



**FINAL TECHNICAL REPORT: PROJECT 3**  
**DEVELOPMENT AND EVALUATION OF AQUATIC INDICATORS**

**PERIOD COVERED BY FINAL REPORT:** October 1, 2001 - September 30, 2006  
**DATE OF FINAL REPORT:** December 15, 2006  
**EPA COOPERATIVE AGREEMENT NUMBER:** CR 829095  
**PROGRAM NAME (TITLE):** SPACE-TIME AQUATIC RESOURCES MODELING AND ANALYSIS PROGRAM (STARMAP)  
**PROJECT TITLE:** Development and Evaluation of Aquatic Indicators  
**INVESTIGATORS:** David M. Theobald (CSU), N. Scott Urquhart (CSU)  
**INSTITUTIONS:** Colorado State University (CSU)  
**RESEARCH CATEGORY:** Research Program on Statistical Survey Design and Analysis for Aquatic Resources  
**PROJECT PERIOD:** October 1, 2001 - September 30, 2006  
**OBJECTIVE OF RESEARCH:** To develop, test, and distribute GIS-based tools that would facilitate computation of useful watershed metrics for statistical analysis of aquatic response variables

**SUPPLEMENTAL KEYWORDS:** GIS, tessellation stratified sampling, water quality, land cover, land use, accuracy, precision

**Relevant Web Sites:** <http://www.stat.colostate.edu/starmap>

The FloWS (Functional Likage of Watersheds and Streams) software is available at [http://www.nrel.colostate.edu/projects/starmap/flows\\_index.htm](http://www.nrel.colostate.edu/projects/starmap/flows_index.htm)

Software for Functional Connectivity Model (FunConn) is available at: [http://www.nrel.colostate.edu/projects/starmap/funconn\\_index.htm](http://www.nrel.colostate.edu/projects/starmap/funconn_index.htm)

Software for Spatially-balanced sampling using RRQRR is available at [http://www.nrel.colostate.edu/projects/starmap/rrqrr\\_index.htm](http://www.nrel.colostate.edu/projects/starmap/rrqrr_index.htm)

**1. ACCOMPLISHMENTS of PROJECT 3: DEVELOPMENT AND EVALUATION OF AQUATIC INDICATORS**

Project 3 developed, tested, and distributed GIS-based tools that would facilitate computation of useful watershed metrics for statistical analysis of aquatic indicator variables. Project investigators met these objectives through three key accomplishments by:

- ◆ Developing ArcGIS-based toolsets called FloWS, FunConn and RRQRR;
- ◆ Conducting series of demonstrations and application of those tools to a range of key EPA constituents; and

- ◆ Collaborating with other scientists and training of students.

FLoWS (Functional Linkage of Waterbasins and Streams) is a set of tools that operate within ArcGIS v9 (written in Python). These tools allow users to rapidly generate a stream network, identify and correct topological errors in a network (fairly common in GIS data), extract watershed characteristics derived from other ancillary data such as topography, land cover, road density, etc. in a way that allows ecologically-relevant processes to be developed. For example, discharge volume (flow volume) is estimated as a function not only of waterbasin area, but also of the precipitation regime and the watershed topographic characteristics, including solar insolation and slope. Project investigators also developed a novel approach to identify catchments around stream reaches by identifying water basin boundaries using a cost-weight method, rather than relying on strictly local conditions (slopes) identified in a Digital Elevation Model. The goal was to ensure that these tools work with very large datasets (basins to nationwide) and in a variety of situations. For example, the traditional approach to identify watersheds failed in the Central Shortgrass Prairie that contains low relief, many intermittent streams, inconsistent network topology, as many local ridges caused the algorithms to “stop short” and caused “holes” or portions of watersheds that would not converge or connect with the larger network. Not only is our new method robust and fast, preliminary analysis suggest that it is more accurate as well. For a small test study area in the Fraser River, Colorado water basin (high topographic relief), we found a higher mean accuracy using our novel methods as compared to the traditional method (i.e. 85% vs. 78% using Jaccard’s coefficient as compared to expert-based delineation of watershed boundaries at 1:24,000 scale).

The goal of the functional connectivity model, whose GIS implementation is named FunConn, is to allow landscape connectivity to be examined from a functional perspective. Functional connectivity recognizes that individuals, species or processes respond functionally (or behaviorally) to the physical structure of the landscape. From this perspective, landscape connectivity is specific to a landscape and species/individual/process under investigation.

Project investigators also strove to develop metrics and approaches that are more robust to possible data quality issues. For example, a well-known problem with “blue-line” hydrography is that the identification of streamlines can abruptly change at a topographic quadrangle boundary. Traditional metrics that rely on Strahler stream order, for example, are very sensitive to these issues, whereas water basin-area computations are more robust.

A key to the investigators’ accomplishment was close interaction and collaboration with a variety of constituents. Two major collaborations were with Oregon Department of Fish & Game (through collaborations with DAMARs personnel) and the Alaskan Department of Fish & Game. Project investigators participated in a variety of workshops and provided technical assistance throughout the STARMAP project.

Two unanticipated products of this Project were the result of synergistic activities. The key to each of these was an informal (initially) exchange of ideas, enthusiasm injected by graduate students involved (esp. Peterson), and the STARMAP Director’s support for risk taking. For example, the new geostatistical method for stream networks developed by ver Hoef,

Peterson, and Theobald was the result of informal discussion at workshops, identification of an important research question, and eagerness of key individual (Peterson) who provided a key trans-disciplinary role. A second example was the development of a robust spatially-balanced sampling design algorithm implemented in ArcGIS, called the RRQRR tool (Reversed Randomized Quadrant-Recursive Raster). This is built fundamentally around Stevens and Olsen's GRTS algorithm, but development within a GIS framework provides the ability to develop a raster of sample locations, as well as extends a tool to a different (and broader) user base.

This project's investigators collaborated closely with investigators working on Projects 1 and 2. Specifically there was close cooperation between Erin Peterson and Andrew Merton, graduate students funded, respectively, under Projects 3 and 1. Merton, under the guidance of Hoeting (Project 1) and Davis (Project 2), developed computer software used extensively by Peterson, and adapted it to several of her special situations. This collaboration produced a jointly authored publication and presentations illustrating how the collaboration functioned. Peterson also collaborated with postdoctoral fellow Ranalli who conducted research under the auspices of Project 2. Another interaction involved Breidt (Project 2), Theobald (Project 3) and international visitors unfunded by STARMAP; this is described in more detail under Project 2. Further, Project 3 investigators developed or assisted in the developing covariate data sets for at least five other graduate student projects.

## **2. SIGNIFICANCE OF ACCOMPLISHMENTS**

The next section gives a list of known adopters of the methodology developed under this Project. The diversity of adopters speaks eloquently to the current significance of the accomplishments of this Project. Adopters ranged from local environmental agencies to national environmental agencies, from governmental agencies to nonprofit agencies to academics, from across the United States to across the world. The acceptance of the products of this Project was due to two factors: The relevancy of the products developed, and the scale of the outreach activities associated with them. The specific outreach activities are documented under Project 4, but it needs to be noted here that this Project's investigators made a major effort in this area.

## **3. STAKEHOLDERS AND USERS OF RESULTS**

This project has written and made web-available three sets of GIS tools oriented toward the design and statistical analysis of data resulting from studies in aquatic systems. The tools are programmed in Python and accessible as ArcGIS tools in v9. Each is further documented and available through this web site:

<http://www.nrel.colostate.edu/projects/starmap/>

- ◆ *FLoWS v1: Functional Linkage of Watersheds and Streams tools for ArcGIS v9:* The goal of the functional linkage of watersheds and streams tools is to allow aquatic and terrestrial landscapes to be hydrologically-linked. In this sense, relationships between sites can be represented through functional distance measures. For many hydrological processes (not all!) downstream flow direction is an important ecological process, so that distance is not symmetric. Also, including important landscape attributes that modify the degree to which nearby locations are connected is important. This would include topographic considerations such as stream gradient and slope, as well as features that

might impede the movement of a species or process such as waterfalls, dams, or certain vegetation types. The agencies and organizations listed below have requested and received a copy of the FLoWS software (as of December 1, 2006):

- US Environmental Protection Agency, National Exposure Research Laboratory, Athens, GA
- US Forest Service, Rocky Mountain Research Station, Boise, Idaho
- US Forest Service, Aquatic and Riparian Effectiveness Monitoring Program, Portland OR
- New Hampshire Geological Survey, Concord, New Hampshire
- Alaska Department of Fish and Game, Juneau, AK
- Oregon Department of Fish and Wildlife, Salem, OR
- Rensselaer Polytechnic Institute, New Orleans, Louisiana
- Missouri Resource Assessment Partnership (MoRAP) at the University of Missouri, Columbia, Missouri
- University of Kansas, Department of Geography, Lawrence, KS
- University of Iowa, Iowa City, IA
- Montana State University, Land Resources and Environmental Sciences, Bozeman, Montana
- Nicholas School of the Environment, Duke University, North Carolina
- Colorado State University, College of Natural Resources, Fort Collins, CO
- Department of Forest Science, Oregon State University, Corvallis, OR
- The Nature Conservancy: Tucson, AZ; Seattle, WA; Madison, WI; Cuddebackville, NY; Beijing, China; San Jose, Costa Rica
- GreenInfo Network, San Francisco, CA
- Colorado Natural Heritage Program, Fort Collins, CO
- TST, Inc. Consulting Engineers, Fort Collins, CO
- TSH = Engineers, Architects, and Planners, Ontario, Canada
- Ontario Ministry of Natural Resources, Ontario, Canada
- BEACONS Project, University of Alberta, Alberta, Canada
- Environnement Canada/ Environment Canada, Quebec, Canada
- Center for Northern Forest Ecosystem Research, Ontario, Canada
- Watershed Science Center, Ontario, Canada
- Instituto Internacional en Conservación, Costa Rica
- Centro Agronomo Tropical de Investigación y Enseanza, Turrialba, Costa Rica
- Water Services, Glasgow Scotland
- Dipartimento di Ingegneria e Fisica dell'Ambiente, Università degli Studi della Basilicata, Italy
- Academy of Sciences of the Czech Republic
- CSIRO Mathematical and Information Sciences, Brisbane, Australia
- NAARM (National Academy of Agricultural Research Management), Hyderabad, India
- ROLTA (software/information technology based engineering and geospatial solutions), Mumbai, India

◆ *Functional Connectivity tools (FunConn)*: There is a large and critical difference between simple hydrological datasets that “look” correct on a map, but must have correct

topology and attribution to run network-based algorithms correctly. The goal of the functional connectivity model is to allow landscape connectivity to be examined from a functional perspective. Functional connectivity recognizes that individuals, species or processes respond functionally (or behaviorally) to the physical structure of the landscape. From this perspective, landscape connectivity is specific to a landscape and species/individual/process under investigation. The agencies and organizations listed below have requested and received a copy of the FunConn software (as of December 1, 2006):

- US Environmental Protection Agency, National Exposure Research Lab, Cincinnati, OH
- US EPA, Washington D.C.
- US Forest Service, Rocky Mountain Research Station, Fire Sciences Lab = LANDFIRE, Missoula, MT
- US Forest Service, Pacific Northwest Research Station, Olympia Forestry Sciences Lab
- US National Oceanic and Atmospheric Administration, Boise, Idaho
- US Geological Survey, Annapolis, MD
- US Fish and Wildlife Service
- University of Montana, Missoula, MT
- Columbia University, New York, NY
- University of Idaho, Remote Sensing and GIS, Moscow, ID
- University of Idaho, Rangeland Ecology and Management, Moscow, ID
- University of Pennsylvania, Anthropology, Philadelphia, PA
- Department of Ecology, University of California, Davis, CA
- Nicholas School of the Environment, Duke University, North Carolina
- Hopland Research and Extension Center, University of California, Hopland, CA
- Northern Arizona University, Flagstaff, AZ
- Department of Fisheries and Wildlife, Michigan State University
- World Wildlife Fund, Washington D.C.
- The Nature Conservancy - many locations
- Wildlife Conservation Society, New York, NY
- CDM Engineers & Constructors Inc, Denver, CO
- ESRI, the corporation which develops and distributes the Arc family of Geographic Information System products, widely used by the environmental community
- Queen's University, Department of Geography, Kingston, Ontario, Canada
- O2 Planning & Design Inc., Calgary, AB, Canada
- Parks Canada
- University of Alberta, Edmonton, Alberta, Canada
- National University, Heredia, Costa Rica
- Centro Agronomo Tropical de Investigación y Enseñanza, Turrialba, Costa Rica
- Escuela de Biología. Univ. de Costa Rica, San Jose, Costa Rica
- Conservation International- Brazil
- Universidad Distrital, Bogotá, Colombia
- University of Reading, Reading, UK

- University of Girona, Spain
  - University of Lleida, Lleida, Spain
  - Lisbon University, Departamento de Biologia Animal, Lisbon, Portugal
  - Dept of Land and Water Resources Engineering, Royal Institute of Technology, Stockholm, Sweden
  - Lund University, GIS Specialty, Lund, Sweden
  - Charles University in Prague, Czech Republic
  - Viterbo University, Viterbo, Italy
  - Department of Vegetable Science, University of Bari, Bari, Italy
  - Sohag, Egypt
  - Istanbul Engineering and Consultancy Services Cooperation, Turkey
  - University of Cape Town, Rondebosch, South Africa
  - Leslie Hill Institute for Plant Conservation, Rondebosch, South Africa
  - TPF, University of Antananarivo, Antananarivo, Madagascar
  - Department of Geography, University of Queensland, Australia
  - Kunming Institute of Zoology, Kunming, Yunnan, China
- ◆ *Spatially-balanced sampling using RRQRR*: The goal of the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm is to provide environmental managers a practical, useful GIS tool to generate simple, efficient, and robust survey designs for natural resource applications. RRQRR generates a rigorous probability-based survey design that is spatially-balanced and allows surfaces to be used to specify the inclusion probability. The agencies and organizations listed below have requested and received a copy of the RRQRR software (as of December 1, 2006):
- US National Park Service, Southeast Coast inventory and Monitoring Network, Cumberland Island National Seashore, St. Marys, Georgia
  - US Forest Service, Northern Research Station, Forest Inventory and Analysis Unit, Newtown Square, PA
  - US National Park Service, Inventory and Monitoring Program, Fort Collins, CO
  - US Department of Defense, San Clemente Island - for designing a monitoring plan for kit fox
  - Backcountry campsite monitoring, Yosemite National Park
  - Department of Fish and Wildlife, University of Idaho, Moscow, Idaho
  - Laramie Foothills Fire Learning Network, Larimer County, CO
  - Soils mapping, Frasier Experimental Forest, Frasier, CO
  - Environmental Systems Research Institute (ESRI, makers of ArcGIS software) – are currently implementing the RRQRR algorithm into their core software package
- ◆ In addition to building tools for statistical analysis of hydrology, this project generated a database (called the FLoWS database) that builds on USGS National Elevation Data and National Hydrography Dataset (1:100K). This effort provided two important benefits:
- A nationwide, pre-processed and pre-packaged dataset that will support many types of hydrological analysis and provides a significant “head-start” for EPA clients; and

- Nationally-consistent, hierarchical, and high-resolution catchment boundaries at a variety of scales – from basins (HUC 2s) to roughly the HUC 14 level.

#### 4. HOW PRODUCTS WILL FURTHER SCIENCE/ MANAGEMENT OF RESOURCES

These products will support the analysis of aquatic responses in diverse contexts, but will be especially useful in developing landscape indicators associated with specific aquatic sample points. These tools and demonstrations will support the more accurate and defensible analysis of diverse environmental variables.

#### 5. LISTING OF SPECIFIC COMMUNICATIONS RELATED TO INDICATOR DEVELOPMENT

Note that the following list is a subset of the entire output list from STARMAP; the complete list, supplied as a separate document as a part of this final report, provides internal links to most of the presentation materials, technical reports, and some manuscripts. Published material ordinarily was copyrighted by the publisher, so access to it usually is restricted to subscribers of that publication. The subset below includes all communications related Indicator Development.

##### ***PUBLICATIONS and ACCEPTED MANUSCRIPTS:***

- ◆ Theobald, D.M. and J.B. Norman (2007). FLoWS (Functional Linkage of Water basins and Streams): ArcGIS tools for network-based analysis of freshwater ecosystems. *HydroLine*, ESRI Press (in press).
- ◆ Peterson, E.E., D.M. Theobald, and J.M. Ver Hoef (2007). Support for geostatistical modeling on stream networks: Developing valid covariance matrices based on hydrologic distance and stream flow. To appear in *Freshwater Biology* (November, 2006).
- ◆ Theobald, D.M., D.L. Stevens, Jr., D. White, N.S. Urquhart, A.R. Olsen, and J.B. Norman. Using GIS to generate spatially-balanced random survey designs for natural resource applications. *Environmental Management* (Accepted July 17, 2006).
- ◆ Ver Hoef, J.M., E.E. Peterson, and D.M. Theobald (2006). Spatial statistical models that use flow and stream distance. To appear in *Environmental and Ecological Statistics* **13**: 449-464.
- ◆ Peterson, E.E. and N.S. Urquhart (2006). Predicting water quality impaired stream segments using landscape-scale data and a regional geostatistical model: A case study in Maryland. *Environmental Monitoring and Assessment* **121**:613-636.
- ◆ Peterson, E.E., A.A. Merton, D.M. Theobald, and N.S. Urquhart (2006). Patterns of spatial autocorrelation in stream water chemistry. *Environmental Monitoring and Assessment* **121**: 569-594.
- ◆ Theobald, D.M. (2006). Exploring the functional connectivity of landscapes using landscape networks. To appear in: Crooks, K.R. and M.A. Sanjayan (eds.). **Connectivity Conservation: Maintaining Connections for Nature**. Cambridge University Press. pp 416-444 of 726.

- ◆ Theobald, D.M., J.B. Norman, E.E. Poston, and S.B. Ferraz (2005). Functional linkage of watersheds and streams: ArcGIS FLoWS tools. *Proceedings, ESRI User Conference 2005*.

### **SOFTWARE**

- ◆ Theobald, D.M., J.B. Norman, and M.R. Sherburne (2006). FunConn v1: Functional connectivity tools for ArcGIS v9. Natural Resource Ecology Lab, Colorado State University.
- ◆ Theobald, D.M. and J.B. Norman (2006). Spatially-balanced Sampling (RRQRR). Natural Resource Ecology Lab, Colorado State University.
- ◆ Theobald, D.M., J.B. Norman, E.E. Peterson, and S.B. Ferraz (2005). *FLoWS v1: Functional Linkage of Watersheds and Streams tools for ArcGIS v9*. Natural Resource Ecology Lab, Colorado State University.

### **MANUSCRIPTS**

- ◆ Theobald, D.M., J.B. Norman, and D. Merritt (2006). Estimating aquatic fragmentation (in preparation for *Bioscience*).
- ◆ Theobald, D.M. and S.B. Ferraz. Hydrologic-weighting for functional watershed modeling. *Journal of American Water Resources Association* (in preparation).
- ◆ Theobald, D.M. Catchment areas, not watersheds: Flexible definition of watersheds to understand aquatic resources. (in preparation).

### **TECHNICAL REPORTS**

- ◆ Theobald, D.M. and J.B. Norman (2006). Spatially-Balanced Sampling Using the Reversed Randomized Quadrant-Recursive Raster Algorithm: A User's Manual for the RRQRR ArcGIS v9 tool. Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO. {Link}
- ◆ Theobald, D.M., J.B. Norman, E.E. Peterson, S.B. Ferraz, A. Wade, and M.R. Sherburne (2006). Functional Linkage of Water Basins and Streams (FLoWS) v1 User's Manual: ArcGIS Tools for Network-based Analysis of Freshwater Ecosystems. Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO. 43 pages.
- ◆ Theobald, D.M., J.B. Norman, and M.R. Sherburne (2006). FunConn v1 User's Manual: ArcGIS Tools for Functional Connectivity Modeling. Natural Resource Ecology Lab, Colorado State University. 51 pages.
- ◆ Peterson, E.E. (2005). Predicting the Likelihood of Water Quality Impaired Stream Segments Using Landscape-scale Data and a Hierarchical Methodology. Doctoral Dissertation, Department of Geosciences, Colorado State University.

### **PRESENTATIONS:**

{Note: The first author listed in the citations below gave the presentation, unless subsequent author is marked with an \* as the presenter.}

- ◆ Williams, S.J. A Comparison of Variance Estimates of Stream Network Resources. Masters Seminar, Department of Statistics, Colorado State University, October 25, 2006

- ◆ Theobald, D.M. and J.B. Norman\*. The FLoWS GIS Tools. Workshop on Modeling Salmon Habitat, hosted by the Alaska Department of Fish & Game and The Nature Conservancy, Anchorage, Alaska, May 17-19, 2006
- ◆ Theobald, D.M., J.B. Norman and E.E. Peterson. Functional Linkage of Water Basins and Streams: FLoWS v1 ArcGIS Tools. Workshop on Modeling Salmon Habitat, hosted by the Alaska Department of Fish & Game and The Nature Conservancy, Anchorage, Alaska, May 17-19, 2006
- ◆ Peterson E.E., D.M. Theobald, N.S. Urquhart, J.M. Ver Hoef, and A.A. Merton. Regional GIS-based Geostatistical Models for Stream Networks. Workshop on Modeling Salmon Habitat, hosted by the Alaska Department of Fish & Game and The Nature Conservancy, Anchorage, Alaska, May 17-19, 2006
- ◆ Peterson E.E., D.M. Theobald, N.S. Urquhart, J.M. Ver Hoef, and A.A. Merton. Patterns of Spatial Autocorrelation in Stream Water Chemistry. Centre for Riverine Landscapes Seminar Series, Griffith University, Brisbane, Australia. March 4, 2006 Abbreviated version presented at North American Benthological Society, Anchorage, Alaska, June 4-9, 2006
- ◆ Peterson, E.E., D.M. Theobald, N.S. Urquhart, J.M. Ver Hoef, and A.A. Merton. Predicting Water Quality Impaired Stream Segments Using Landscape-scale Data and a Regional Geostatistical Model. Statistical Society of Australia, St. Lucia, Queensland, Australia. October 18, 2005
- ◆ Theobald, D.M., J.B. Norman, E.E. Peterson and S.B. Ferraz. Functional Linkage of Watersheds and Streams Using Landscape Networks of Reach Contributing Areas. Fourth Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources, Corvallis, OR, September 7 - 9, 2005
- ◆ Theobald, D.M., J.B. Norman, and D.M. Merritt. Quantifying Fragmentation of Freshwater Systems Using a Measure of Discharge Modification (and Other Applications). Fourth Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources, Corvallis, OR, September 7 - 9, 2005
- ◆ Norman, J.B., D.M. Theobald, E.E. Peterson and S.B. Ferraz. Functional Linkage of Watersheds and Streams: ArcGIS FLoWS Tools. Fourth Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources, Corvallis, OR, September 7 - 9, 2005
- ◆ Peterson, E.E. Predicting the Likelihood of Water Quality Impaired Stream Segments Using Landscape-scale Data and a Hierarchical Methodology. Doctoral Defense Seminar in Earth Resources, Department of Geosciences, Colorado State University, August 23, 2005
- ◆ Peterson, E.E., A.A. Merton, N.S. Urquhart\*, D.M. Theobald, and J.A. Hoeting. Using the Maryland Biological Stream Survey Data to Test Spatial Statistical Models. Second Maryland Stream Conference, Carroll College, Westminster, MD, August 10 - 13, 2005
- ◆ Theobald, D.M., J.B. Norman, and D.M. Merritt. Quantifying Fragmentation of Freshwater Systems Using a Measure of Discharge Modification (And Other Applications). ESRI User Conference 2005, San Diego, CA, July 26, 2005

- ◆ Norman, J.B., D.M. Theobald, E.E. Poston, S.B. Ferraz. Functional Linkage of Watersheds and Streams: FLoWS v1 ArcGIS tools. ESRI User Conference 2005. San Diego, CA, July 26, 2005
- ◆ Theobald, D.M., J.B. Norman, E.E. Poston, S.B. Ferraz. Functional Linkage of Watersheds and Streams: ArcGIS FLoWS Tools. ESRI User Conference 2005. San Diego, CA, July 26, 2005
- ◆ Theobald, D.M., B.R. Noon, and A.R. Olsen. Vital Signs Monitoring Sample Design Workshop – Inventory and Monitoring Program, Intermountain Region. Short Course, National Park Service, Lakewood, CO, May 25 - 26, 2005
- ◆ Theobald, D.M. Developing Practical and Efficient Sample Designs for Inventory and Monitoring of Natural Resources Using Spatially-balanced Sampling. University of Redlands and Environmental Systems Research Institute (makers of ArcGIS), Redlands, CA, May 12, 2005 (ESRI is interested in potentially incorporating a spatially-balanced sampling tool in their core GIS product with release v9.3.)
- ◆ Theobald, D.M., J.B. Norman, E.E. Poston, S.B. Ferraz. A Framework to Develop Useful Landscape Indicators for Measuring Aquatic Responses. Seminar. WED/NHEERL/EPA, Corvallis, OR, February 2, 2005
- ◆ Theobald, D.M. Robust Spatial Sampling of Natural Resources Using a GIS Implementation of the GRTS Algorithm. Monitoring Science and Technology Symposium, Denver, CO, September 21-24, 2004
- ◆ Peterson, E.E., T.M. Theobald, and J.M. Ver Hoef. Ecologically Representative Distance Measures for Spatial Modeling in Stream Networks. Monitoring Science and Technology Symposium, Denver, CO, September 21-24, 2004
- ◆ Theobald, D.M., J.B. Norman, E.E. Peterson, and S.B. Ferraz. A Framework for Landscape Indicators for Measuring Aquatic Responses. Third Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources, Fort Collins, CO, September 10 - 11, 2004
- ◆ Peterson, E.E. Predicting the Likelihood of Water Quality Impaired Stream Reaches Using Landscape Scale Data and a Hierarchical Methodology. Third Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources, Fort Collins, CO, September 10 - 11, 2004
- ◆ Ver Hoef, J.M. and E.E. Poston. Some New Spatial Statistical Models for Stream Networks. Graybill Conference, Colorado State University, Fort Collins, CO, June 17 - 18, 2004
- ◆ Theobald D.M., S.B. Ferraz, E.E. Poston, and J. Deems. Linking Watersheds and Streams Through Functional Modeling of Watershed Processes. American Water Resources Association Specialty Conference on GIS and Water Resources. Nashville, TN, May 17-19, 2004
- ◆ Theobald, D.M. Modeling Functional Landscape Connectivity Using Effective Distance and Graph Theory. International Association of Landscape Ecologists, Las Vegas, NV, April 1, 2004
- ◆ Theobald, D.M. Landscape Metrics Based on Hydrologic Networks and Hydrologically-weighted Distances. Seminar, EPA/NHEERL/WED Lab, Corvallis, OR August 13, 2003

- ◆ Theobald, D.M. Linking Watersheds and Streams Through Functional Landscape Metrics. Second Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources , Corvallis, OR, August 11 - 13, 2003
- ◆ Theobald, D.M. and M. Kneeland. Hydrologic Network Metrics Based on Functional Distance and Stream Discharge. Seminar, Department of Geosciences, Oregon State University, Corvallis, OR, May 16, 2003 Related material presented as seminars, Department of Geography, University of Utah, April 18, 2003, and at University of Colorado, Boulder, April 23, 2003; and to US-International Association of Landscape Ecologists Annual meeting, Banff, Alberta, April 3, 2003
- ◆ Theobald, D.M. and M. Kneeland. Hydrologic network metrics based on stream discharge. US-International Association of Landscape Ecologists Annual meeting, Banff, Alberta. April 3, 2003
- ◆ Ritter, K.J., D. Birkes, and N.S. Urquhart. Quantifying Taxonomic Richness in Terms of the Level of Rarity Assessed by a Fixed Count. First Annual Conference on Statistical Survey Design and Analysis For Aquatic Resources, Colorado State University, Fort Collins, CO, September 21, 2002
- ◆ Theobald, D.M. Developing GIS Indicators and Metrics. First Annual Conference on Statistical Survey Design and Analysis For Aquatic Resources, Colorado State University, Fort Collins, CO, September 21, 2002

### ***POSTERS***

- ◆ Theobald, D.M., J.B. Norman, E.E.Peterson, and S.B. Ferraz. Functional Linkage of Watersheds and Streams (FLoWS): Network-based ArcGIS Tools to Analyze Freshwater Ecosystems. Poster displayed at the Maryland Stream Conference, Carroll College, Westminster, MD, August 10 - 13, 2005 and at the Fourth Annual Conference on Statistical Survey Design and Analysis for Aquatic Resources, Corvallis, OR, September 7-9, 2005.
- ◆ Peterson, E.E., D.M. Theobald, M.J. Laituri, and N.S. Urquhart. Predicting the Likelihood of Water Quality Impaired Stream Reaches Using Landscape Scale Data and a Hierarchical Methodology: A Case Study in the Southern Rocky Mountains. Displayed at the American Water Resources Association GIS Specialty Conference, Nashville, TN, May 17-19, 2004 ; related posters displayed the Second Annual Conference: Statistical Survey Design and Analysis for Aquatic Resources, Corvallis, OR, August 11 - 13, 2003, and the Third Annual Conference on Statistical Survey Design and Analysis For Aquatic Resources, Colorado State University, Fort Collins, CO, September 10 - 11, 2004.
- ◆ Kneeland, M. and D.M. Theobald. Networked Catchments Based on Delineation and Flow Accumulation Methods. Displayed at the Second Annual Conference on Statistical Survey Design and Analysis For Aquatic Resources, Oregon State University, Corvallis, OR, August 11 - 13, 2003.
- ◆ Kneeland, M. and D.M. Theobald. Linking Watersheds to Streams: Using a Direct Measure of Flow to Model Hydrological Networks. Displayed at the First Annual Conference on Statistical Survey Design and Analysis For Aquatic Resources, Colorado State University, Fort Collins, CO, September 21, 2002.

- ◆ Kneeland, M. and N.S. Urquhart. Statistical Survey Design and Analysis for Aquatic Resources: External Collaborators of the CSU and OSU Programs. Displayed at the First Annual Conference on Statistical Survey Design and Analysis For Aquatic Resources, Colorado State University, Fort Collins, CO, September 21, 2002.

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