Environment and Natural Resources Trust Fund (ENRTF) M.L. 2015 Work Plan

Date of Report: 15 October 2014

Date of Next Status Update Report: January 2016

Date of Work Plan Approval:

Project Completion Date: June 30, 2018

Does this submission include an amendment request? **No**

PROJECT TITLE: Understanding Water Scarcity, Threats, and Values to Improve Management

Project Manager: Bonnie Keeler

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Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$234,000**
	Amount Spent:	**$0**
	Balance:	**$234,000**

Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 04a

Appropriation Language:
$234,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to model and map statewide water scarcity and abundance; assess water-related risks to industry, municipalities, and ecosystems; and quantify the economic values of changes in water quality and quantity in order to inform long-term water sustainability strategies. This appropriation is available until June 30, 2018, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Understanding Water Scarcity, Threats, and Values to Improve Management

II. PROJECT STATEMENT:
Minnesota is rich in water resources, but growing and diversifying demands on water have led to water stress, declining lake levels, and threats to water quality. Compared to other states, Minnesota still retains a comparative advantage in water resources needed to support healthy communities and economic development. In order to secure a long-term sustainable water future, managers need to be able to predict changes in the availability and quality of water, especially in response to emerging threats to water including climate change, land-use change, and development. Information is also needed on the economic value of our clean water resource.

Previous work on water sustainability in Minnesota includes visioning assessments (e.g. the state water plan and the water sustainability framework), and index models and planning tools (e.g. Environmental Quality Board water availability project). While these projects provide snapshots of water sustainability, they do not account for feedbacks between climate and land-use, rely on outdated climate models and data, and cannot be used to evaluate alternative scenarios that capture future threats to water sustainability. We propose to address these gaps through an integrated biophysical and economic analysis of water sustainability in Minnesota. Our proposed work includes the following three activities: 1) parameterizing and applying a statewide water balance model using downscaled climate data, 2) assessing threats to water sustainability and evaluating the impacts of those threats on water quality and quantity, 3) quantifying the economic impacts of changes in the availability of clean water to support recreation, health, industry, and other water-related services.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of*:* January 2016

Project Status as of: July 2016

Project Status as of: January 2017

Project Status as of: July 2017

Project Status as of: January 2018

Final project report: June 2018

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Statewide water balance and land surface modeling (Agro-IBIS modeling)
Description: Human activities have altered landscapes in ways that affect the fluxes of energy, water, and carbon between the atmosphere and the land surface. Understanding the relationships among these factors and how they are likely to change as a result of changes in land cover, land management, and climate is critical for responsive and sustainable management of water and land resources. For example, removing vegetation or converting from one land-use type to another (e.g. conversion of grassland or forest to agriculture) has been shown to significantly increase runoff and streamflow. Changes in land use can also affect the delivery of nutrients and sediment to surface waters and groundwater. The processes that dominate water fluxes between the land surface and atmosphere and fluxes of nutrients and sediments are complex and vary over time and space. Addressing questions about how changes in land use, water use, and climate will affect the amount and quality of water seasonally and spatially requires sophisticated modeling approaches.

We propose to use an adaptation of a dynamic global vegetation model (DGVM) that includes modules for vegetation canopy physics, soil physics and hydrology, phenology, and ecosystem biogeochemistry. The model, called Agro-IBIS, was developed specifically for the continental US and can represent common cropping systems represented in Minnesota such as corn, soybean, and wheat, along with natural ecosystems of grasslands, forests, and shrublands (Figure 1). Agro-IBIS allows for variable fertilizer inputs as well as irrigation and farmer management decisions.

Another key advantage of using a DGVM is the ability to use the model to understand the consequences for water quality and quantity due to specific interventions in different parts of the state. Climate, as well as the coverage of natural and managed ecosystem types (e.g. forests, crops, grasslands) varies across Minnesota. Whereas many other models do not directly simulate the growth of vegetation in their water balance calculations, the Agro-IBIS model will allow us to make predictions about changes in water fluxes (to evapotranspiration, surface runoff and groundwater recharge) and nutrient losses based on local climate, vegetation, and management in each pixel. The ability to directly simulate the biological and physical response of vegetation to changes in climate in individual grid cells will produce greatly improved water quantity and quality estimates over previous statewide models (e.g. 2008 LCCMR-Project 4a).

Our work will also take advantage of the latest advancements in future climate projections and incorporate these data into our water balance modeling. Agro-IBIS uses as input high-resolution climate data down-scaled from the most recent CMIP5 global climate model output (used in the 2013 IPCC AR5 report). These updated climate models have improved estimates for how water availability will change in the future, including variability in the seasonality and intensity of precipitation out to the year 2100. We will downscale global resolution climate data (currently at 1-3 degree resolution – about 100-300 km) to a 10 km resolution for input into the Agro-IBIS model. This downscaled climate data product will be useful for our water balance modeling in Minnesota, as well as for other analyses and models that rely on downscaled climate information.

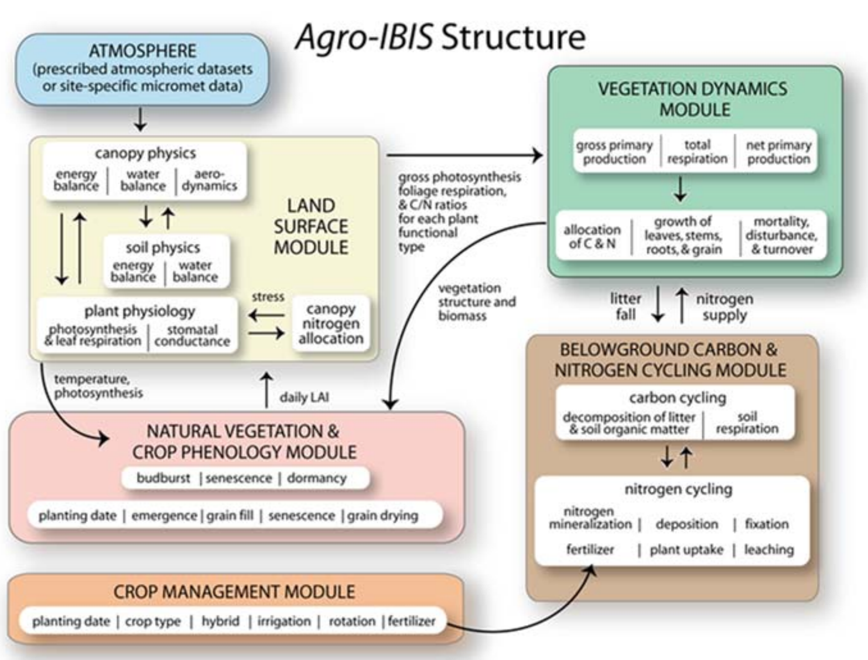

Figure 1: Schematic of the Agro-IBIS model. Agro-IBIS simulates multiple ecosystem processes within the natural biomes of forests, grasses, and shrubs, as well as crops including maize, soybean, and wheat.

We will use Agro-IBIS to simulate the growth and water use of vegetation at every grid cell statewide. Outputs of the model include water loss through evapotranspiration, drainage, and runoff for any time period of interest.

We will also use the model to simulate changes in nutrient fluxes as a function of changing agricultural or land-use practices. The model can also account for irrigation and municipal, domestic, and industrial water use and adjust water balance calculations accordingly.

In order to run the model in Minnesota, we will need to process soils, land use, and climate data to parameterize the model. As noted above, this activity requires downscaling global climate data from the most recent global climate models for use at finer spatial resolutions in Minnesota. Where available, we will also assemble current information on the location and consumptive rates of water users (irrigation, municipal consumption, and other water-intensive industries). Outputs of the model will include gridded maps of water balance, including quantification of streamflow and groundwater recharge and changes in water quality by sub-watershed.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 73,153**
Amount Spent: $ 0
Balance: $ 73,153

Outcome	**Completion Date**
1. Processed soils, land-use, and downscaled climate data needed for water balance calculations and model calibration. Where available, we will also assemble current information on the location and consumptive rates of water users (irrigation, municipal consumption, and other water-intensive industries).	*Fall 2015*
2. Gridded map of water balance, including quantification of streamflow and groundwater recharge by sub-watershed.	*Spring 2016*
3. Statewide water scarcity metric that will identify regions of annual or seasonal water stress that can be used for planning and assessment.	*Fall 2016*

Project Status as of*:* January 2016

Project Status as of: July 2016

Project Status as of: January 2017

Project Status as of: July 2017

Project Status as of: January 2018

Final Report Summary:
ACTIVITY 2: Water scarcity and threats assessment
Description: The outputs of the water balance model can be interpreted to identify regions of water scarcity or water stress. Quantifying and mapping water scarcity is crucial to managing shortages and finding solutions, such as identifying regions where it is important to re-use water or to anticipate tradeoffs among competing water uses. Periodic and localized scarcity of water is common, even in water-rich regions like Minnesota. Short term water scarcity can pose high economic and environmental costs, including lost economic development and investments in expensive infrastructure to transport or treat water. It is also important to consider both consumptive use of water as well as withdrawals, thus accounting for water that returns to a water source after use and becomes available for re-use. Evaluating water scarcity at high spatial and temporal resolution, and considering whether water demand is consumptive or re-usable, provides a more realistic estimate of water stress at any given location.

We will incorporate the results of the water balance modeling into an assessment of water scarcity which considers how metrics of scarcity change in the face of future threats. Water sustainability in Minnesota may change in the future as a function of changes in temperature and precipitation patterns, changes in the extent and intensity of water intensive industries, and changes in land use and land management such as new cropping systems or irrigation technologies. Agro-IBIS has the ability to assess the impacts of these threats on water balance calculations and water quality changes in individual grid cells and then these changes can be interpreted and mapped using different metrics of water scarcity.

We will also use the model to assess scenarios specific to different rates of water withdrawal and consumption. For example, we will estimate total water withdrawals for the five most important water use sectors: irrigation, livestock based agriculture, manufacturing, electricity production, and households and small businesses. Where data are not available at the local scale, we can estimate water use in the manufacturing and domestic based on data from county and state-level statistics and reports and allocated to sub-county grid cells based on geo-referenced population density and urban population maps. For example, water withdrawals for livestock can be computed by multiplying the number of animals per grid cell by the livestock-specific water use intensity. We can use these data to project impacts of likely future development.

We will then use the outputs of the Agro-IBIS model to map regions of water scarcity or depletion. Water depletion is defined as the ratio of consumptive water use by human activities to the amount of renewable freshwater available in a watershed on annual, seasonal, and inter-annual time scales. We will evaluate "seasonal depletion" to describe watersheds that exceed 75% depletion in any month of an average year and "drought depletion" to describe watersheds in which monthly depletion exceeds 75% within the historic range of water availability. In addition, we will evaluate the sensitivity of water scarcity to defining stress conditions at different levels of depletion. Water depletion as characterized here differs from other indicators of water scarcity in three important ways: temporal evaluation, spatial resolution, and consideration of consumptive water use rather than water withdrawals.

These maps of water scarcity or depletion, evaluated seasonally and spatially, will greatly improve previous estimates of water sustainability in Minnesota. Because the metrics are based on underlying biophysical and climate drivers represented in the Agro-IBIS model, we can simulate a wide variety of alternative futures and conditions that may affect water security. In addition to changes in water availability, we will also use the model outputs to identify regions where there are likely to be changes in water quality. The model structure and analytical framework allow for investigations into the tradeoffs between water quality and quantity statewide. Different regions may experience different future stressors for water sustainability, with some regions facing growing concerns about water quality, whereas other regions may experience water shortages. We will map these challenges to water sustainability statewide, including identifying regions facing dual stressors to both water quality and quantity.

Summary Budget Information for Activity 2:

ENRTF Budget:	**$ 97,869**
Amount Spent:	**$ 0**
Balance:	**$ 97,869**

Outcome	**Completion Date**
1. Maps capturing the location and impacts of threats to future water quality and quantity. Where there is uncertainty about water use or future threats, we will use scenarios to explore many plausible alternatives.	*Fall 2016*
2. Identification of key tradeoffs, risks, and vulnerabilities of water-dependent sectors and groundwater-dependent ecosystems (i.e. lakes, trout streams) based on modeled scenarios of future climate, land and water-use.	*Spring 2017*

Project Status as of*:* January 2016

Project Status as of: July 2016

Project Status as of: January 2017

Project Status as of: July 2017

Project Status as of: January 2018

Final Report Summary:
ACTIVITY 3: Economic valuation of water-related ecosystem services
Description: We systematically underestimate the value of water in decisions and planning because we lack an accounting of the full costs associated with changes in water quality and quantity. In order to evaluate how modeled changes in water quality and quantity affect the health, livelihoods, and economic development in Minnesota, new spatial datasets and models are needed that quantify and value the impacts of changing water quality and quantity on human wellbeing. We propose a comprehensive inventory of the value of water that can be used in cost-benefit studies, risk analyses, and return-on-investment calculations. The economic value of clean water includes costs associated with water treatment, lost property values, degraded recreational opportunities, beach closures and water-borne diseases, impacts to groundwater-dependent ecosystems, and water-related infrastructure investments. Many of these data are collected by state agencies, but have not been assembled and evaluated such that they can be used in spatial planning or integrated with alternative scenarios of water use (such as those generated by the model in Activities 1 & 2).

There are numerous approaches employed by economists to place an economic value on water-related ecosystem services. In brief, economists can ask respondents directly how much they would be willing to pay for a given improvement in water quality or quantity (stated preference methods). Alternately, economists can indirectly estimate the value of changes in the availability of clean water through observations of human behavior such as willingness to drive longer distances to visit areas of higher water quality (revealed preference methods). Additional approaches include estimating the costs associated with degraded water quality (e.g., sediment dredging, drinking water treatment), investing in water-related infrastructure (e.g. pipelines), costs associated with irrigation or other consumptive uses of water, or the costs associated with increased health risks due to contact or consumption of unsafe water.

There are five key benefits of clean water that are both policy-relevant and in need of more study in Minnesota: 1) the value of avoided health impacts associated with drinking water or contact with water through recreation, 2) the infrastructure and treatment costs required to maintain a clean and adequate supply of water for communities and industry, 3) the benefits associated with aquifer storage and groundwater-dependent ecosystems, 4) the economic values of lake and stream recreation, and 5) the value of clean water to support agricultural and livestock production. We will build on the water valuation framework introduced by Keeler et al. (2012, Figure 2) to collect cost data on these five sources of water values in Minnesota and integrate the results into models that related a change in water quality or quantity in a given region of the state to a change in a specific water-related value. The results will identify spatially where investments in improvements in water quality or quantity are likely to generate the greatest returns to public goods. Our analysis will also be the first comprehensive assessment of the value of clean water in Minnesota considering multiple sources of value (e.g. health, recreation, treatment and infrastructure costs).

Biophysical Modeling | Economic Modeling

Ecosystem Service	Change in Constituent	Endpoint	Change in Valued Attribute	Beneficiaries	Valuation Approach
Lake recreation	P	Lakes	Water clarity	Lake recreationists Lakeshore property owners	Recreational demand model Willingness to pay for recreation Hedonic pricing
Clean drinking water	N	Sourcewater treatment facilities	[Nitrate] above 10ppm	Treatment facility & taxpayers	Avoided treatment costs for nitrate
Clean drinking water	N	Groundwater	[Nitrate] above 10ppm	Well owners	Avoidance costs (bottled water) Remediation costs (treatment) Replacement costs (new well)
Clean drinking water	N	Drinking water (surface or groundwater)	[Nitrate]	Consumers, particularly at-risk subpopulations	Increased risk of disease * value of statistical life/health Avoidance costs
Commercial fisheries	N	Bays, estuaries, coasts	Fish and shellfish productivity	Fish and shellfish industry and consumers	Fishery rents Value per unit fish/shellfish
Coastal recreation	N	Ocean beaches and coasts	Extent, frequency, or intensity of algal blooms	Coastal recreationists	Willingness to pay for recreation Recreational demand model
Safe contact with water	N and/or P	Swimming beaches	Prevalence of aquatic pests and parasites	Swimmers	Avoidance costs Irritation/health costs
Coldwater angling	Stream temperature	Coldwater streams	Trout abundance or habitat area	Anglers	Willingness to pay per fish or per unit area habitat Recreational demand model
Avoided sedimentation	Sediment	Reservoirs, lakes, harbors, ports, channels	Amount of sediment	Taxpayers, commercial, navigation interests	Avoided costs (dredging)
Safe drinking water	Sediment Dissolved organic carbon (DOC)	Source water treatment facilities	[DOC]	Treatment facility & taxpayers	Avoided treatment costs (DOC can react with chlorine to form suspected carcinogens)
Safe drinking water	Toxins, bacteria, or other contaminants	Drinking water (surface or groundwater)	[toxin]	Consumers	Increased risk of disease * value of statistical life/health Avoidance behavior costs
Safe contact water	Toxins, bacteria, or other contaminants	Swimming areas	[toxin]	Swimmers	Increased risk of disease * value of statistical life/health Avoidance costs
Safe consumption fish and shellfish	Toxins, bacteria, or other contaminants	Recreational or commercial fishing endpoints	[toxin]	Consumers	Increased risk of disease * value of statistical life/health
Adequate water for irrigation, energy, drinking, or groundwater-dependent ecosystems	Water quantity (too little)	Rivers, aquifers, lakes or other endpoints	Change in water quantity or flow at a given endpoint of use.	Taxpayers, consumers, irrigators, recreationists, homeowners.	Avoided costs (pumping or storage), market price for hydropower or ag, hedonic pricing (change in water levels), lost recreation value (WTP, travel cost).
Flood risk reduction	Water quantity (too much)	Rivers, lakes, floodplains	Flooding that affects property or other valued land-uses	Taxpayers, homeowners, insurance companies	Avoided damages
Non-use value	Unspecified	All aquatic endpoints	Existence or bequest value	Non-users	Willingness to pay for existence or bequest value

Figure 2: The multiple ecosystem goods and services affected by water quality and quantity. For each benefit we list the biophysical changes that impact costs and benefits, the location and groups of beneficiaries affected by changes, and the economic approaches used to value each change. Table adapted from Keeler et al. 2012.

Summary Budget Information for Activity 3: **ENRTF Budget:** **$ 62,978**
Amount Spent: **$ 0**
Balance: **$ 62,978**

Outcome	**Completion Date**
1. Statewide inventory of water-related costs and benefits.	*Winter 2016*
2. Spatially-explicit economic values for changes in water quality and quantity based on alternative future scenarios developed in Activities #1-2.	*Summer 2017*

Project Status as of*:* January 2016

Project Status as of: July 2016

Project Status as of: January 2017

Project Status as of: July 2017

Project Status as of: January 2018

Final Report Summary: June 2018

V. DISSEMINATION:
Description: We expect the results of our work to be useful to the diverse groups of planners, regulators, agencies, and managers with an interest in water sustainability in Minnesota. We will make all data products and reports available to the LCCMR and complete all regular project reports. We will also collaborate with the Institute on the Environment's digital media platform ensia.com to create web- based resources to disseminate data and highlight key findings generated through project activities.

Project Status as of*:* January 2016

Project Status as of: July 2016

Project Status as of: January 2017

Project Status as of: July 2017

Project Status as of: January 2018

Final Report Summary: June 2018

VI. PROJECT BUDGET SUMMARY:
A. ENRTF Budget Overview:

Budget Category	**$ Amount**	**Overview Explanation**
Personnel:	$ 234,000	Funding is requested to support time for the three lead investigators (Twine- 1 month for 1 yr at $12,375, Brauman- 2 months for 2 years at $34,891, Keeler- 3 months for 2 years at

		$46,372) to supervise the project and lead research activities. Two full-time staff will support the work and report to the lead investigators. One full-time, 12 month appointment for a Post-doctoral Research Associate in the Department of Soil, Water, and Climate. This individual will generate new down-scaled climate data and parameterize and run the Agro-IBIS model to support Activity #1. Estimated cost: $60,375. One full-time, 16.5 month appointment for an Assistant Scientist to be based at the Institute on the Environment. This individual will assist with spatial data management, mapping and analysis, and new data collection to support proposed Activities #1-3. Estimated cost: $79,584.
TOTAL ENRTF BUDGET:	**$234,000**	

Explanation of Use of Classified Staff:

Explanation of Capital Expenditures Greater Than $5,000:

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 3.3 FTE's

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

B. Other Funds: N/A

VII. PROJECT STRATEGY:
A. Project Partners: N/A

B. Project Impact and Long-term Strategy:
The proposed work will deliver valuable information on the status, trends, and future condition of one of the state's most valuable resources. The project leverages existing state data and cutting-edge research and models to create new spatial maps and tools that will support more informed water management. The outcomes of the work will identify current problem areas, major threats to water sustainability by region, and potential risks to different sectors that rely on clean water. In addition, the project will provide in-demand information on the value of clean water – information that can be used in cost-benefit assessments, permitting decisions, and more informed analyses of tradeoffs. This project is a stand-alone effort and not part of a longer-term funding request, although it builds and expands on model development and applications in Minnesota and globally.

C. Funding History: N/A

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:
N/A

IX. VISUAL COMPONENT or MAP(S):
See attached visual component.

X. RESEARCH ADDENDUM:
See attached research addendum.

XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 2016, July 2016, January 2017, July 2017, and January 2018. A final report and associated products will be submitted by June 30, 2018.

Environment and Natural Resources Trust Fund
M.L. 2015 Project Budget

Project Title: Understanding Water Scarcity, Threats, and Values to Improve Management
Legal Citation: *M.L. 2015, Chp. 76, Sec. 2, Subd. 04a*
Project Manager: Bonnie Keeler
Organization: University of Minnesota
M.L. 2015 ENRTF Appropriation: $ 234,000
Project Length and Completion Date: 3 Years, June 30, 2018
Date of Report: October 10, 2014

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Water modeling***			***Water risks and scarcity assessment***			***Water valuation***				
Personnel (Wages and Benefits) Overall	$73,153	$0	$73,153	$97,869	$0	$97,869	$62,978	$0	$62,978	$234,000	$234,000
Personnel: Full-time, 12 month appointment for a Post-doctoral Research Associate in the Department of Soil, Water, and Climate. This individual will generate new down-scaled climate data and parameterize and run the Agro-IBIS model to support Activity #1. Salary is $50,000 plus $10,375 fringe (20.75%). Estimated total $60, 375											
Personnel: One-month salary equivalent for Dr. Twine to supervise the Agro-IBIS modeling and mentor the Post-docoral Associate. One month salary is $9,644 plus $3,134 for fringe benefits (32.5%). Estimated total $12,778.											
Personnel: Two-month salary equivalent, in each of the two project years for Dr. Brauman to complete the water scarcity analysis and risk assessments described in Activities #1-2. One month salary is $6,583 plus $2,140 for fringe benefits (32.5%). Estimated total $34,891.											
Personnel: Full-time, 16.5 month appointment for an Assistant Scientist to be based at the Institute on the Environment. This individual will assist with spatial data management, mapping and analysis, and new data collection to support proposed Activities #1-3. Annual salary is $43,000 per year plus $14,706 fringe (34.2%). Estimated total $79,584. Note that appointment length was reducedfrom the original proposal to accomodate for LCCMR-approved budget allocation.											
Personnel: Three-month salary equivalent, in each of the two project years for Dr. Keeler to complete the water quality risk assessment and water valuation work described in Activities #2-3. In addition, Keeler will serve as project manager, supervise the Assistant Scientist, and coordinate project activities and data dissemination. One month salary is $5,833 plus $1,896 for fringe benefits (32.5%). Estimated total $46,372.											
COLUMN TOTAL	**$73,153**	**$0**	**$73,153**	**$97,869**	**$0**	**$97,869**	**$62,978**	**$0**	**$62,978**	**$234,000**	**$234,000**