, CA, and PETER R. JAFFE, Princeton University, Princeton, NJ

Leakage Mechanism Through Double Liner Systems: ABDUL R. MULLA SALEH, CDM, Tampa, FL

Permeation of Organic Chemicals through HDPE Geomembranes: JONI P. SAKTI, JIM K. PARK, and JOHN A. HOOPES, University of Wisconsin, Madison, WI

Design of Landfill Drainage Systems: BRUCE M. McENROE, University of Kansas, Lawrence, KS

Session 6/10:30am-12:00pm

SESSION: HY-36 Convention Center 301 OPEN CHANNEL HYDRAULICS

Presiding: M.H. CHAUDHRY, Dept. of Civil & Environmental Engineering, Washington State University, Pullman, WA

Vedernikov's Number as a Measure of Flow Stability: C. CHEN, U.S. Geological Survey, Menlo Park, CA

Optimum Channel Contraction for Supercritical Flows: P. RUTSCHMANN, Swiss Federal Institute of Technology, Zurich, SWITZERLAND, O. JIMENEZ, Engineer, San Jose, COSTA RICA, and M.H. CHAUDHRY, Dept. of Civil & Environmental Engineering, Washington State University, Pullman, WA

Return Flows in Large Rivers Associated with Navigation Traffic: N.G. BHOWMIK, B.S. MAZUNDER, and T.W. SOONG, Illinois State Water Survey, Champaign, IL

Energy Loss at Combining Pipe Junction: MARC SERRE and A.J. ODGAARD, Iowa Institute of Hydraulic Resources, The University of Iowa, Iowa City, IA; REX A. ELDER, Consultant, Tiburon, CA

SESSION: HY-45 Convention Center 302 URBAN STORMWATER AND DETENTION

Presiding: W.H. ESPEY, JR., Espey, Huston & Associates, Inc., Austin, TX

Accumulation Effects of Stormwater Management Detention Basins: R.G. TRAVER and R.A. CHADDERTON, Civil Engineering Dept., Villanova University, Villanova, PA

Experiments with Wind Effects on Pavement Runoff: JOSEPH R. REED, Dept. of Civil Engineering, Penn State University, University Park, PA, DAVID F. KIBLER, Dept. of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA and G.A. KRALLIS, Whitman and Howard, Inc., Wellesley, MA

Design Storms for Emergency Spillways of SWM Ponds: O. YUCEL, John E. Harms, Jr. & Associates, Inc., Pasadena, MD

FAA Storm Water Program: W.H. ESPEY, JR., Espey, Huston & Associates, Inc., Austin, TX, R.R. ROSE, Espey, Huston & Associates, Inc., Williamsburg, VA, and G.J. LEGARRETA, FAA U.S. Department of Transportation, Washington, D.C.

SESSION: HY-44 Convention Center 303 HYDRAULICS OF BRIDGE SCOUR

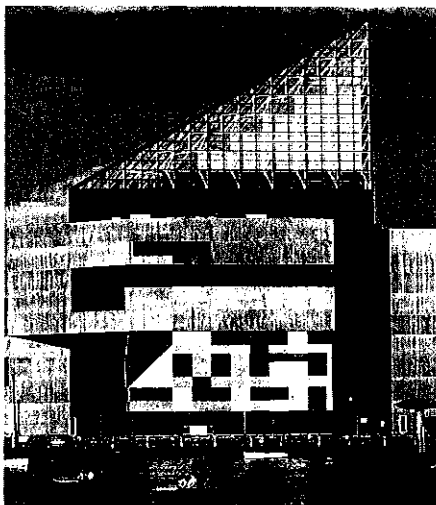
Presiding: D.J. HAGERTY, Civil Engineering Dept., University of Louisville, Louisville, KY

Seepage Influence on Stability of Bridge Abutments: D.J. HAGERTY and A.C. PAROLA, Civil Engineering Dept., University of Louisville, Louisville, KY

BRSC — A Spreadsheet Program for Bridge Scour Sensitivity Analysis: ONER YUCEL, John E. Harms, Jr. & Associates, Inc., Pasadena, MD

Geomorphic and Hydraulic Factors Affecting Stream Stability at New York Thruway Bridges: SUFIAN A. KHONDKER, Ebasco Services, Inc., New York, NY, KEITH E. GILES, New York State Thruway Authority, CARL J. MONTANA, Ebasco Services, Inc., New York, NY, and MARK A. HIXSON, New York State Thruway Authority

Seepage Effects on Bridge Pier Scour: A.C. PAROLA and D.J. HAGERTY, Civil Engineering Dept., University of Louisville, Louisville, KY



National Aquarium, Baltimore

SESSION: HY-35 Convention Center 304 SEDIMENTATION AND STABLE CHANNEL DESIGN

Presiding: ROGER A. KUHNLE, USDA National Sedimentation Lab, Oxford, MS

Design of a Threshold Channel: G. VIGILAR and P. DIPLAS, Dept. of Civil Engineering, Virginia Polytechnic Institute, Blacksburg, VA

Critical Evaluation of Thickening Theories: A. PAPANICOLAOU and P. DIPLAS, Dept. of Civil Engineering, Virginia Polytechnic Institute, Blacksburg, VA

Loop Rating Curves from Goodwin Creek: R.A. KUHNLE and A.J. BOWIE, USDA National Sedimentation Lab, Oxford, MS

Darcy-Weisbach Roughness Coefficients for Gravel and Cobble Surfaces: J.E. GILLEY, E.R. GOTTWITZ and G.A. WEIMAN, University of Nebraska, Lincoln, NE

SESSION: HY-47 Convention Center 305 CASE STUDIES OF NATURAL DISASTERS

Presiding: SHOU-SHAN FAN, Federal Energy Regulatory Commission, Washington, D.C.

Flood Control Experiences in China and 1991 Flood Disaster: D.J. GUNARATNAM, World Bank, Washington, D.C.

Floods in Bangladesh: B.K. LEE, Harza Engineering Co., Chicago, IL

The Drought Occurrence and Response Measures in Taiwan Area — 1991: HONG-HSI HSU, Water Resources Planning Commission, Taipei, TAIWAN and J-C YANG, National Chiao Tung University, Hsinchu, TAIWAN

The Landfall of Hurricane Hugo: BILLY L. EDGE, Edge & Associates, Inc., Charleston, SC, BEN L. SILL, Clemson University, Clemson, SC, and O.T. MAGOON, Guenoc Winery, Middletown, CA

SESSION: HY-13 Convention Center 306 COASTAL HYDRAULICS AND TRANSPORT

Presiding: E.R. HOLLEY, Dept. of Civil Engineering, University of Texas, Austin, TX

Model for Transport of Floating Debris in the Ocean: Y.C. SU, Espey, Huston & Associates, Inc., Austin, TX, E.R. HOLLEY and G.H. WARD, Dept. of Civil Engineering, University of Texas, Austin, TX

Model Study to Determine the Wave Forces Acting on the St. Lucie Velocity Caps: SUFIAN A. KHONDKER, Ebasco Services, Inc., New York, NY, TATSUAKI NAKATO, Institute of Hydraulic Research, University of Iowa, Iowa City, IA, H. ROGER GAVANKAR and RUDY D. GIL, Florida Power & Light Co.

Verification Techniques Used in Modeling Charleston Harbor, South Carolina: S.B. HELTZEL, USAE Waterways Experiment Station Vicksburg, MS

Erosion of a Thin Lutocline Under Homogeneous Turbulence: P.D. SCARLATOS, Dept. of Ocean Engineering, Florida Atlantic University, Boca Raton, FL

Session 9/8:15-9:45am Con't.

Recovery of Metals from Water Using Ion Exchange: THOMAS A. HICKEY, B&V Waste Science and Technology Corp, Kansas City, MO, and DAVID K. STEVENS, Pritchard Corporation, Jverland Park, KS

Atrazine Biodegradation in Biological Granulated Activated Carbon Columns: M.K. BANKS and C.M. HUANG, Kansas State University, Manhattan, KS

Effects of Pre-Oxidation on In-Line Filtration: Particle and Manganese Removal: JOHN E. TOBIASON and NAGARAJU K. VINOD, University of Massachusetts, Amherst, MA

Removal of Trihalomethane Precursors by Ferric Chloride Coagulation: ANNE STUDESTILL, Jordan, Jones, and Goulding, Atlanta, GA, and APPIAH AMIRTHARAJAH, Georgia Institute of Technology, Atlanta, GA

SESSION: ID25 Ballroom F HYDROLOGIC APPLICATIONS OF WATERSHED MANAGEMENT

Presiding: LARRY M. YOUNKIN, Bucknell University, Lewisburg, PA

Darcy-Weisbach Roughness Coefficients for Selected Residue Materials: JOHN E. GILLEY, EUGENE R. KOTTWITZ and GARY A. WIEMAN, University of Nebraska, Lincoln, NE

An Evaluation of Rainfall-Runoff Equations: ALBERT H. HALFF, HENRY M. HALFF and JUAN RODRIGUEZ, Albert H. Halff Associates, Inc. Dallas, TX

Prediction of Sedimentgraph From a Small Watershed in Poland in a Changing Environment: KAZIMERZ BANASIK, Warsaw, Agricultural University, Warsaw POLAND, DONALD E. WOODWARD, USDA-SCS, Washington, DC

7-Day 10-Year Low Flow Relationships for Ungauged Sites in Central Italy: PIEGIORGIO MANCIOLA and STEFANO CASADEI, University of Perugia, Perugia, ITALY

SESSION: ID20 Chesapeake A CURVE NUMBERS — STATUS AND DEVELOPMENT

Presiding: ALAN T. HJELMFELT, JR., University of Missouri, Columbia, MO

Soil Moisture and Runoff — Another Look: JOSEPH A. VAN MULLEM, Soil Conservation Service, Bozeman, MT

Retention Parameter Estimates for Curve Number Runoff Procedure: W. CARLISLE MILLS, ADRIAN W. THOMAS, ANTHONY L. DILLARD, USDA-ARS, Southeast Watershed Research Laboratory, Tifton, GA, WILLARD M. SNYDER, Hydrologic Consultant, Athens, GA

Progress Report ARS/SCS Runoff Curve Number Work Group: DON WOODWARD, USA-SCS, Washington, DC, W.J. GBUREK, USDA-ARS, University Park, PA

In Defense of Curve Numbers, A Professional Quandary: R.H. HAWKINS and A.T. HJELMFELT, University of Missouri, Columbia, MO

SESSION: ID29 Chesapeake B INTENTIONAL WEATHER MODIFICATION

Presiding: DON GRIFFITH, North American Weather Consultants, Salt Lake City, UT

Targeting of Agl in a Utah Winter Orographic Storm: J.A. HEIMBACH, JR., University of North Carolina, Asheville, NC, A.B. SUPER, Bureau of Reclamation, Denver, CO

Results From a Long-Term Winter Cloud Seeding Program in Utah: DON A. GRIFFITH, JOHN R. THOMPSON and DAN A. RISCH, North American Weather Consultants, Salt Lake City, UT

The Present Status of Precipitation Enhancement by Cloud Seeding: R.T. BRUINJES, T.L. CLARK, W.D. HALL, National Center for Atmospheric Research, Boulder, CO

Cloud Seeding: The Engineering is Done, But What About Social Impacts?: MAURICE ROOS, California Department of Water Resources, Sacramento, CA

Session 10/10:15-11:45am

SESSION: HY-14 Ballroom C GROUNDWATER AND CONTAMINANT TRANSPORT

Presiding: LOUIS H. MOTZ, Dept. of Civil Engineering, University of Florida, Gainesville, FL

Groundwater Quality Model with Applications to Various Aquifers: M.M. SOLIMAN, and A. HASSAN, Ain Shems University, Cairo, EGYPT

Comparison of Numerical Modeling Approaches for Subsurface Immiscible Contaminant Transport: K. RATHFELDER and LINDA M. ABRIOLA, Dept. of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI

Use of Groundwater Models to Simulate Remediation: L.H. MOTZ, P.A. CHADIK, B.L. KOOPMAN, K. HATTFIELD, R.L. HUTTON, G.A. TOOTLE and R.W. WATTS, Dept. of Civil Engineering, University of Florida, Gainesville, FL

Groundwater Modeling of Wastewater Management Options: D.N. BROCARD, Metcalf & Eddy, Inc., Wakefield, MA, and A. PROTOUPAS, Polytechnic University of New York, Brooklyn, NY.

SESSION: HY-21 Ballroom D 3-D FREE-SURFACE HYDRODYNAMIC MODEL VERIFICATION

Presiding: S.Y. WANG, Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford, MS

Numerical Model Verification by Prescribed Solution Forcing — A Test Case: D.P. DEE, Delft Hydraulics, THE NETHERLANDS, F.M. TORO and S.Y. WANG, Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford, MS

Verification Of A Three-Dimensional Modeling in Apalachicola Bay: T.S. WU, NW Florida Water Management District, Havana, FL

A Three-Dimensional Tidal Circulation Model Based On Semi-Implicit Finite-Difference Methods: RALPH T. CHENG, U.S. Geological Survey, Menlo Park, CA, and VINCENZO CASULLI, University of Trento, ITALY

Data Set for Verification of 3-D Free Surface Hydrodynamic Models, Carquinez Strait, California: P.E. SMITH, R.N. OLTMANN and M.R. SIMPSON, U.S. Geological Survey, Sacramento, CA

Computational Model Verification Test Case Using Flume Data: Y. JIA AND S.Y. WANG, Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford, MS

Open Boundary Condition for Multiple Level FE Tidal Current Flow Analysis: TOSHIO KODAMA, Salo Kogyo Co. Ltd., Kanagawa, JAPAN, and MUTSUO KANAGAWA, Chuo University, Tokyo, JAPAN

SESSION: HY-50 Ballroom E GENERAL HYDROLOGY & HYDRAULICS

Presiding: R.B. JENNINGS, U.S. Geological Survey, Ft. Worth, TX

Application of Monthly Model of Los Angeles Aqueduct System to Investigate Impacts from Mono Lake Tributary Diversions: R.T. BROWN, Jones & Stoke Associates, Sacramento, CA, and W.R. HUTCHINSON, Luhdorff and Scalmanini, Inc., Woodland, CA

User Interface For Pipe Network Program: ISTVAN LIPPAI, National Park Service, Lakewood, CO

Design of Pneumatic Diffuser System: STEVE WILHELMS, C.W. DOWNER and R.E. PRICE, USAE Waterways Experiment Station, Vicksburg, MS

Analysis of Special Hazards and Flooding Problems in Tropical Island Environments: R.C. MACARTHUR, D.L. HAMILTON, M.D. HARVEY, Resource Consultants & Engineers, Davis, CA, Tustin, CA and Ft. Collins, CO respectively and H.W. KEKAULA, USAE, Pacific Ocean Division, Ft. Shafter, HI

SESSION: HY-56 Ballroom F WASTE SITE REMEDIATION FOR CONTAMINATED GROUND WATER/ SOILS

Presiding: RAYMOND L. MONTGOMERY, USAE Waterways Experiment Station, Vicksburg, MS

Treatment of Contaminated Groundwater Using Chemical Oxidation: M.E. ZAPPI, B.C. FLEMING and M.J. CULLINANE, JR., USAE Waterways Experiment Station, Vicksburg, MS

Removal of Extremely Low Levels of Nitrates In A Drinking Water Supply: R.M. BRICKA and W. SHARP, USAE Waterways Experiment Station, Vicksburg, MS

Reduced Recharge Capacity of a Pump and Treatment System: C. TEETER, D. GUNNISON, N. FRANCINGUES, and M. ZAPPI, USAE Waterways Experiment Station, Vicksburg, MS

Properties of Solidified/Stabilized Chromium Contaminated Soil: B.C. FLEMING and M. JOHN CULLINANE, JR., USAE Waterways Experiment Station, Vicksburg, MS

Session 10/10:15-11:45am Con't.

SESSION: WR30 Frederick REHABILITATION OF WATER MAINS

Presiding: ARUN K. DEB, Roy F. Weston, Inc., West Chester, PA

Water Main Rehabilitation — Needs for the 90's: D. KELLY O'DAY, Massachusetts Water Resources Authority, Boston, MA

A Review of Current UK Techniques for Rehabilitating Water Mains: MIKE JONES, Severn Trent Water Limited, Leicester, UNITED KINGDOM

Costs of Rehabilitation of Water Distribution Systems: PETER K. MAC EWEN, Chester Water Authority, Chester, PA

Rapid Rehabilitation Techniques: STEVEN E. COOPER and GREGORY C. HEITZMAN, Louisville Water Company, Louisville, KY

SESSION: WR50 Annapolis WATER SUPPLY AND CONSERVATION II

Presiding: CLAIRE WELTY, Drexel University, Philadelphia, PA

Economic & Financial Implications of Water Conservation in a Southeastern City: DAVID H. MOREAU, University of North Carolina, Raleigh, NC

Statistical Analysis of Wastewater Flow Reduction: ROGER PUTTY and M. NAJMUS SAQUIB, James Montgomery, Inc, Sacramento, CA, WILLIAM O. MADDAUS, James Montgomery, Inc, Walnut Creek, CA, KAYLEEN WARNER, Office of Environmental Management, San Jose, CA

Water Conservation in the Delaware River Basin: JEFFEREY FEATHERSTONE, Delaware River Basin Commission, West Trenton, NJ

SESSION: WR45 Columbia STORM WATER FACILITIES

Presiding: CHARLES H. CALL, Salt Lake City Public Utilities, Salt Lake City, UT

Efficient Sizing of Stormwater Treatment Ponds: THOMAS R. SEARS and BRENDA VAN RAVENSWAY, CH2M Hill, Orlando, FL

Retrofitting Storm Water Facilities for Quantity and Quantity Control: STUART G. WALES, Valparaiso University, Valparaiso, IN

A Storm Water Utility Case Study Salt-Lake City, Utah: CHARLES H. CALL, Salt Lake City Public Utilities, Salt Lake City, UT

Analytical Hydraulic Modeling of Road Culverts: R. SALEH, Alameda County Public Works Agency, Hayward, CA & R. HWANG, Sacramento State University, Sacramento, CA

SESSION: EE12 Calv/Pratt SOLID WASTE RECYCLING

Presiding: GENE L. NEFF, Baltimore County Dept. of Public Works, Towson, MD

The Evolution of Modern Trash-to-Energy Technology: STEVEN G. TOMCZEWSKI and FRANCIS A. FERRARO, Wheelabrator, Baltimore, MD

Baltimore City Recycling Program — Case History: GEORGE G. BALOG, KENNETH J. STRONG, and ELLEN L. KOBLER, Baltimore City Dept of Public Works, Baltimore, MD

Planning Centralized Recovery Facilities: RENEE A. LAWVER, and JAY R. LUND, University of California, Davis, CA

Solid Waste Management: The Extension Service Initiative: MOHAMED F. DEHAB and WAYNE E. WOLDT, University of Nebraska, Lincoln, NE

SESSION: EE22 Camden/Lombard WATER POLLUTION-TOXICITY REDUCTION EVALUATION

Presiding: RUSSELL S. DYKES, Roy F. Weston, Houston, TX

Municipal Toxicity Reduction Evaluations: Possible Approaches for Controlling Effluent Toxicity: TIMOTHY MORRIS, and CRAIG COKER, Engineering-Science, Fairfax, VA
Nonpolar Organics Toxicity in a Municipal Effluent: CARLOS H. VICTORIA-RUEDA, Engineering-Science, Austin, TX

Case History: TRE at a Refinery/Chemical Plant: CAROL L. LA BRECHE and RUSSELL S. DYKES, Roy F. Weston, Houston, TX

State Permit Program and Toxics Individual Control Strategies: A Case Study: ALTAF A. MEMON, Buchart Horn, York, PA

Toxicity Reduction of Petroleum Refinery Wastewaters by Aerated Submerged Biological Filters: RADAWN MARTINEZ, JANAKY RAMASWAMY, JOHN N. VEENESTRA MARTHA ANNE WEINERT, and S.L. BURKS, Oklahoma State University, Stillwater, OK

Toxicity Identification and Reduction Evaluation of a Metal-Finishing Wastewater Treatment Plant: SAY ONG, GREGORY J. SMITH, WENDY M.C. HUANG, WILLIAM H. CLEMENT, Battelle Memorial Institute, Columbus, OH, GEORGE M. DeGREAVES, and MARY JAKEWAY, Battelle Great Lakes Environmental Center, Traverse City, MI

SESSION: ID17 Baltimore USE OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS FOR PLANNING AND MANAGEMENT OF IRRIGATION AND DRAINAGE SYSTEMS

Presiding: CHRISTOPHER NEALE, Utah State University, Logan, UT

Regional Sustained Yield Groundwater Planning Using GIS: R. PERALTA and C.M.U. NEALE, Utah State University, Logan, UT

Irrigation and Drainage System As-Built Map Preparation Using Satellite Digital Imagery and a GIS: Christopher Neale, Utah State University, Logan, UT

Role of Land Information System in Operation and Maintenance of Irrigation and Drainage Systems Bureau of Reclamation: JAMES B. ROBERTSON and SHAREN L. WOOD, Bureau of Reclamation, Denver, CO

Crop Classification and Area Estimation Using Multispectral Video-Radiometer Remote Sensing: R. AHMED and CHRISTOPHER NEALE, Utah State University, Logan, UT

SESSION: ID21 Chesapeake A DISTURBED LANDS HYDROLOGY

Presiding: VICTOR HASFURTHER, University of Wyoming, Laramie, WY

Hydrologic Considerations in Mined Land Reclamation: PATRICK T. TYRRELL and MARTIN W. STEARNS, Thunder Basin Coal Company, Wright, WY

Variations in Curve Number for a Reclaimed AML Site: K. JAMES FORNSTROM and JAMES L. SMITH, University of Wyoming, Laramie, WY

Hydrogeotechnical Considerations for the Disposal of Oil Shale Solid Waste Material: VICTOR R. HASFURTHER and JOHN P. TURNER, University of Wyoming, Laramie, WY

Simulation of Runoff and Infiltration of Disturbed Land: BEN C. YEN, University of Illinois at Urbana-Champaign, Urbana, IL, ROBERT RIGGINS, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, IL

SESSION: ID27 Chesapeake B WEATHER MODIFICATION AND CLIMATE CHANGE

Presiding: DON GRIFFITH, North America Weather Consultants, Salt Lake City, UT

Seven Legal Strategies to Cool Global Warming: RAY JAY DAVIS, Brigham Young University, Provo, UT

The Sensitivity of Streamflow and Water Supply in the Colorado Basin to Climatic Changes: LINDA L. NASH, Pacific Institute for Studies in Development, Environment, and Security, Berkeley, CA

Importance of Tropical Rainfall Measuring Mission (TRMM) Satellite to Hydrological Investigations: JOANNE SIMPSON, NASA/Goddard Space Flight Center, Greenbelt, MD

The Use of Sophisticated Three-Dimensional Numerical Models in Weather Modification Efforts: T.L. CLARK, R.T. BRUINJES, W.D. HALL, National Center for Atmospheric Research, Boulder, CO

**Hydraulics Division
Wednesday Awards Luncheon**
Ballroom B 11:45 am-1:15 pm
Presiding: ADNAN ALSAFFAR, Chair, Hydraulics Division