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Landuse Type

# Muskegon Futures:

Hydrologic Modeling

Muskegon Watershed Research Partnership

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#### Overview

The Muskegon River Ecological Modeling System (MREMS) project is providing unique insight into the impact of land use change on hydrology. The project combines models of land use change and stream routing with the new Integrated Landscape Hydrology Model (ILHM) that directly simulates the terrestrial hydrologic cycle. These linked models provide a means to evaluate a variety of complex hydrologic and ecological questions. Ultimately, the MREMS simulations can help address how land management decisions might respond to and help mitigate changes to streamflows, which are intricately linked to pollution loads and sediment fluxes. Over the past century streamflows have increased across much of the Midwestern United States; the Muskegon River Watershed (MRW) is no exception. During that period, temperatures and precipitation amounts have trended upwards, and great shifts occurred in land use patterns.

What has caused the trends in

streamflows, changes in land use, climate, or both? Answers to this question are critical for land maagement over the next century as large changes occur in these drivers.

MREMS simulations indicate that historical changes in the percentages of urban, forest, and agricultural cover are important contributors to the observed rising streamflows. Changes in land use, however, cannot account for all of the rising streamflow trend. Climate also plays an important role, as precipitation has increased, seasonal patterns have shifted, and temperatures have warmed across the region. Land use change projections for the 21st century indicate further increases in streamflow, even without additional increases in temperature or precipitation.

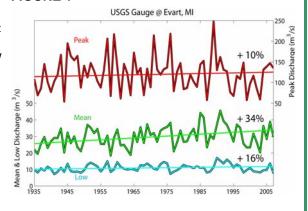
Projecting forward, the MREMS models can be used to investigate the combined effects of changes in climate and land use, and the impacts of management decisions across the MRW.

#### **Historic Streamflow Observations**

The US Geological Survey (USGS) has recorded streamflows within the watershed since the early 20th century. Over most of that period, flows of the Muskegon River and its major tributaries have been increasing. The USGS gauge at Evart experienced an increase of 34% in mean flow, 16% in low flow, and 10% in peak flow since monitoring began in 1935 (see FIG. 1). The magnitude of these trends is similar at other USGS gauges in the region.

Groundwater supplies about 85% of the flow within the MRW. Furthermore, most of the groundwater is discharged to streams, wetlands, and inland lakes, not directly to Lake Michigan. Thus, an increase of roughly 35% in annual stream flow means that groundwater recharge has increased by a similar amount.

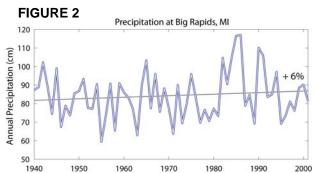
#### FIGURE 1



## **Climate Change**

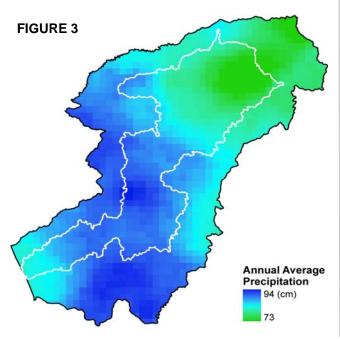
Observations across the watershed show long term trends of increasing temperature and precipitation during the 20th century. These two trends have altered the hydrologic cycle in the MRW in a variety of ways.

There have been significant trends in precipitation over the last century in areas that receive lake effect precipitation. For example, Big Rapids experienced a 6% increase in precipitation from 1940 to 2001 (see FIG. 2).



Changes in temperature have increased the growing season length over this period, which tends to increase the amount of water evaporated and transpired by plants. The influence of increased temperatures on snow compounds these factors, since snowmelt provides that largest source of annual recharge in Michigan.

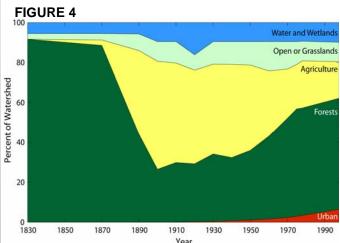
Lake effect precipitation is an important phenomenon in the MRW, as shown by the map of average annual precipitation from 1980-2006 (white outline is the MRW boundary, see FIG. 3). As expected, there is less precipitation farther from the lake. Also, the greatest precipitation is not adjacent to the lake but in the central portion of the watershed.



# **Landuse Change**

Land use has changed dramatically across the watershed over the past 120 years. The area was predominantly forested prior to settlement, then a majority of the land rapidly transitioned into agriculture as forests were cut to provide timber after the great Chicago fire. In the late 1930's, many marginal agricultural lands were abandoned and allowed to transition back to forests, a process that has continued to the present. The most recent data available, from 1998, show that forests covered roughly 56% of the landscape. Urbanization became an important factor after 1950 and now accounts for approximately 7% of the watershed (see FIG. 4).

These major alterations to the landscape have impacts to the hydrology across the watershed. However, it is difficult to directly evaluate such impacts without a set of models that predict the flows. The coupled set of codes predicts flows with minimal calibration, so forecasts are possible for a range of management scenarios.



# **Recharge Drives Streamflow**

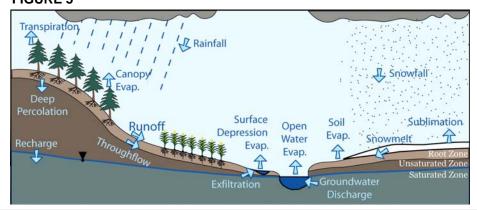
The vast majority of streamflow in Michigan is derived from groundwater (including shallow throughflow) rather than surface runoff. The dominance of groundwater inputs to the stream is due to relatively high permeability soils that allow rapid percolation of precipitation, and low relief landscapes that discourage overland flow. Recharge is effectively the amount of water left over from precipitation after overland flow and evaporation and transpiration — together called evapotranspiration (ET)— are removed.

It is thus critical to understand the processes that control the paths water takes in the hydrologic cycle once it is supplied as precipitation. Factors that influence recharge rates include the slope and permeability of soils, and the ET demand, which is controlled by climate, land cover, and soil moisture availability.

## **Integrated Landscape Hydrology Model (ILHM)**

A new code called the Integrated Landscape Hydrology Model (ILHM) was developed to evaluate influences of both land use and climate changes on the hydrology at scales that matter for management. ILHM simulates all major surface and near-surface hydrologic processes including ET, snowmelt, groundwater recharge, and stream discharge (see FIG. 5). Moisture is redistributed from precipitation to various subsurface and surface pathways, including canopy interception, snowmelt, surface depression storage, infiltration, evapotranspiration, throughflow, recharge and stream routing. Input for the model consists of climate data and any available information about the distribution of soils and glacial sediments.

FIGURE 5

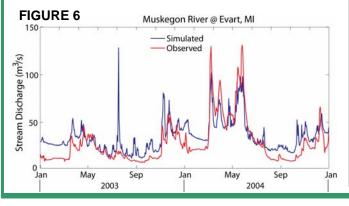


#### **Streamflow Simulations**

The accuracy of models is determined by how well they can simulate some measurable aspect of reality. Hydrologic models are commonly compared to observations at stream gauging stations, or water table elevations measured in wells (see FIG. 6). In addition to several USGS gauging stations, the MREMS team installed and monitored 11 stream gauging stations for several years of this project.

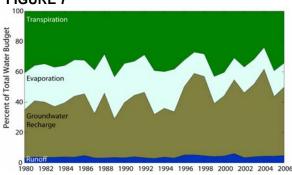
Within MREMS, ILHM calculates overland flow and groundwater discharge components of streamflow which are then routed using an existing watershed modeling tool called HEC-HMS. Comparison of the modeled streamflows with gauged values shows that, while not every peak is matched, overall the model does a good job simulating streamflows.

In particular the model simulates summer low-flow values (called baseflow) accurately. Simulating this period accurately is crucial for all other aspects of the linked set of ecological models, including fisheries and sediment transport modeling. It allows MREMS to reproduce long term water balances at basin USGS gauging sites within 5%.



# **Regional Water Budget**

#### FIGURE 7



Two dominant components of the water budget are evaporation (from water, wetlands, plants, and soil), and transpiration (the water taken up by roots and emitted to the atmosphere). Groundwater recharge based on the ILHM simulations accounts for approximately 30-40% of annual precipitation (see FIG. 7).

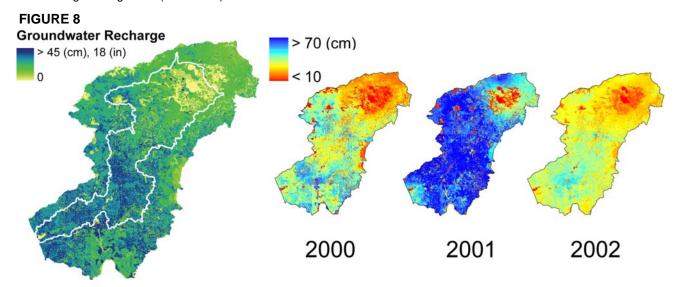
The smallest component of the water budget in this watershed is overland flow, with only 4-6% of annual precipitation. Because of the relatively sandy soils within the watershed, most of the water that falls on the land-scape percolates into the soil instead of flowing directly into streams. This result has significant implications for land use management.

Because precipitation varies each year, the total magnitude of each portion of the water budget varies greatly as well. For example, in some years average groundwater recharge across the watershed may be 4 inches, followed by 16 inches just two years later. Understanding these fluctuations is critical for water resources management decisions.

#### The Bottom Line...

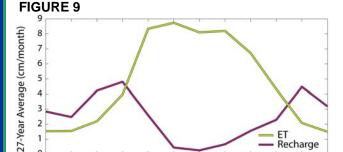
The ILHM results illustrate a dramatic difference between average annual recharge in the lower and upper portions of the Muskegon River Watershed. This 50% variation between the two regions is partly due to the enhanced snow-pack resulting from lake effect precipitation in the lower watershed. In addition, the upper watershed has a larger forested fraction and generally lower permeability soils, which both tend to decrease recharge rates.

The simulations also show dramatic differences in recharge from one year to the next. For example, conditions in 2001 allowed more than twice the recharge compared to the two adjacent years. This clearly illustrates the importance of accounting for year-to-year variations in recharge. It also demonstrates the importance of simulations that account for variable recharge through time (see FIG. 8).



# **Recharge by Season and Landuse Type**

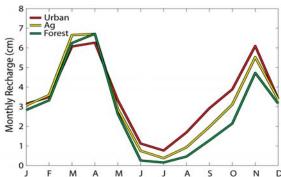
The ILHM simulations also illuminate critical differences in hydrologic processes related to land cover and climate variability. Approximately 75% of precipitation in this area of Michigan becomes recharge during leaf-off periods while there is almost no recharge during the growing season (May through September) when ET is the dominant component of the hydrologic cycle (see FIG. 9).



There are also large interannual variations in simulated flow across the 27 year simulation, with factor of three differences between years. The components of the water budget show interesting trends with increases in the proportion of recharge over the last 10 years, based on an assumed fixed land use condition.

Land use type also plays an important role in determining the amount of recharge based on the ILHM model results. The recharge rates are similar in agricultural and forested areas from late fall through winter, however the forest has approximately 10% less recharge during the growing season. This is mainly due to two factors, larger canopy interception and thicker root zones for water uptake and transpiration in the forests (see FIG. 10).





These differences indicate that reforestation would result in decreases in flow as reforestation occurs. However, this trend is complicated by urbanization, which increases the amount of streamflow.