PRIORITIZED MONITORING FOR THE LAKE SUPERIOR BASIN
(Grant number: GL00E28801-0)

FINAL REPORT

January 2010

Prepared by:
George Host, Tom Hollenhorst, Terry Brown and Lucinda Johnson
Natural Resources Research Institute
University of Minnesota Duluth
Duluth, MN 55811-1442

NRRI Technical Report NRRI/TR-2010/03

Given this overall goal, the specific objectives for this project were to:

1) create a scalable system of fine-resolution, hierarchically nested watersheds across the Lake Superior basin;
2) quantify the natural environmental and human disturbance gradients for fine-scale watersheds;
3) use these gradients to provide supporting data for intra- and cross-agency monitoring and sampling designs;
4) identify reference (least impacted) and degraded watersheds and coastal regions within the Lake Superior basin;
5) develop tools that allow users to scale data appropriate to their sample domain and response variables;
6) disseminate project outputs via an updated LSDSS website.

METHODS and RESULTS

Objective 1: Create a scalable system of fine-resolution, hierarchically nested watersheds across the Lake Superior basin.

We used ArcHydro, a data model developed by ESRI (Maidment & Morehouse 2002), designed to manage and process watershed delineations and watershed summary information. Using flow direction and flow accumulation grids derived from elevation maps, stream networks were identified based on a minimum flow accumulation threshold. This allows for selectively delineating streams at either broad scales or very fine scales. Once the stream networks were delineated, flow direction was used to delineate the contributing area or sub-catchment for each stream reach between stream confluences (Hollenhorst *et al.* 2007).

The watershed delineation was based on a 10 m Digital Elevation Model (DEM) for the U.S. side of the Lake Superior basin, and 20 m DEMs on the Canadian side. Drainage enforcement, the process of removing spurious 'sink' data points from the DEM, was done using stream data from the National Hydrologic Data (NHD) for the U.S. portion of the basin and the Water Virtual Flow Seamless Provincial Data Set for the Canadian basin.

The ArcHydro model maintains hydrologic continuity, by assigning a unique "Hydro-ID" to each subcatchment, and identifying a downstream Hydro-ID for the next downsteam catchment. These attributes are also transferred to the corresponding stream reach and pour points. Because of this "nextdown" ID, it is possible, to accumulate information as the streams flow down the drainage network. For example, area-weighted means of relative values associated with each catchment (i.e. proportion or density) can be accumulated down the network.

The ArcHydro procedure resulted in the delineation of approximately 131,000 subcatchments in the Lake Superior basin (Figure 1). The average size of each subcatchment was 93 ha (230 ac). Subcatchments were combined based on their Hydro-IDs to identify watersheds emptying into Lake Superior. Approximately 7,000 Lake Superior tributary watersheds (hereafter referred to as simply 'watersheds') and the adjacent coastal areas that drain directly into the lake (interfluves)

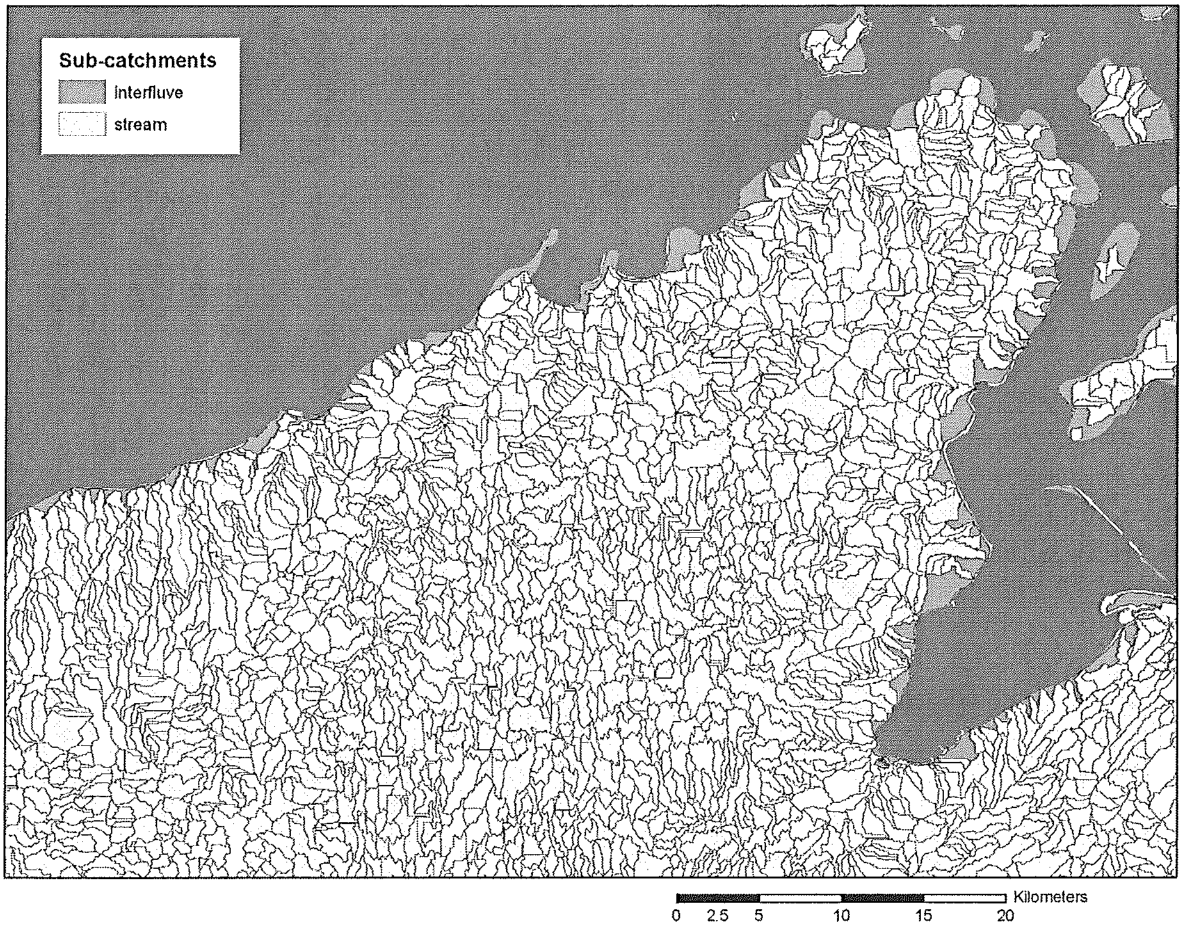

Figure 2. Detail of subcatchments for an area of the Bayfield Peninsula, WI.

were identified. (Figure 2). The GIS shapefiles for the watersheds and subcatchments can be downloaded at *www.nrri.umn.edu/lsgis2* or viewed at *http://gisdata.nrri.umn.edu/geomoose/GLNPO.html*.

Evaluation

We evaluated the ArcHydro delineation of watersheds on the U.S. side of the basin by overlaying the fine-scale watersheds with stream reaches from the National Hydrologic Database, and observing the correspondence between stream confluences in the NHD and the pour points of individual watersheds. We also overlaid selected ArcHydro linework on 1:24,000 Digital Raster Graphics and compared watershed boundaries with topography from the DRG.

Objective 2: Quantify the natural environmental and human disturbance gradients for fine-scale watersheds.

The source data identified for this analysis were derived from the Great Lakes Environmental Indicators project (Danz *et al.* 2005a,Danz *et al.* 2005b), which identified stressor gradients for watersheds of the Great Lakes basin, and Host et al. (2005), who developed *a priori* analyses for

Table 2. Road class weights for U.S. and Canadian highway systems.

Nation	Road Class	Description	Weight
Canada	Arterial	Arterial	1
Canada	Collector	Collector	1
Canada	Expressway / Highway	Expressway / Highway	2
Canada	Local / Strata	Local / Strata	1
Canada	Local / Street	Local / Street	1
Canada	Local / Unknown	Local / Unknown	1
Canada	Ramp	Ramp	3
Canada	Resource / Recreation	Resource / Recreation	1
Canada	Service	Service	1
Canada	Winter	Winter	1
U.S.	0	Limited Access	2
U.S.	1	Limited Access	2
U.S.	2	Highway	2
U.S.	3	Major Road	1
U.S.	4	Local Road	1
U.S.	5	Minor Road	1
U.S.	6	Other Road	1
U.S.	7	Ramp	3
U.S.	8	Ferry	0
U.S.	9	Pedestrian Way	0

U.S. point source data were obtained from the National Pollutant Discharge Elimination System permit system database, which includes industrial, municipal and other facilities that discharge pollutants into U.S. waters. Canadian point source data was obtained from Environment Canada's National Pollution Release Inventory.

Point sources were weighted based on the number and types of stressors potentially resulting from these sources. Stressors within the point source coverage included sewage, pathogens, PAHs, solvents, nutrients, salts and pharmaceuticals. A full listing of the stressors and their weights by SIC code is presented in Appendix I.

Stressor transformations and summaries

We evaluated a number of normalizing transformations for each variable, including log, ln, and arcsine transformations. The use of high-resolution watersheds resulted in a large number of zeros (i.e. non-occurrence of the stressor) for many of the variables. The best results were obtained using a $\log_{10}$ transformation of non-zero values (Appendix II). Each of the variables' data values (x) were transformed to $\log_{10}$ (x), using the minimum non-zero value of x to replace zero values. These transformed (x') values were then standardized, $(x'-\mu)/\sigma$, with μ and σ being the mean and standard deviation for all x', respectively. These standardized values (x'') were then normalized, (x''-min)/(max-min), with min and max being the minimum and maximum for all x'', respectively. Finally the five "x'" values for each variable in each watershed were summed and the summed values normalized again to give a single number – SUMREL - for each watershed. SUMREL ranges from 0.0-1.0, with 1.0 representing the maximum composite stress within a geographic coverage of interest. Note that this design allows stressor scores to be calculated for any given spatial extent – from local watersheds to an ecoregion, lake, or basin.

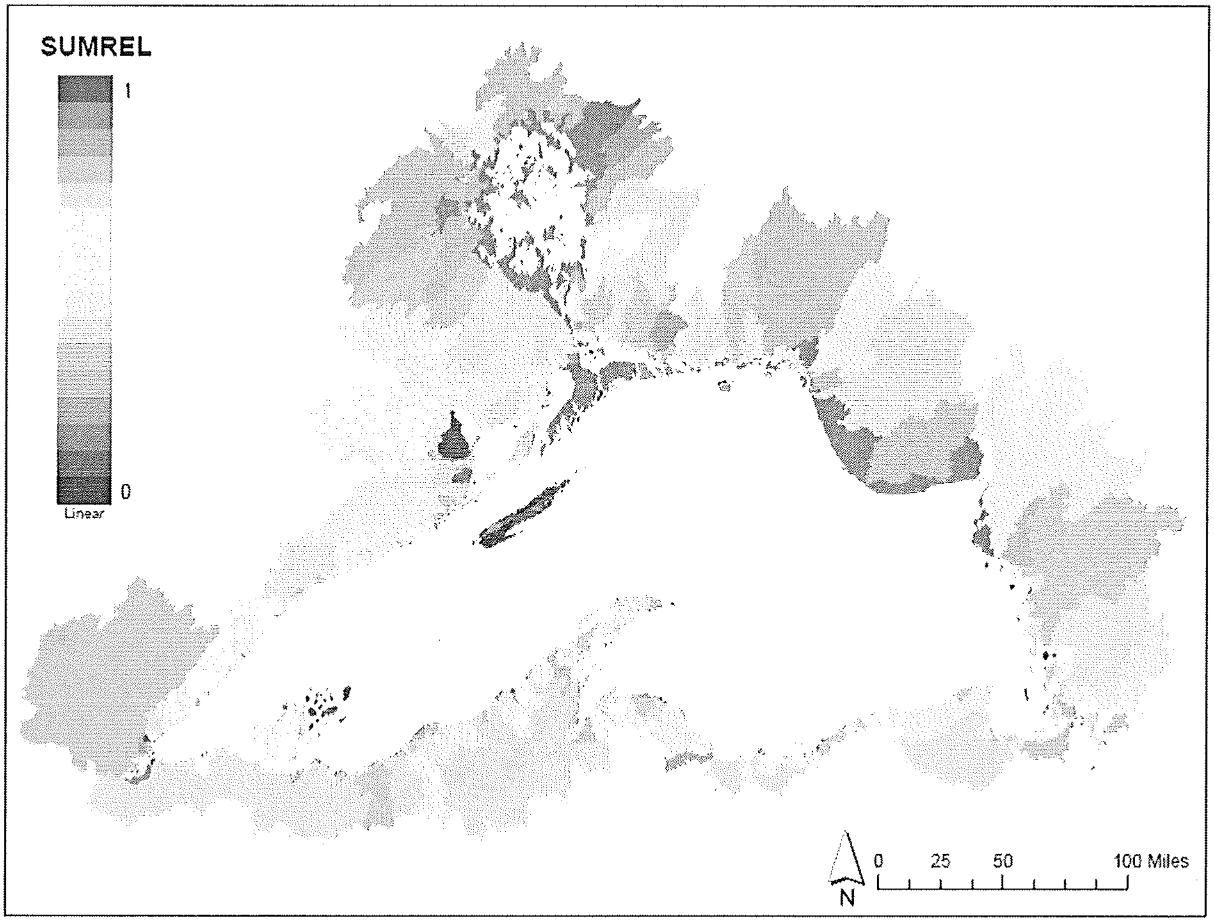

Figure 3. SUMREL stressor scores, summarized for Lake Superior tributary watersheds and interfluves. Red indicates higher stress based on the composite stressor index.

One of the key issues addressed in the Great Lakes Environmental Indicators (GLEI) project was identification of the appropriate extent for calculating a stressor gradient (Brazner *et al.* 2007). For example, across the Great Lakes basin, watersheds of the Erie and Ontario basin have much higher stressor scores than those of the Lake Superior basin, confounding an interpretation of reference condition. The Lake Superior basin itself has a broad range of watershed conditions. For this reason, we provide the ability to calculate SUMREL scores for user-defined extents, such as ecoregions or HUC watersheds. Figure 5 shows an example of stressor scores rescaled to three HUCs (St. Louis, Cloquet, and Beaver-Lester) along Lake Superior's north shore.

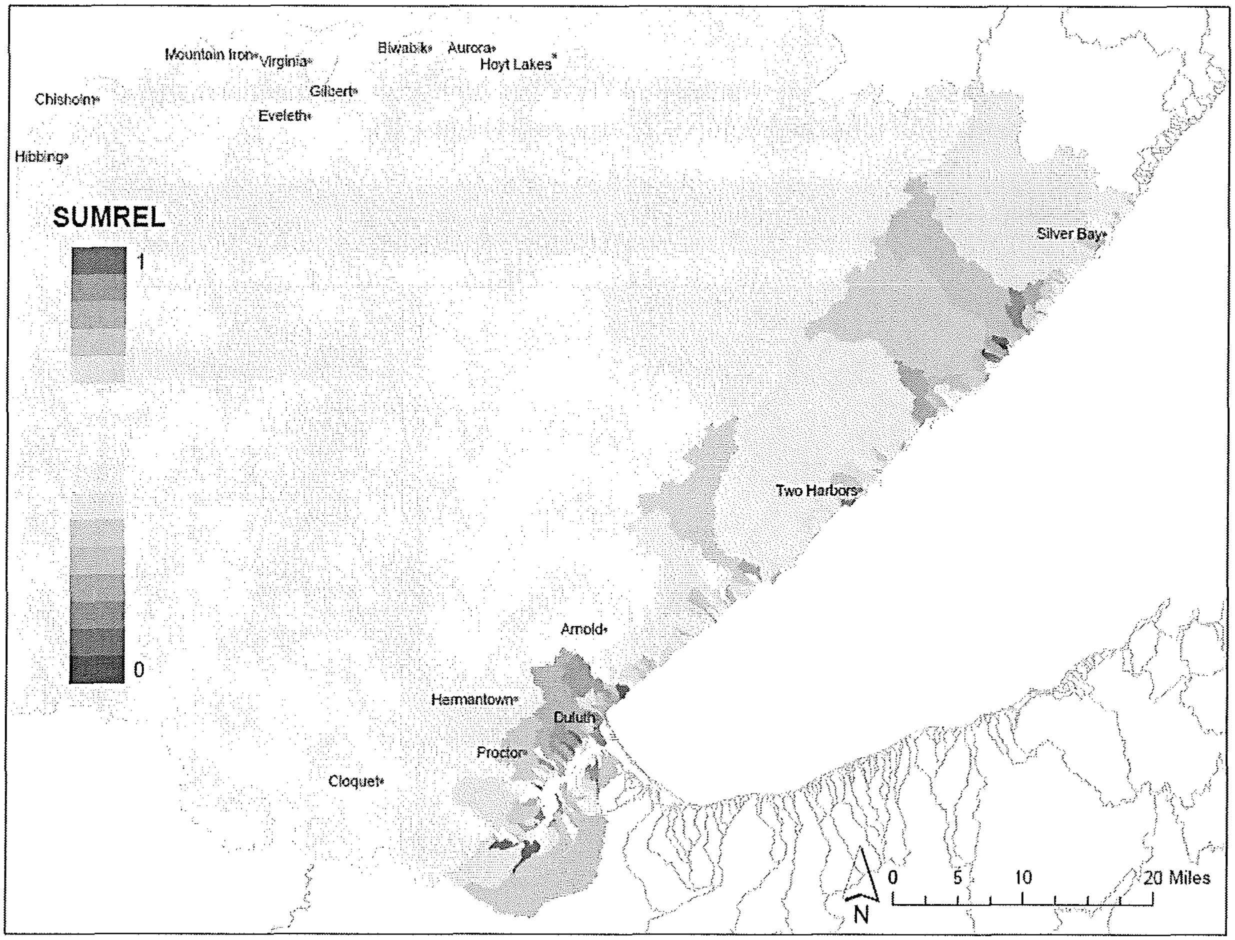

Figure 5. SUMREL scores rescaled to the St. Louis, Cloquet, and Beaver-Lester HUC watersheds.

Evaluation

Stressor gradient SUMREL scores were modified from methods from Host et al 2005. The SAS code used as the basis for the current work was originally developed under EPA Grant R828777: "Protocols for Selecting Classification and Reference Conditions" and was written as a generalized and transportable routine for calculating stressor scores for watersheds. The code contained subroutines for all data transformations and summaries, and had been used to identify reference sites in the St. Louis River AOC and the Lester-Amity watershed on Lake Superior's north shore. The transformation and summary routines were rewritten in the statistical language

• Lake shore: Generalized lake shore as a reference

The ISV also has a unique information tool – it allows a user to click on an individual catchment and retrieve information on the stressor types and magnitudes associated with that particular catchment. The tool identifies the subcatchment at the point where the user clicked (red), the set of upstream subcatchments which drain into the selected subcatchment (green), and the set of downstream subcatchments which lead to the lake (blue) (Figure 7). The ISV also displays subcatchment counts, area, percent agricultural land cover, percent developed land cover, population, and a weighted road index. These variables are summarized for the selected catchment, as well as all upstream, downstream, and combined catchments. Graphical indicators show the relative intensity of each of these factors. The application generates a simple visualization comparing the magnitude of each stressor relative to other catchments within the Lake Superior basin.

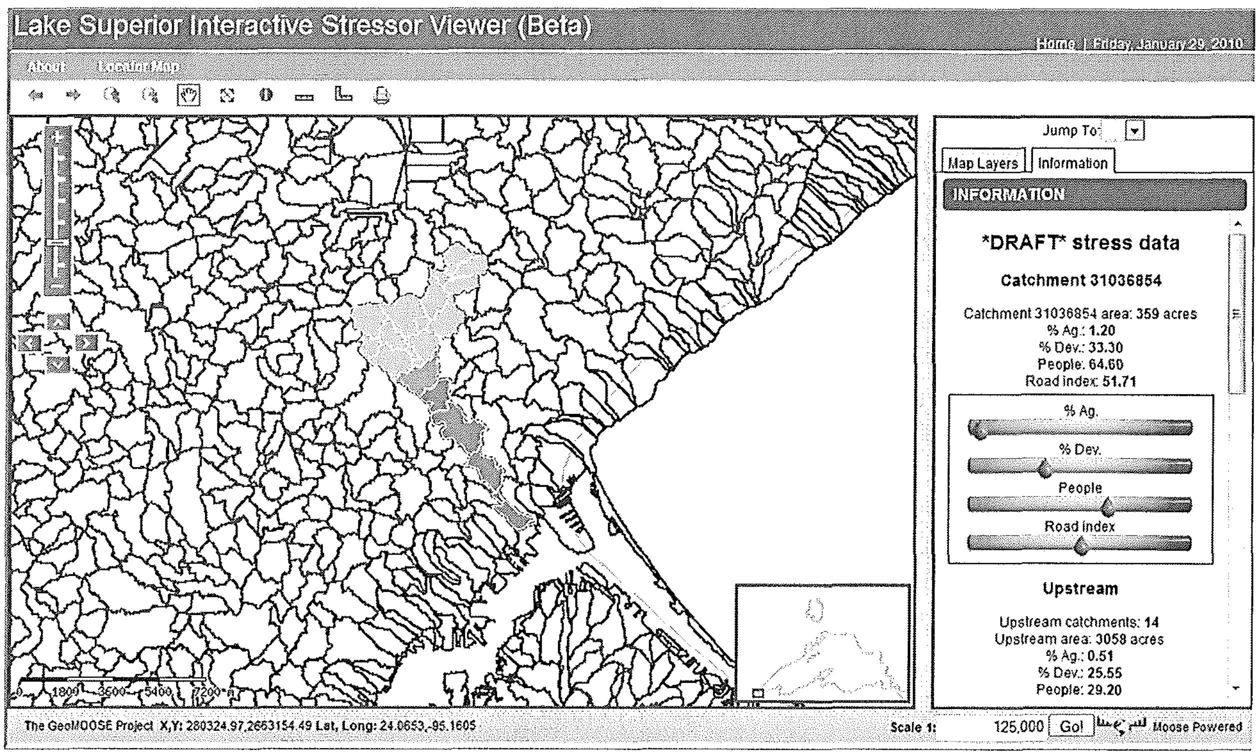

Figure 7. Tool for visualizing relative stressor data for a target catchment (red), as well as a summary of upstream (green) and downstream (blue) catchments.

Objective 6: Disseminate project outputs via an updated LSDSS website

The Lake Superior Decision Support Project was an early effort to develop GIS-based decision support applications focused on the Lake Superior basin. Funded by the USEPA Region 5 Coastal Environmental Management Grant Program through the Minnesota Department of Natural Resources, the project created synoptic databases of fundamental natural resource and infrastructure layers on the U.S. and Canadian sides of the Lake Superior basin. The website was designed for a wide audience, including local governments, regional planning agencies, resource management groups, educational and interpretive organizations and individual citizens. The

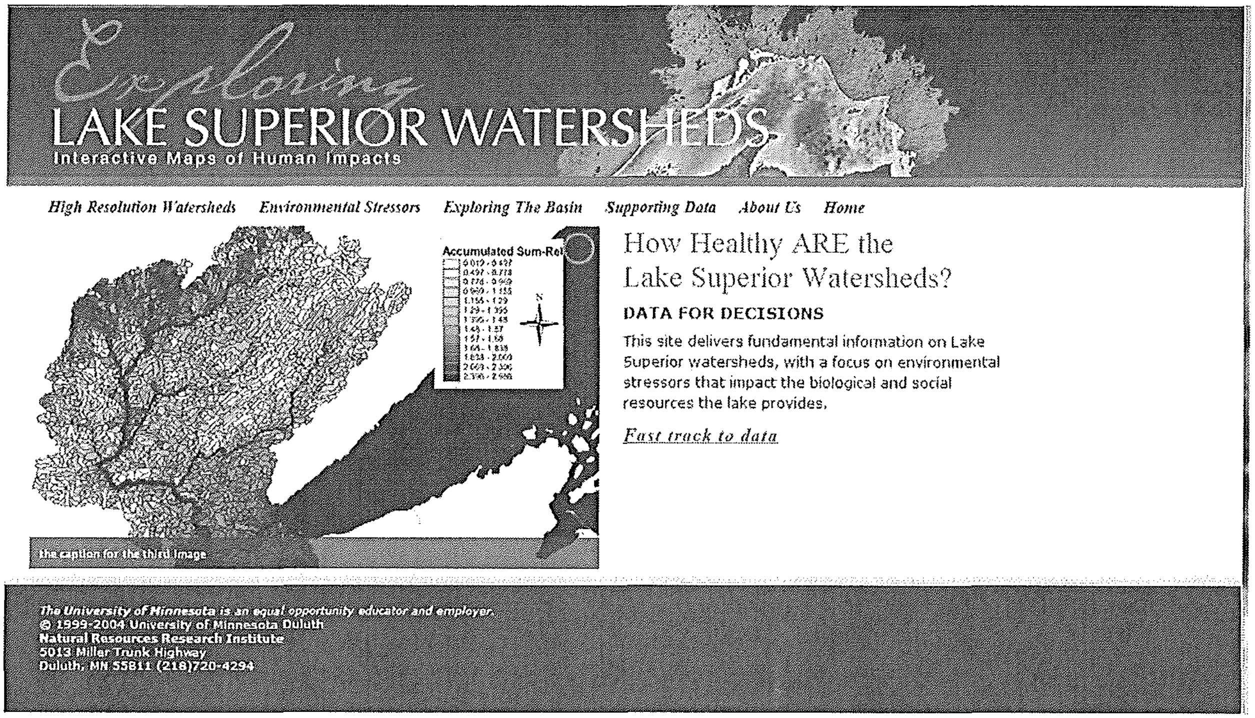

Figure 8. Homepage for "Exploring Lake Superior Watersheds"

The "Exploring Lake Superior Watershed's" site can be found at _www.nrri.umn.edu/lsgis2_

Summary

This project achieved several important objectives that will inform upcoming efforts related to the Cooperative Science and Monitoring Initiative (CSMI), the upcoming coastal wetland monitoring program, the EPA's Coastal Assessment, and other ongoing or proposed efforts in the basin. First, data encompassing the entire Lake Superior Basin were assembled in one location, and the spatial data were "harmonized" to enable mapping and analysis across the basin. This process involved cross-walking the unique classification systems for each of the data sets in the U.S. and Canada, and placing these in a common geographic coordinate system. Next, delineation of highly resolved subcatchments within the basin's tributary watersheds will enable managers and decision-makers to identify: 1) specific tributaries that account for disturbances in the coastal and nearshore zone of the lakes, and 2) specific locations within the tributary, as well as specific stressor types that may potentially result in impairments to that part of the river system. Identification of the location and magnitude of point and nonpoint source stressors will also permit identification of both reference and degraded conditions which will inform the process of prioritizing restoration and protection efforts. Furthermore, identification of "least impacted" areas within a watershed can serve as a benchmark for restoration efforts. Lastly, the development of tools to identify the stress gradient over a user-specified region (e.g., HUC, basin), can inform the design of future monitoring and assessment programs. Upcoming sampling in the Lake Superior Basin will benefit from the data and tools provided by this effort.