1999 Project Abstract
For the Period Ending June 30, 2001

FINAL REPORT

TITLE: Predicting water and resources health and sustainability
PROJECT MANAGER: JoAnn M. Hanowski
ORGANIZATION: Natural Resources Research Institute
ADDRESS: 5013 Miller Trunk Hwy, Duluth, MN 55811
WEB SITE ADDRESS: http://www.nrri.umn.edu/SUSTAIN/
FUND: Minnesota Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 1999, Ch. 231, Sec. 16, Subd. 12 (paragraph (a): 012e Predicting Water and Forest Resources Health and Sustainability)

APPROPRIATION AMOUNT: $300,000

Overall Project Outcome and Results

We developed a decision support model (SUSTAIN) that can be used by resource managers to predict future forest ecosystem sustainability. We used existing databases for forest birds, amphibians, aquatic insects and native plant communities and created indicators of sustainability and health for northern Minnesota forests. The model quantifies health for a forest stand and predicts sustainability at the landscape level. Indicator response (e.g., population of a bird species indicator) was calculated for; current forest condition, historical condition (based on range of natural variation (RNV)), and future conditions. The model output is interpreted in the context of whether the planned management will move the forest toward or away from sustainability (based on RNV). The model incorporates information for two ecological classification system (ECS) sections in northern Minnesota (Drift and Lake Plains and Northern Superior Uplands), 55 bird species, and 12 ecosystem types. Watershed models were developed for aquatic insects and fish but were not included in the final version of the SUSTAIN model due to computation difficulties. Indicators of amphibian health and sustainability were not included in the final model because we lack information required to predict their response to forest management.

Project Results Use and Dissemination

The model will be available to local and regional land managers to aid in decisions regarding forest management activities (downloadable from web site). Training sessions for the model were attended by representatives from major landowners (USFS, DNR and St. Louis County), as well as Minnesota Center for Environmental Advocacy, and The Nature Conservancy. Staff involved with this project presented results and information about the project on approximately 12 different occasions, including scientific meetings and meetings with resource managers. We also provided information on RNV to two landscape planning groups in northern Minnesota coordinated through the Minnesota Forest Resources Council.

Date of Report: July 1, 2002
LCMR Final Work Program Report
Project Completion Date: 30 June 2002

LCMR Work Program 1999

I. PROJECT TITLE: Predicting Water and Forest Resources Health and Sustainability

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Total Biennial Project Budget:

$LCMR:	300,000
-$LCMR Amount Spent:	300,000
=$LCMR Balance:	000

A. Legal Citation: ML 1999, [Chap. 231], Sec. [16], Subd. [12]. Benchmark and Indicators Predicting Water and Forest Resources Health and Sustainability

Appropriation Language

Carryforward Language: ML 2001, 1st Special Session, Ch. 2, Sec. 14, Subd. 18, paragraph (a): The availability of the appropriations for the following project is extended to June 30, 2002: ML 1999, Chp 231, Sec. 16, Subd 12(e) Predicting Water and Forest Resources Health and Sustainability $150,000 the first year and $150,000 the second year are from the trust fund to the University of Minnesota, Natural Resources Research Institute, to assess ecosystem health using indicators to develop models that incorporate landscape composition change.

B. Status of Match Requirement: No match required.

II and III. FINAL SUMMARY

Overall Project Outcome and Results

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IV. OUTLINE OF PROJECT RESULTS

Result 1. To identify and compile existing data for specific biota and physical parameters in three regions in Minnesota.

Study areas: Our original plan was to develop a "sustainability model" for three ECS (ecological classification system) subsections in the State. The subsections selected were North Shore Highlands, Chippewa Plains, and Rochester Plateau. This plan was changed because relevant analyses (e.g., range of natural variation calculations) were only available at the ECS section level. The section level is the step above the subsection level and involves significantly larger areas of the State. For example, the Northern Superior Uplands section which we have chosen for this project includes four subsections (Border Lakes, Nashwauk Uplands, Laurentian Highlands, and North Shore). The Northern Minnesota Drift and Lake Plains which we also developed a model for, has four subsections (Chippewa Plains, St. Louis Moraines, Pine Moraines and Outwash Plains, and Tamarack Lowlands). Because of this change, we increased the area that our models will be relevant for by several thousands of acres.

Due to this change, we did not complete a model for the Rochestor Plateau subsection as originally planned. We analyzed relevant biotic data from the southeast region of Minnesota and were unable to identify relationships between physical and biological data. For example, with current land condition (e.g., the large amount of land in agriculture land use) in this area, we were unable to identify relationships between land cover in watersheds and stream condition (based on aquatic insects and fish). In addition, bird reproductive success in this region is not related to landscape condition (e.g., patch size). Therefore, models to quantify and predict sustainability could not be developed without relevant biological indicators and their relationship to land condition. We concluded that an effort similar to what we accomplished for a large portion of the forested area of northern Minnesota could not be achieved for the southeast area with the same methods.

We identified and compiled relevant data for the biotic (amphibians, birds, fish and aquatic insects) and physical components (GIS data bases) required for the project. Data were compiled separately for each group and more specific details follow.

Amphibians: Little survey data exists for amphibians in Minnesota, therefore we compiled data from the primary literature and other publications to determine species-habitat relationships for Minnesota amphibian species and 2 turtles. We compiled a large bibliography and scanned many papers and books for appropriate information. Amount and quality of data pertaining to each species varied widely.

Birds: Several relevant data exists for breeding birds in both ECS sections. For this study we used forest bird monitoring data that has been collected by NRRI staff over the past 5-9 years. These data were chosen because: 1) they are linked directly to forest cover type and age; 2) they represent standardized counts conducted by qualified and trained observers; 3) relative abundance and probability of occurrence of over 90 species are available; and 4) it is the largest data base available for breeding birds in the upper midwest.

Aquatic insects and fish: We gathered existing macroinvertebrate data sets as well as some stream fish data sets. Both macroinvertebrate and fish data were less abundant for the Northern Minnesota Drift and Lake Plains section, but plentiful for the Northern Superior Uplands. Macroinvertebrate data sources included: 1) Northern Superior Uplandsstudy area collected by NRRI personnel; and 2) Northern Minnesota Drift and Lake Plains study area from Leech Lake Reservation and possibly Cass Lake Lab. Fish data sources included: 1) Northern Superior Uplandsstudy area from EPA (Duluth office) and MPCA; and 2) Northern Minnesota Drift and Lake Plains study area from USFS (Chippewa National Forest) and MnDNR. We gathered all data that were available.

Native ecosystems and range of natural variation. Another major task completed was defining "sustainability" and how it would be quantified for use in our models. We used the concept of natural range of variation in native plant communities as the basis for defining sustainability. In this sense, we infer that forest and water resources will be sustainable if we manage within the range of variation that they occurred on the landscape throughout time. Two steps were required to obtain this information. The first step, calculation of the range of natural variation for native plant communities was completed by Lee Frelich. The next step was to map locations and extent of native communities so that we were able to calculate the amount of area and location of the various native communities. This was completed for the Northern Minnesota Drift and Lake Plains study area by Dave Shadis and John Almendinger. The Northern Superior Uplands study area was mapped by personnel at NRRI. We used this definition of sustainability for the northern study areas where the map and range of variability has been completed.

In order to apply the range of natural variation calculations to determine the land area occupied by vegetation growth stages, a map showing the distribution of native ecosystem types is required. We used a statistical based modeling approach utilizing GIS, forest inventory, classified Landsat Thematic Mapper data and other vegetation plot data along with physical data such as soils, landform, climate and topography to predict the distribution of 8 native ecosystem classes in the Northern Superior Uplands ecological section. We acquired vegetation data from the following sources: the Superior National Forest, Minnesota DNR Resource Assessment, Minnesota DNR Non-Game Heritage Program releve plots, and classified satellite data from P. Wolter from the University of Minnesota, Natural Resources Research Institute. The physical data came from a variety of sources, including: Minnesota Soil Atlas, Geomorphology of Minnesota, USGS digital elevation models, and Zedex High Resolution climate data.

Analysis of current and future sustainability required that we map the current forest cover and composition. For public lands outside of the BWCAW data on current composition and age structure were derived from inventory data from the Minnesota DNR, counties, and the Superior National Forest. Inventory polygons were augmented with compositional information from an existing satellite based classification (P. Wolter, NRRI/UMD). Specifically, this was used to indicate mixed conifer and deciduous patches. Private non-industrial forest conditions were estimated from Forest Inventory and Analysis located on private lands. Sample density was approximately one point per 1200 acres. Area expansion factors were applied to estimate age and forest type. Private industrial forests, which account for approximately 3% of the NSU area, were not included at this time, although these data could be incorporated at a later date. Note that for areas outside the Boundary Waters Canoe Area Wilderness (BWCAW), stand age is estimated from tree ages, and may not always reflect time since disturbance, especially in the older age classes.

For the BWCAW, a number of data sources were used to derive age and composition. Age in the BWCAW is based on time since disturbance data. We integrated stand origin data based on Heinselman's stand origin maps (S. Friedman, University of MN, Dept. of Forestry) with maps of timber harvest areas within the BWCAW that occurred from the 1940s to middle 1970s to estimate forest age. This map was then combined with a Landsat based classification (P. Wolter, UMD/NRRI) to estimate species/cover type composition.

Budget: LCMR Budget: $49,000
Balance: $0

Result 2: To develop metrics for biodiversity, soil productivity, and water quality to assess ecosystem condition at different scales.

Amphibians: Amphibian species life history characteristics and habitat requirements were assembled into a database and reviewed by five regional experts. This information was used to develop habitat association indicators for the amphibian group. For example, existing data relating amphibians to different wetland types was used to develop metrics of species-habitat relationships.

When we attempted to incorporate species-habitat relationships into the modeling framework, we found that there was a paucity of spatial data depicting location of vernal pools, one of the primary woodland habitats for amphibian. We attempted to use historic wetland data and soils maps, in conjunction with derived statistical relationships between landforms and prevalence of vernal pools (Palik, et al. *in preparation*) to develop a map that reflected the probability of occurrence of vernal pools in an area. This information was critical in the development of the general model structure in result 3. Although work will continue on this aspect of the project in coordination with work being conducted by Brian Palik at North Central Forest Experiment Station in Grand Rapids, it was not in a stage that was useful for SUSTAIN model development. Therefore, we did not include amphibian indicators in the final SUSTAIN model.

Birds: Indicator species for the two northern study sites were selected. Our intent for this exercise was to identify bird species that would best reflect changes in the amount of specific cover types in the landscape. Indicator values were calculated for all bird species by cover type and age category (when data were available). With this process, we selected three bird species that had the highest indicator value for each cover type and age class. Thirty-two species were selected for the Northern Minnesota Drift and Lake Plains and 33 species will be used as indicator species for the Northern Superior Uplands study area.

Aquatic insects and fish. Our objective was to develop predictive indicators of stream condition for the Northern Superior Uplands and Northern Minnesota Drift and Lake Plains Sections. The approach that we took was to relate land use/land cover of watersheds to stream macroinvertebrate metrics. The candidate metrics for these analyses were: Ephemeroptera taxa richness, Plecoptera taxa richness,Trichoptera taxa richness, EPT taxa richness, intolerant taxa richness, proportion of total abundance of tolerant taxa, Hilsenhoff Biotic Index (modified), ratio of Hydropsychidae to Trichoptera (abundance), proportion of abundance of dominant 3 taxa, total insect abundance,clinger taxa richness, proportion of total abundance of clinger taxa, proportion of total abundance of predator taxa, proportion of total abundance of Chironomid taxa, Index of Biotic Integrity. We used land use/land cover variables (using GAP data base with classes combined); agricultural, barren, conifer, deciduous, grassland, open water, wetland, forest (conifer + deciduous).

In the development of the indicators we used a variety of statistical analyses to address the following questions. Correlations between metrics and land use (Which metrics show the strongest relationships with land use?). Selection procedure within multiple regression (Using the selected metrics from #1, what are the best multivariate relationships?). Selected individual simple linear regressions (Using information from #1 and 2, what are the simplest and best univariate relationships between metrics and land use?). Correlations between individual metrics (Are the individual metrics selected above telling us the same thing? Which metrics might be universal?). Bivariate plots (Are there thresholds of stream ecological condition for either macroinvertebrate metrics or land use?).

From these analyses we found thattTotal insect taxa richness, EPT taxa richness, intolerant taxa richness, clinger taxa richness, and IBI were significantly correlated with the most land use classes. These relationships were also in the same direction and made ecological sense. Following a sensitivity analysis, we decided that the bird and plant ecosystem indicators were more sensitive to changes in forest cover type and age compared to the fish and macroinvertebrate indicators. In essence, if we have forests that are determined to be sustainable as measured by plant communities and birds, we infer that the aquatic resources will also be sustainable. Therefore, we did not include any of the fish and macroinvertebrate indicators in the final SUSTAIN model.

Budget:	LCMR Budget:	$83,000
	Balance:	$ 0

Result 3. To evaluate the effects of land use changes on these metrics for a variety of management scenarios.

The structure of the general model that will predict forest and water resources sustainability was defined. The basic unit is a Population Metric (PM), a single number that represents the population of a single bird species, or amount of a particular forest cover type and age. The SUSTAIN application can interpret PM rule files, and we used it to predict the expected trends for bird species' abundance in response to changes in covertype. The current rules specify bird abundance in terms of cover types used by Lee Frelich in his work that calculated the range of natural variation of cover types in the two northern study areas.

We worked with Chad Skally of the Minnesota Forest Resources Council and created a more detailed version of the common format forest inventory data for RNV-SUSTAIN analysis in the Northern Superior Uplands and the Drift and Lake Plains. This comprehensive database for public forest lands now has more complete compositional information and consistent age data. This is significant because the RNV analysis relies on species composition and age structure for assessing current forest conditions. As we did for the Northern Superior Uplands, we used the new common format data along with FIA sample points to represent public and private forest land in the Drift and Lake Plains section in order to produce a more complete representation of current forest conditions. The RNV analysis feeds into the SUSTAIN model.

Budget:	LCMR Budget:	$71,000
	Balance:	$0

Result 4. To develop decision making models that can be used by land managers for landscape planning purposes.

Development of the GIS interface to run models and predict sustainability was completed. We chose ArcView with Spatial Analyst as the required user software for this application. The model was designed to be user friendly and requires a basic knowledge of ArcView. The model requires that the user input or select a number of candidate stands that will be harvested. After this step, the SUSTAIN model makes sustainability predictions for each bird and ecosystem type and successional stage indicators. Calculations are made for each forest stand for each indicator that is relevant to that stand. The score for each stand is scaled to a plus one to a minus one, indicating the deviation of the condition of the stand to future sustainability. Projections are made for bird and plant indicators immediately following harvest (age 0), twenty, and forty years after harvest. The stand scores can be sorted to determine which stands received the most positive scores. Harvesting these stands (positive scores) would move the landscape to a more sustainable condition. On the other hand, harvesting stands that had negative scores would move the landscape to a non-sustainable state.

Concise information, the stand score, as well as detailed output for each indicator in each stand is provided. Our intent is to provide the user with the information and not to dictate future harvest. The information output by the model provides an additional piece of information (in addition to stand age and condition) that land managers can use to plan harvests.

Budget:	LCMR Budget:	$58,000
	Balance:	$ 0

Result 5. To promote model use with outreach efforts and collaboration among multiple land-planning agencies.

A steering committee was established to aid us in making decisions regarding the projects outreach activities. The committee met twice and provided important advice on how to approach land use planners with the SUSTAIN model concept. One on one meetings were held with personnel from United States Forest Service, Minnesota Department of Natural Resources and St. Louis County. The objective of these meetings was to confirm that ArcView extension that reports the RNV impact of possible management options would fit with existing planning and harvest selection processes.

Training sessions to teach users how to implement the SUSTAIN model were held in June, 2002 on the University of Minnesota-Duluth campus. Three, one-half day sessions were held and were attended by representatives from St. Louis County, United States Forest Service, Minnesota Department of Natural Resources, Minnesota Center for Environmental Advocacy, and The Nature Conservancy. In addition to the training sessions, a general email was sent to various agency personnel when the final SUSTAIN model was posted on our web site.

Staff involved with this project have given several presentations and provided information for Minnesota Forest Resources landscape planning committees. In addition, JoAnn Hanowski has presented results of the project at 1) Society of American Foresters meeting, Stevens Point, WI; 2) North American Forest Ecology meeting, Duluth, MN, 3) Practical Silviculture in and Ecological World; Management Planning Strategies for Forest Stewardship Plan Preparers, Cloquet, MN. Mark White and George Host have presented information on the Range of Natural Variation calculations and mapping at the North American Forest Ecology meeting, Duluth, MN and in Finland.

Budget:	LCMR Budget:	$39,000
	Balance:	$ 0

V. DISSEMINATION: Information gathered in this project was presented to a variety of audiences including both public and private land use planners and the scientific community. The final product, a decision making model is available as a download from http://www.nrri.umn.edu/SUSTAIN.

VI. CONTEXT

A. Significance: Minnesota's forest and water resources are important contributors to the well-being of citizens located throughout the state. Maintaining these vital resources is a common goal among Minnesota's public because they provide a wide variety of benefits that contribute to the economy, local community and the natural environment. Measuring current, and predicting future forest and water resource health and sustainability is difficult because they are influenced by many factors (e.g., climate, land use change, land management practices, soil type, natural disturbances) and complex interactions among these factors. In addition, coordinated planning for multiple uses of these resources including resource management, tourism and recreation is difficult due to the existence of multiple regulatory bodies, existing land ownership patterns, and the inherent complexity of these ecosystems. Decisions regarding management of these systems is difficult because all of these factors need to be considered simultaneously. This situation mandates a need to develop novel approaches to assess current, and to predict future conditions in the economy, community and natural environment under different management regimes.

We can begin to understand this complex picture by identifying the role that each factor has and the scale on which they impact water and forest resource sustainability. Some of this information exists for Minnesota including a multiscale ecological classification of Minnesota (Ecological Classification System). Additional technological developments including geographic information systems (GIS), multivariate statistical methods, and spatially-explicit simulation models provide analytical capabilities not previously available. Basic research on animal species has provided important information on distribution of these species, their response to environmental stress, and their relationship to landscape features. Therefore, this combination of spatial databases, statistical methods, and biotic databases provides the potential to develop predictive models and decision making tools for assessing the response of organisms to a variety of management strategies and a method for measuring water and forest resource health.

Information for measuring forest and water resource health can be obtained directly by conducting a large number of individual measurements (a time-consuming and expensive procedure), or we can select a few important factors that have been shown to indicate ecosystem health. A large body of work has already been undertaken to quantify the response of sentinel organisms such as birds, amphibians and aquatic insects to a range of environmental conditions. Birds are key biological indicators of the health and stability of forest ecosystems and are relatively easy to study because their ecology is well known. Breeding birds also represent 60 to 70% of the terrestrial species biological diversity in Minnesota's forests and the highest species richness in North America occurs in Minnesota. Current knowledge indicates that birds have a strong link to the forest economy due to their insectivorous habits and declines in numbers would result in a reduction in forest productivity. Because amphibians use both land and water resources, information on this group will provide the crucial link between water and forest systems. The use of benthic invertebrates for environmental monitoring also has long history due to their reliability and effectiveness as environmental indicators. They are an integral part of riverine systems and play a large role in detrital processing, nutrient cycling and are also a food source for higher trophic levels such as fish and birds. Macroinvertebrates are being used by resource managers in environmental monitoring and as indicators of local scale site conditions.

Investigators in this study have already gathered a large data set on birds and aquatic insects in several Minnesota watersheds and are currently documenting changes in terrestrial and aquatic species due to a variety of forest and agricultural management practices. The proposed work will complement these efforts by adding species group information where it is currently lacking. In addition, several GIS data layers have been developed for Minnesota including forest cover classification, elevation, hydrography, soils, surficial geology and wetland classification. Using both existing and newly collected data, we propose to integrate tools such as geographic information systems, satellite image analysis, multivariate statistical methods, and simulation models to predict forest ecosystem health and sustainability using forest birds, amphibians and aquatic insects.

B: Time: Objectives will be completed during 1999-2002.

C: Budget Context: Researchers at the Natural Resources Research Institute have already gathered much of the information that will contribute to the database developed and used in this project. These include (but are not limited to the following: 1) Minnesota Forest Resources Council $120,000: Some baseline data on birds and aquatic insects as well as GIS information have been gathered for three watersheds in northern Minnesota. 2) Environmental Protection Agency $925,000: A project to develop aquatic macroinvertebrate indicator species models including work in the proposed site in SE Minnesota. 3) Minnesota Forest Bird Diversity Initiative $1,200,000: GIS forest cover data for the forested area of Minnesota and landscape models for breeding birds; 4) United States Forest Service $300,000: Trend and habitat information for breeding birds in the Chippewa and Superior National Forests, and $25,000: Effect of wetlands and forest harvest on stream insects. 5) Minnesota Sea Grant $94,828. 6) Lake

Superior Decision Support Systems, $515,000: Development of detailed GIS databases and decision support tools for the Lake Superior Basin. 7) USFS Great Lakes Assessment $100,000: Development and data visualization and decision support tools for Minnesota, Wisconsin and Michigan.

We have developed a good working relationship with several forest product companies and Counties in northern Minnesota over the past 10 years. The companies and Counties have cooperated with us on several projects by: 1) providing property to conduct studies, 2) conducting forest experimental manipulations on these study areas, and 3) assigning representative foresters and biologists to participate in design and implementation of experiments. For this project, all three of the major pulp and paper companies in northern Minnesota (Boise Cascade, Blandin-UPM and Potlatch) will cooperate on this project. Lake County is also participating on this project. The value of the cooperators in-kind investment in this project is about $30,000 each or a total of $120,000. This represents costs for land-use, forest inventory and other data, and staff time. Cooperators will also be part of a steering committee that will provide input to the investigators during all stages of the project. In addition, a subset of the cooperators will test the model during the development process.

The $300,000 allocation from LCMR was used to compile and analyze existing biotic data that to develop indicators to assess forest and water resources health and sustainability. This information was applied to develop a decision support program that will be used by resource planners across the State.

VII. COOPERATION:
George Host, Natural Resources Research Institute, contributed 15% time to the project.
Lucinda Johnson, Natural Resources Research Institute, contributed 20% time to the project.
Carl Richards, Natural Resources Research Institute, contributed 15% time to the project.
Mike Houser represented Potlatch Corporation, Cloquet, MN, Jim Marshall represented UPM-Blandin Company, Grand Rapids, MN, Tom Martinson represented Lake County Land Department, Two Harbors, MN, and Steve Earley represented Boise Cascade, International Falls, MN.

VIII: LOCATION: Lake, St. Louis, Itasca, Cass, Carlton, Itasca, Beltrami, Aitkin, Mille Lacs, Counties

The current SUSTAIN model is valid for the Northern Superior Uplands and N. Minnesota Drift and Lake Plains sections.