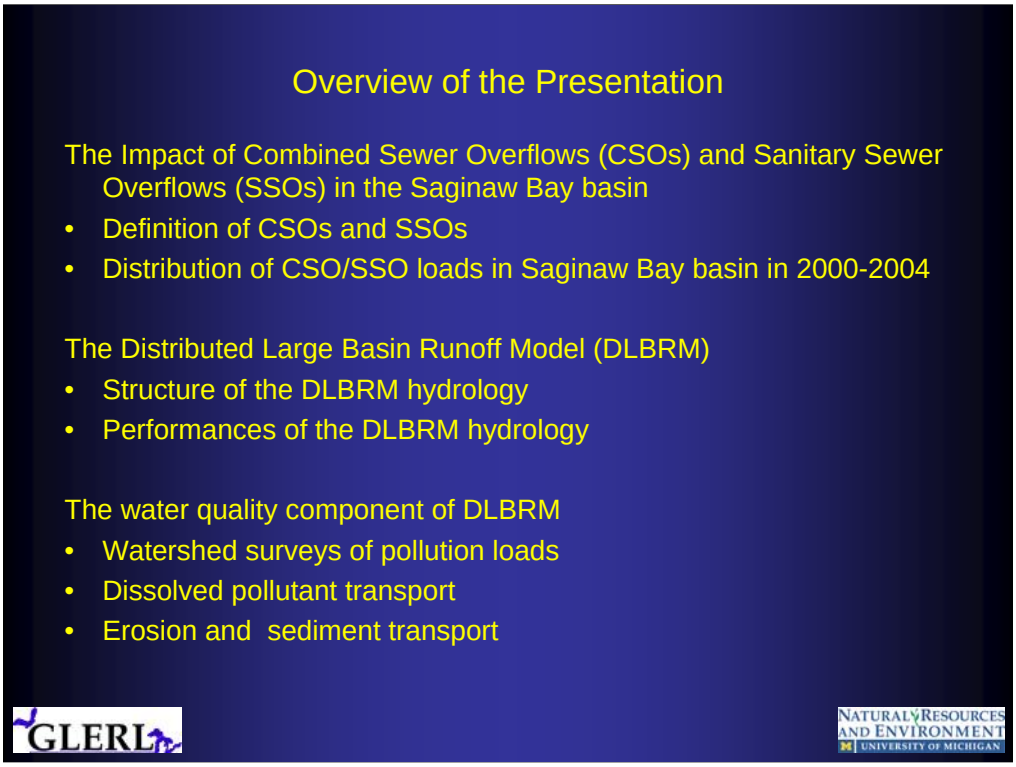
This seminar will look at the efforts that are currently underway at the Great Lakes Environmental Research Laboratory and at the School of Natural Resources and Environment of the University of Michigan to characterize the hydrology and water quality of the Saginaw Bay watershed. I need to mention that the results I am presenting today would not have been possible without the efforts by Tom Croley, who developed DLBRM later, and by Chansheng He, who developed the GIS tools for producing the spatial distribution of model parameters.



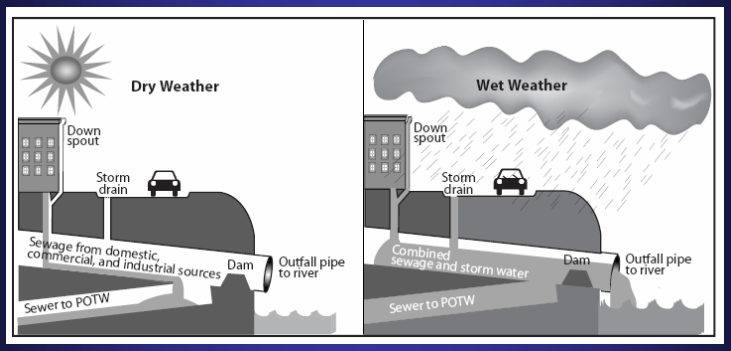
In the first part of the presentation, I will talk about the CSOs and SSOs in Saginaw Bay, looking at their location and contribution to the nutrient loads reaching the bay.

I will then talk about the DLBR, the model we are developing at GLERL for evaluating point and non-point source pollution in watersheds around the Great Lakes Basin, including Saginaw Bay.

I will first look at the hydrology component of the model and then at the water quality component.

What are Combined Sewer Overflows?

- A Combined Sewer System (CSS) is a wastewater collection system that conveys *domestic, commercial, and industrial wastewater and storm water runoff through a single pipe system* to a publicly-owned treatment works (POTW).

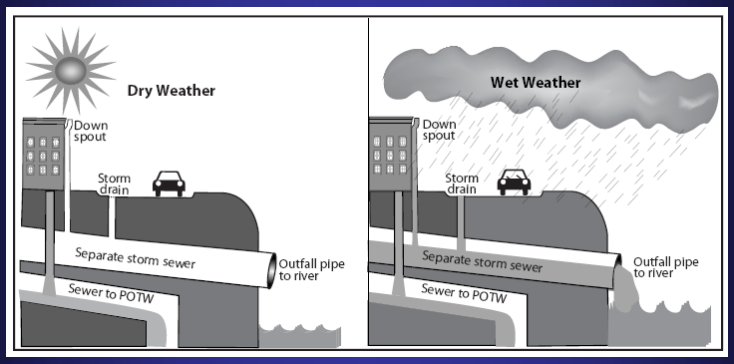


United States Environmental Protection Agency, 2004

So we have one single pipe system that collects both sewage and storm water and conveys it to the Waste Water Treatment Plant. During heavy storm or snowmelt, a lot of water storm water enters the pipe. Sometimes, the amount of sewage and storm water exceeds the sewer conveyance capacity. In these conditions this mixture could surge back into houses and streets. To prevent these unpleasant and unhealthy possibilities, some “safety valves” are placed in the system in forms of weirs (or dams). During normal operations, the level of the flow is lower than the height of the weir and all the sewage is conveyed to the POTW. On the other hand, the sewage never surge back into houses and streets because it exceeds the weir level before becoming dangerous. The excess flow is then spilled without treatment into nearby river or detention basins (Combined System Overflows).

What are Sanitary Sewer Overflows?

- A Sanitary Sewer System (SSS) is a wastewater collection system that conveys *domestic, commercial, and industrial wastewater, and limited amounts of infiltrated groundwater and storm water* to a POTW. Areas served by SSSs often have a *municipal separate storm sewer system* to collect and convey runoff from rainfall and snowmelt.



United States Environmental Protection Agency, 2004

Here we have one pipe system that collects only the sewage and a different one that collects the storm water. During heavy storm or snowmelt, the storm water is discharged directly or through a sedimentation basin, into to the river system. The raw sewage, on the other hand, is unaffected by the rain and follows the normal treatment. Sanitary sewer overflows take place in three instances:

1) The sewer system is old and damaged, in which case subsurface flow following a storm could infiltrate the broken pipes, causing a surge in the system. Separate sewer systems still have “safety valves” in the form of weirs and dams to prevent the formation of dangerous flow.
2) A similar dynamics could take place in the case that some pump or lifting mechanisms fails due to malfunctioning or power outages. In this case, sewage that accumulates in parts of the sewer system would be spilled into nearby rivers before becoming dangerous.
3) A pipe is broken during construction works.

It is probably clear that SSOs are normally more random than CSOs and do not require special treatment if not in the form improving functioning and backup systems for pumps and water lifts and maintaining the pipe network.

Water Quality Characterization of CSOs and SSOs

	Fecal Coliform (M/100 ml)	BOD_5 (mg/l)	TSS (mg/l)	TP (mg/l)	TN (mg/l)
Untreated WW/ Dry SSOs	6.4M* 1 M -1 B	120* 88 - 451	206* 118 - 487	5.8 1.3 - 15.7	33 11.4 - 61
Wet SSOs	500,000	42 6 - 413	91 10 -348	2.0	10*
CSOs	215,000 3 – 40M	43 3.9 – 696	127 1 – 4,420	0.7 0.1 - 20.8	3.6 0 – 82.1
Stormwater	5,081 1 – 5.23M	8.6 0.4 – 370	58 0.5 – 4,800	0.27 0.01 - 15.4	1.4 0.05 – 66.4
Treated WW	<200	30	30	1.65 0.07 - 6	3.95 0.5 - 32

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This table summarizes the typical values of major water quality parameters for untreated wastewater and dry SSOs, wet SSOs, CSOs, and treated waste water for the US. The values written in RED are the median values; the values in BLUE represent the typical range of values. The * sign labels values that were not reported by EPA, but that I estimated and used in the following analysis.

We can note the following:

- Water quality parameters have very large possible intervals, especially in terms of bacteria.
- Dry SSOs' quality is much worse than that of treated WW.
- Quality of CSOs does not seem too bad, but you should keep in mind that the volumes of water discharged during CSO's may be large, thus increasing the total load reaching the river system

4)Quality of CSOs is considerably worse than storm water's.

CSS are not built anymore because they are clearly inferior to SSS. However, until the damage CSOs cause to the environment was not clear, they were the common way to build sewer system and, consequently, they are very diffuse, especially in the Northeast, in the Mid-west, and in larger cities (e.g., Atlanta).

Replacing CSS with SSS is very expensive and involve extensive traffic disruptions, making it an unpalatable option. Thus, detention basins and storage facilities are often added to CSS to minimize the CSOs' impact.

CSO and SSO Events in Saginaw Bay (2000-2004)

	CSOs Events	Wet SSOs Events	Dry SSOs Events	CSOs Discharge (MGal)	Wet SSOs Discharge (MGal)	Dry SSOs Discharge (MGal)
Saginaw	126	85	48	3,766	68.5	14.7
AuGres	0	0	2	0	0	0.018
Pigeon	0	6	7	0	0	0.305

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Michigan Department of Environmental Quality, 2000-2005

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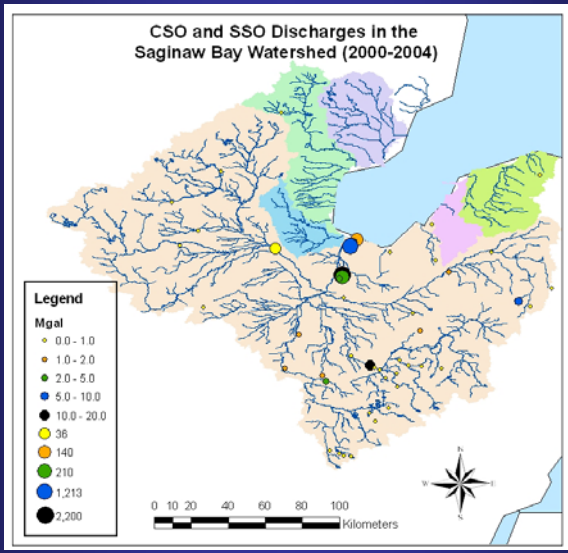
This table summarizes the CSOs and SSOs that took place in the Saginaw Bay watershed in 2000-2004, as reported by the Michigan Department of Environmental Quality. Note that it was not possible to identify the location of some of the SSO, so they are not included. However, the missing discharge contributions were almost negligible.

We note that although CSOs are numerically less than SSO, they account for almost 98% of discharges. We also note that most discharges take place in the Saginaw River watershed.

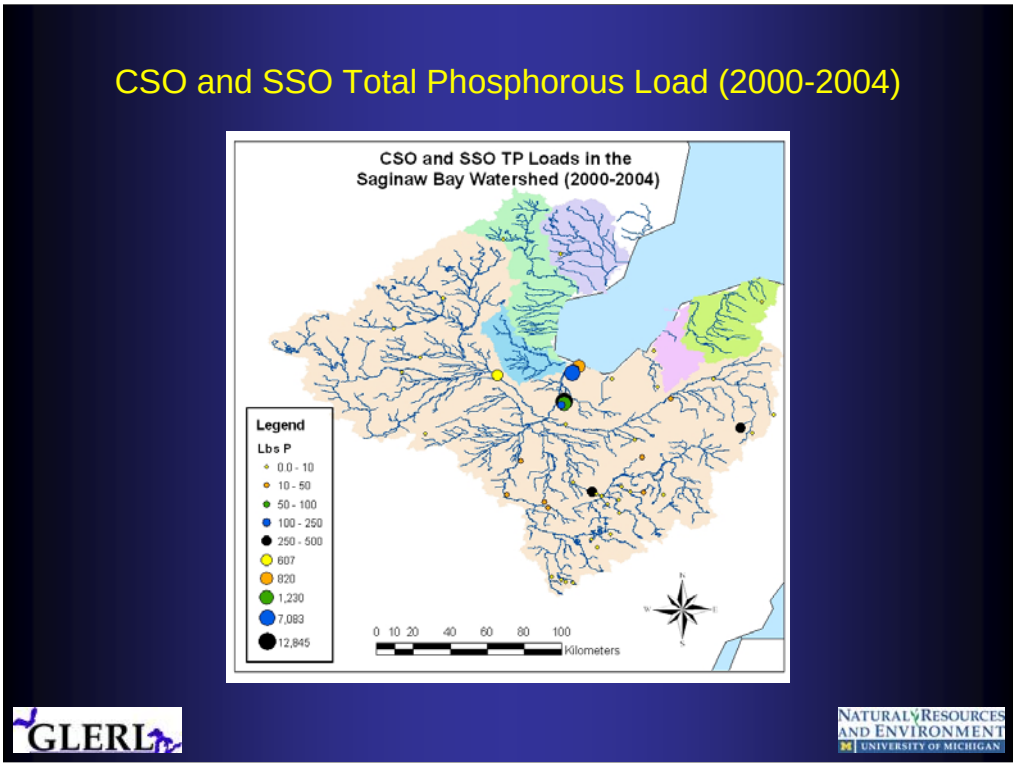
MDEQ's reports did not contain information on the quality of the released untreated water. Consequently, the average values from the previous table were used to derive the following slides.

MDEQ apparently measures, but does not publish, the quality of some of these discharges making possible to derive more specific relations and further improve this analysis.

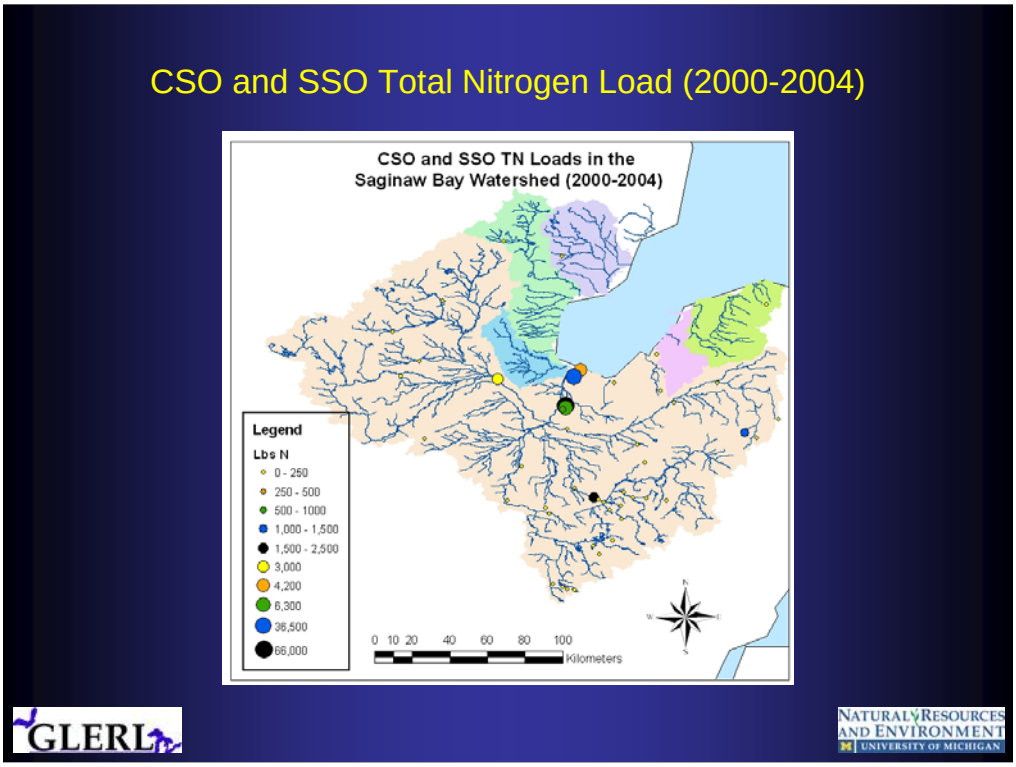
CSO and SSO Spatial Distribution (2000-2004)



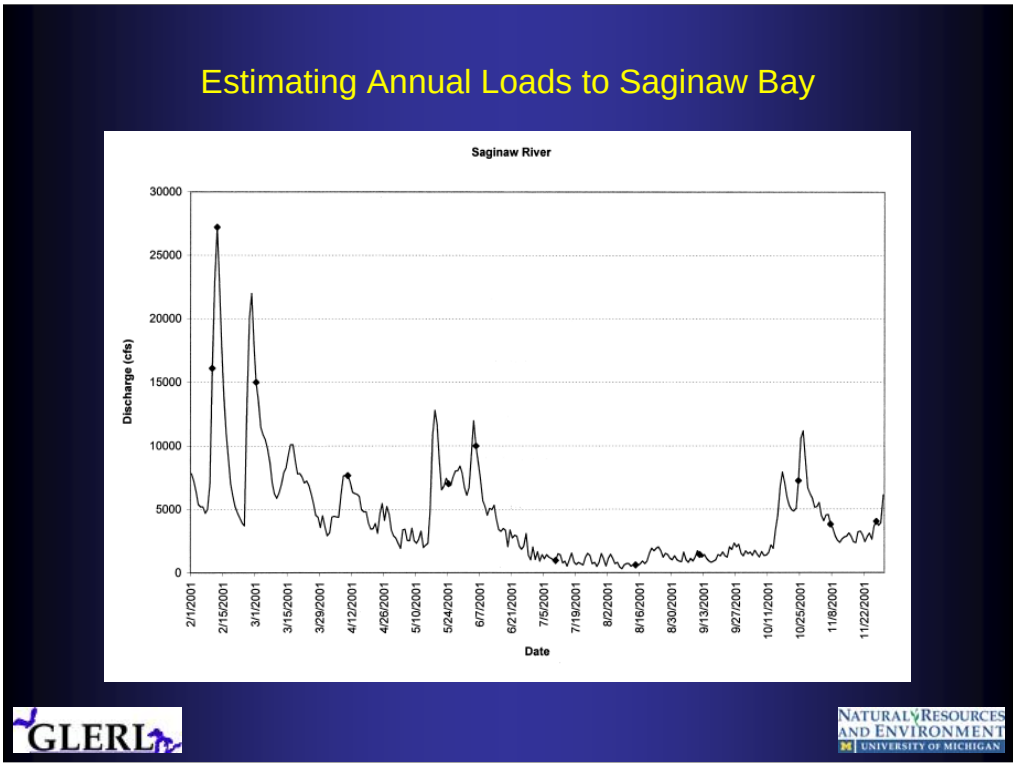
We see that the largest CSOs/SSOs discharges are generated by the Saginaw, Bay, Saginaw township, and Essexville. Midland and Flint add some small discharges.



Given the fact that CSOs dominates the discharges and that the water quality is estimated by using the same set of typical values, the contributions to the bay's TP load to the bay follow the same trend of the CSO/SSO discharges.



Same for Total Nitrogen



To understand the contribution of CSOs/SSOs to Saginaw Bay's pollution, we first need to estimate the total pollution load entering the bay. In this analysis we will consider only the load coming from the Saginaw River. This is appropriate because the Saginaw River basin is more than 70% of the entire watershed and hosts the major towns and almost all CSOs/SSOs.

The right way to estimate the pollution load carried by a river would require measuring the discharge and analyzing its quality at least once a day and maybe more often during floods. While measuring the discharge is relatively inexpensive after the appropriate facilities are built, monitoring water quality is much more expensive since it needs a lot of laboratory work.

The result of this is that while discharge is available at the USGS gage in Saginaw on a daily basis, water quality parameters are measured 12 times/year at Essexville by MDEQ and 3-4 times/year at Saginaw by USGS. In average this means one sample every 3-4 weeks. This frequency is too low for confidently assessing the pollution load just by multiplying the discharge times the average pollutant concentration derived from consecutive samples.

Fortunately, for many parameters (Suspended solids, Total Phosphorous, Total Nitrogen, etc.) there are good relations between the river discharge and the pollutant concentration that help us in estimating the pollutant load. These relations reflect the influence of precipitation on the generation and transport of these parameters: for example, suspended solids are mainly generated by soil erosion due to rainfall; sediments from agricultural soils and lawns are rich in Phosphorous; Nitrogen in fertilizers is mobilized by runoff.

Unfortunately, while these general relations between river discharge and the pollutant concentration vary from site to site, depending on basin parameters such as land use, river slope, presence of dams and reservoirs, distribution of cities and industries.

There are several methods for taking advantage of such relations. MDEQ uses the Stratified Beale Ratio. In this method, the Average Pollutant Concentration is derived by weighting pollutant samples with the relative discharge. The total uncorrected annual load is then determined by multiplying the average pollutant concentration times the total annual discharge. The final load estimate is obtained by multiplying the uncorrected load times a factor that takes into consideration the correlation between concentration and discharge. MDEQ estimates each year's annual load using only the 12 measurements taken during that year.

CILER instead uses all available measurements taken since 1989 both by MDEQ and USGS to develop a regression estimator of the pollutant concentration based on the river discharge. It then applies such relationship to the daily measurements of instantaneous discharge to estimate the pollutant concentration during each day. The annual load is obtained by summing up the products of daily discharge times the correspondent estimated pollutant concentration.

CSO/SSO Fraction of TSS Annual Load to Saginaw Bay

	CSO/SSO CILER (Met. Ton)	Total Load MDEQ (Met. Ton)	Total Load CILER (Met. Ton)	Fraction of MDEQ load (%)	Fraction of CILER load (%)
2000	322	--	110,757	--	0.29
2001	436	202,957	171,717	0.21	0.25
2002	517	180,572	185,206	0.29	0.28
2003	82	47,411	62,405	0.17	0.13
2004	486	349,882	306,405	0.14	0.16

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Here we compare the estimated Total Suspended Solids loads produced by CSOs/SSOs with the TSS loads carried by the river.

First, we can observe that the MDEQ and CILER methods are very close (<10% difference) despite the different approach (MDEQ estimate was not available for 2000).

Second, we see that CSOs/SSOs contribute for around 0.3% to the Saginaw River TSS output.

CSO/SSO Fraction of TP Annual Load to Saginaw Bay

	CSO/SSO CILER (Met. Ton)	Total Load MDEQ (Met. Ton)	Total Load CILER (Met. Ton)	Fraction of MDEQ load (%)	Fraction of CILER load (%)
2000	1.78	--	278	--	0.64
2001	2.43	642	412	0.38	0.59
2002	3.02	513	416	0.59	0.73
2003	0.59	345	174	0.17	0.34
2004	2.98	724	660	0.41	0.45

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Here we compare the estimated Total Phosphorous loads produced by CSOs/SSOs with the TP loads carried by the river.

First, we can observe that the MDEQ and CILER methods are very close, but less than for TSS(<25% difference). Again, MDEQ estimate was not available for 2000.

Second, we see that CSOs/SSOs contribution is higher than for TSS, but still less than 1%.

CSO/SSO Fraction of KN Annual Load to Saginaw Bay

	CSO/SSO CILER (Met. Ton)	Total N CILER (Met. Ton)	Kjeldahl N* CILER (Met. Ton)		Fraction of KN load (%)
2000	9.17	7,870	2,910	--	0.31
2001	12.51	11,528	4,270	--	0.29
2002	15.49	11,746	4,350	--	0.36
2003	3.12	5,341	1,978	--	0.16
2004	15.36	16,804	6,224	--	0.25

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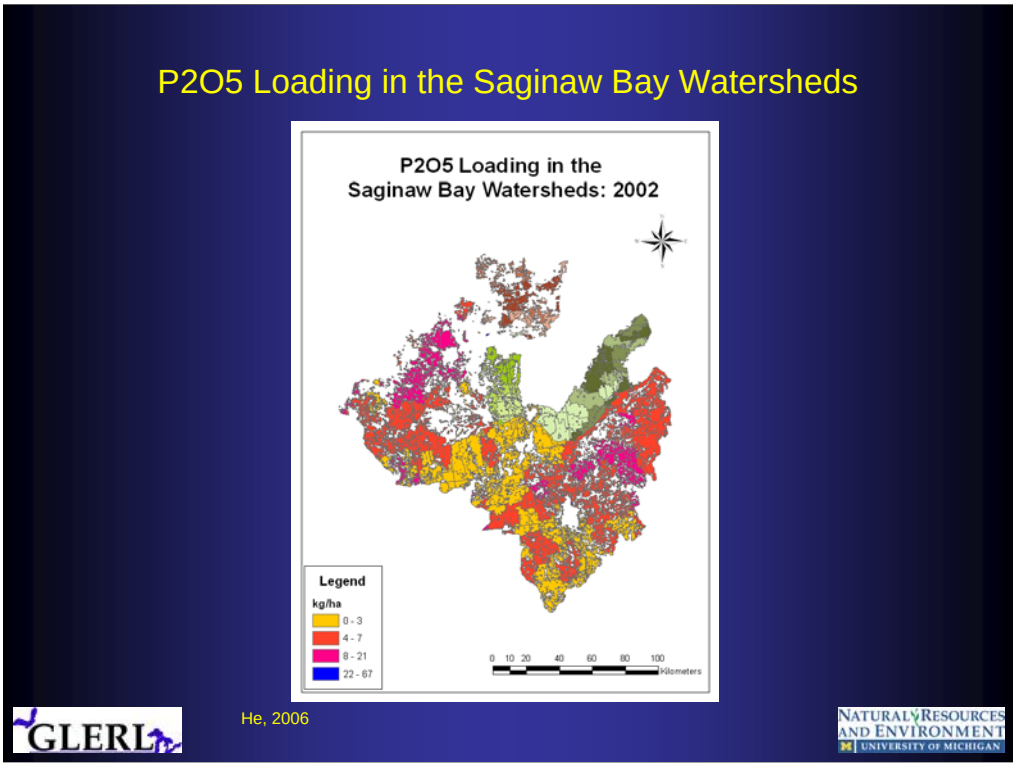
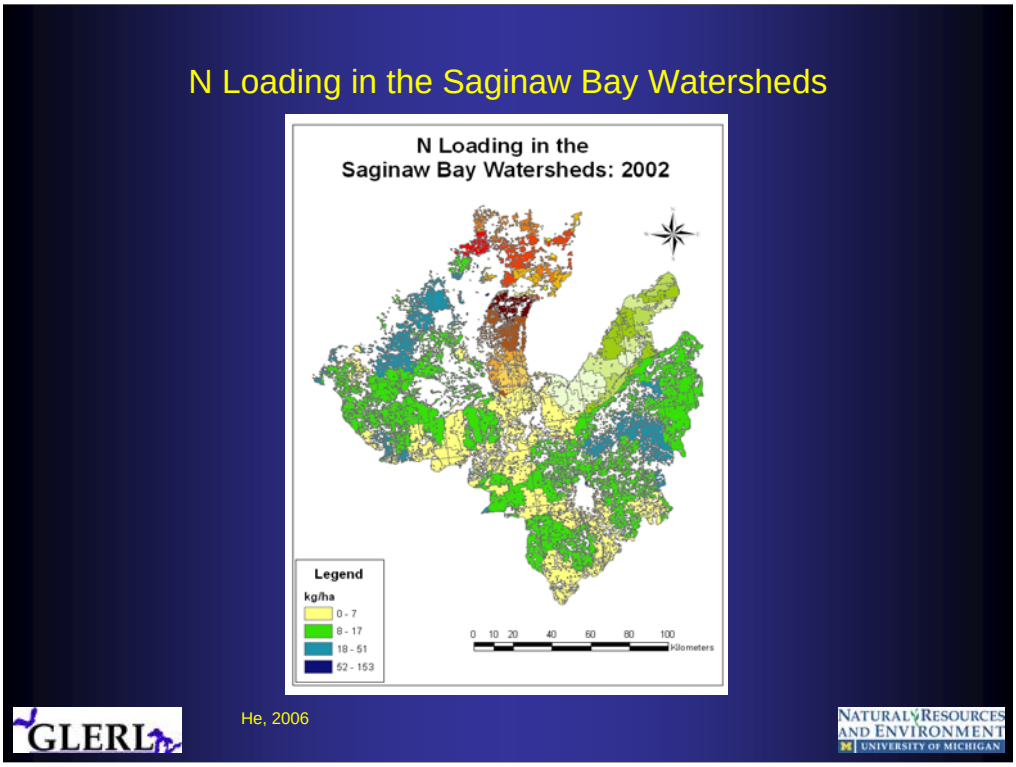
Here we compare the estimated Kjeldahl Nitrogen loads produced by CSOs/SSOs with the KN loads carried by the river. TKN is the sum of organic nitrogen; ammonia, NH3 and ammonium, NH4+. Total Nitrogen is the sum of TKN and Nitrites and Nitrates.

MDEQ did not estimate the Nitrogen load, so we cannot compare. CILER developed a regression estimator of the Total Nitrogen concentration from river discharge. KN is roughly estimated from TKN using a fixed ratio. This estimate is not precise and is used only for comparison purposes.

Even in this case, CSOs/SSOs contribution is less than 0.3%.



Dr. He of Western Michigan University estimated P2O5 (Phosphate) loadings in the Saginaw Bay watershed from manure and fertilizer application data.



TN loadings in the Saginaw Bay watershed from manure and fertilizer application data.

These are maps of pollutant applications in the bay watersheds. However, only part of this loads will reach the bay. To know what fraction of pollutants reaches the bay we need to use models.

Watershed Hydrology and Water Quality Models

- Mathematical models of watershed hydrology and water quality are necessary for:
  - Evaluating the contribution of different sources to the watershed pollutant outputs
  - Predicting hydrology and water quality response of the watershed to changes in population, land use, and climate
  - Evaluate the impact of alternative remediation strategies
- Mathematical models of watershed hydrology and water quality are based on:
  - Physically based and empirical models regulating the horizontal and vertical transport of water and pollutants in the watershed
  - Surveys of point and non-point pollutant sources in the watershed

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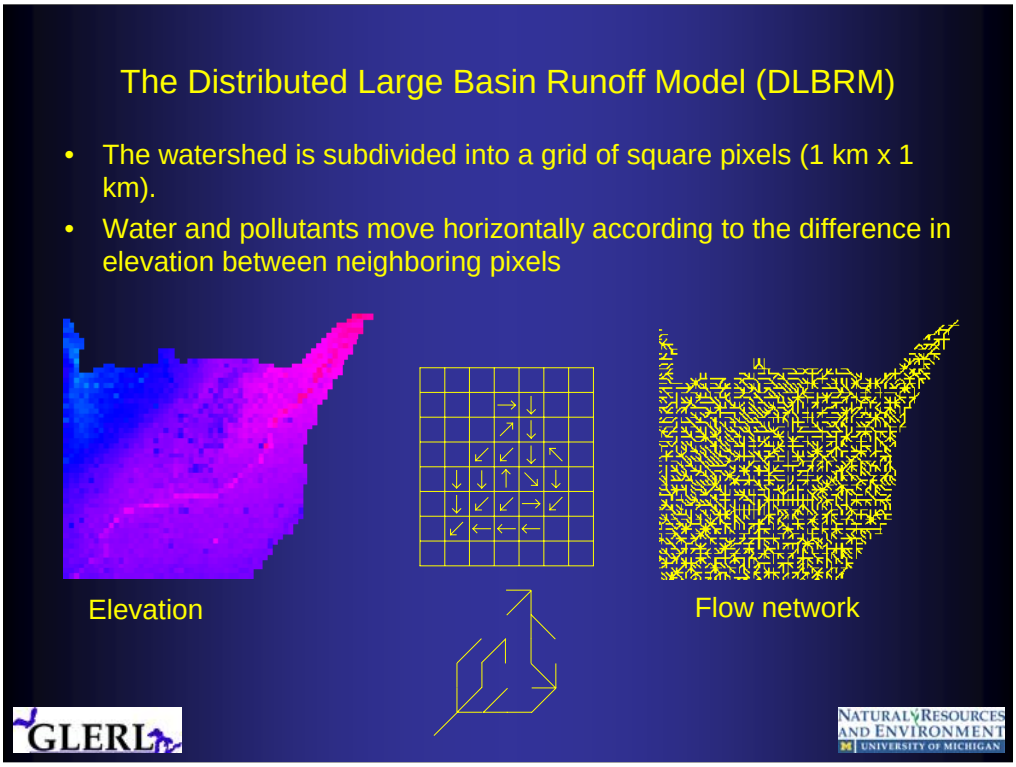
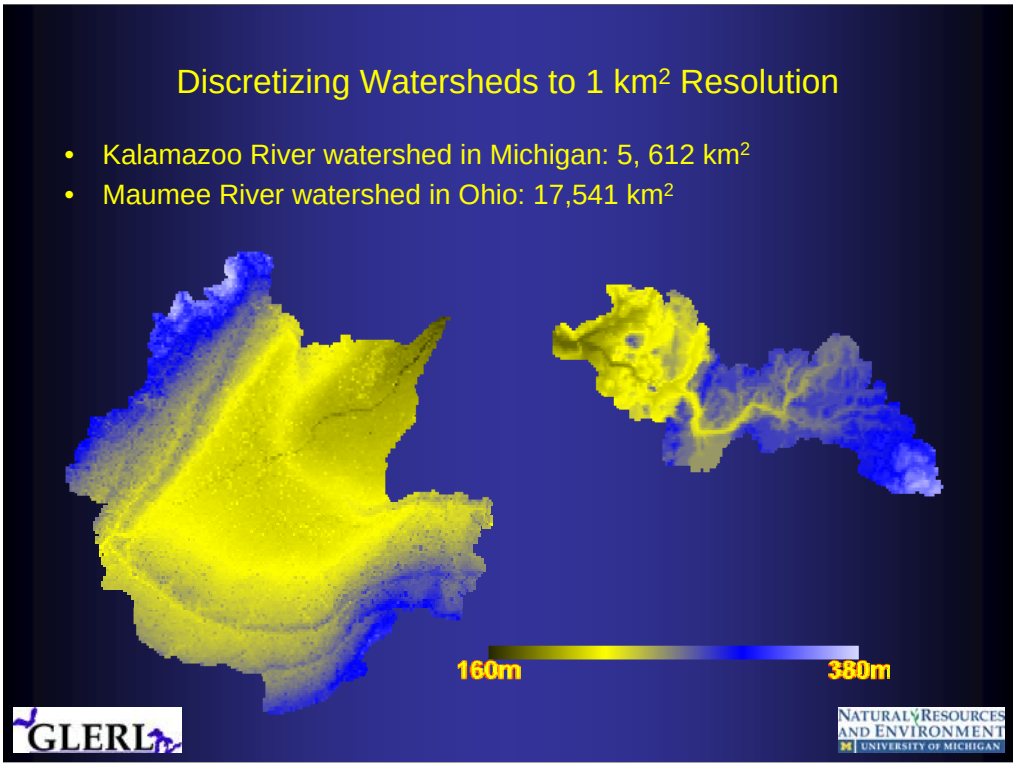
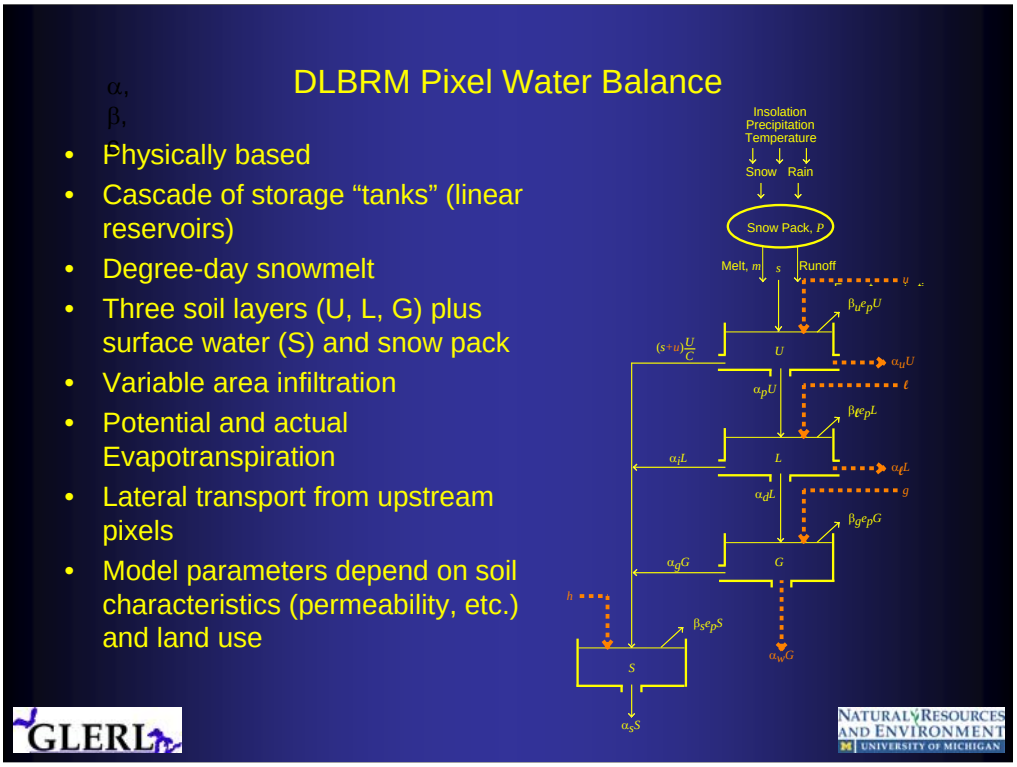


The flow network is reconstructed from the digital elevation data. This is a part of the Maumee watershed.



Examples of watershed digital elevation maps.



GLERL's Distributed Large Basin Runoff Model (DLBRM) consists of moisture storages arranged as a serial and parallel ***cascade of "tanks"*** to represent the perceived basin storage structure.

Precipitation enters the snow pack. It is kept here if temperature is below freezing or applied to the basin surface if temperature is above freezing (***degree-day snowmelt***).

Available supply either infiltrates into the upper soil or moves into surface water as runoff, according to the wetness of the upper soil (***partial-area infiltration***).

Water in the upper soil is subject to evaporation, vertical percolation to the lower soil zone, or lateral movement to the upper soil zone of the immediately downstream cell.

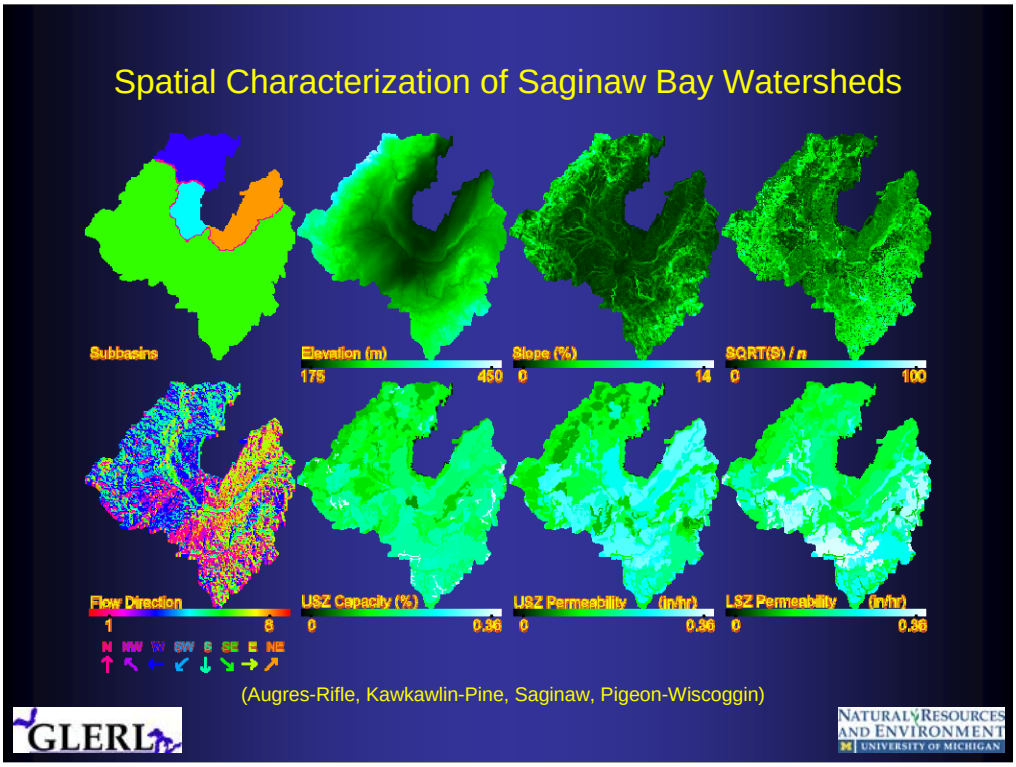
Water in the lower soil zone evaporates, percolates to ground water, moves laterally to the lower soil zone of the immediately downstream cell, or exfiltrates to the surface water (interflow). Groundwater, instead, either moves laterally to the groundwater zone of the immediately downstream cell or exfiltrates to the surface water (groundwater flow).

Flows from all tanks are proportional to their amounts (***linear-reservoir flows***).

Model parameters (evaporation rates, percolation rates, and lateral movement rates) vary spatially to match the distribution of selected observable watershed characteristics, such as upper and lower soil zone permeability, upper soil zone available water capacity, and the square root of surface slope divided by Manning's roughness coefficient. Minimization of the root mean square error between observed and modeled daily watershed outflow is used to determine the watershed-wide average of the model parameters, thus limiting the calibration parameters to 15.

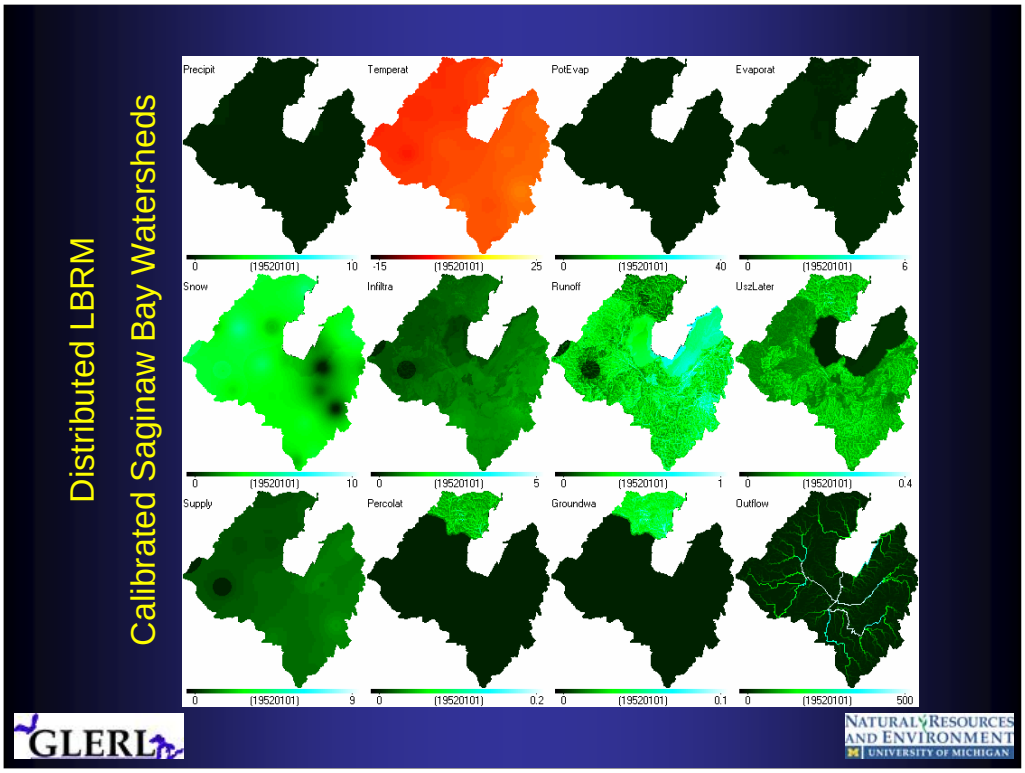
Mass conservation applies for the snow pack and tanks; ***energy conservation*** applies to evapotranspiration.

Dashed lines indicate the lateral movement of water between neighboring pixels.



Subdivision of the Saginaw Bay watershed used for the modeling;

Spatial distribution of soil and topographical parameters in the Saginaw Bay watershed.

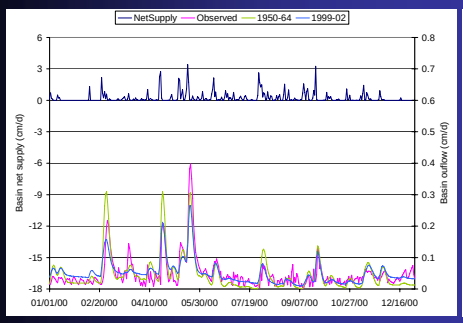


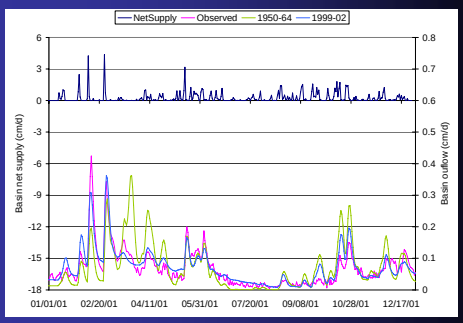
We can demonstrate hydrological modeling, again at the daily time step, for the watersheds of Saginaw Bay.

These watersheds have little or no groundwater storage (I've exaggerated the groundwater flow map by animating very low levels). Supplies either run off directly or infiltrate and percolate into the upper and lower soil zones, respectively, providing some lagged response to rainfall. Again, the lower right map reveals the drainage structure of the watersheds flow network.

DLBRM Performances for Saginaw River (1999 – 2002)

- Calibrated for 1950-1964; Validated for 1999 – 2002; Recalibrated for 1999 – 2002





	Bias	Correlation	Nash-Sutcliffe	RMSE/Avg.
Calib. 50-64	0.98	0.79	0.61	0.70
Calib. 99-02	1.02	0.88	0.68	0.48

Let's look the performances of the hydrologic module for the Saginaw River. The procedure was the following:

We calibrated the model against observed and reconstructed flow at Saginaw for the 1950-1964 period;

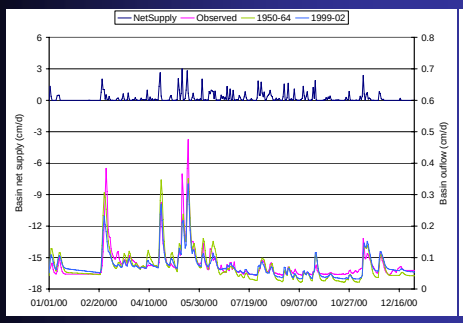
We applied the model to the period 1999-2002 without changes to test model performances

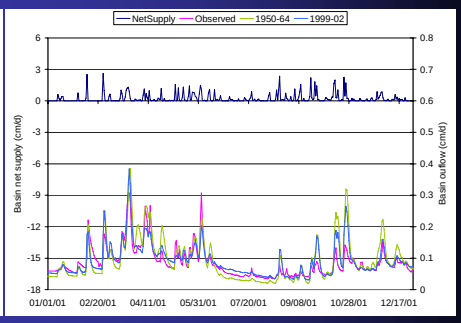
We recalibrated the model for the 1999-2002 starting from the 1950-1964 parameters to better reflect recent meteorology. The charts and table shows that the recalibrated model (Calib. 99-02) performances are very good (the performances are computed for the daily flow). The 1950-64 parameters (Calib 50-64) are still acceptable, although there are clearly some differences.

We can say that the model is resilient and still able to represent well the runoff from a watershed even after 35 years.

DLBRM Performances for AuGres-Rifle River (1999 – 2002)

- Calibrated for 1950-1964; Validated for 1999 – 2002; Recalibrated for 1999 – 2002





	Bias	Correlation	Nash-Sutcliffe	RMSE/Avg.
Calib. 50-64	0.99	0.84	0.70	0.40
Calib. 99-02	0.99	0.86	0.65	0.33

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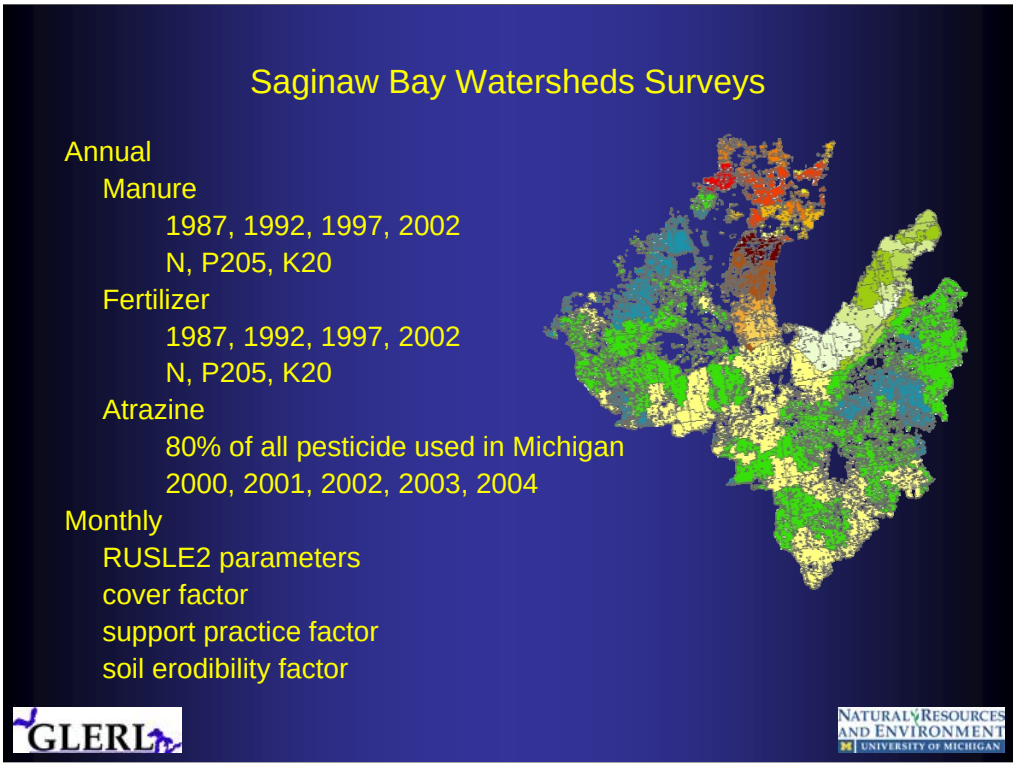
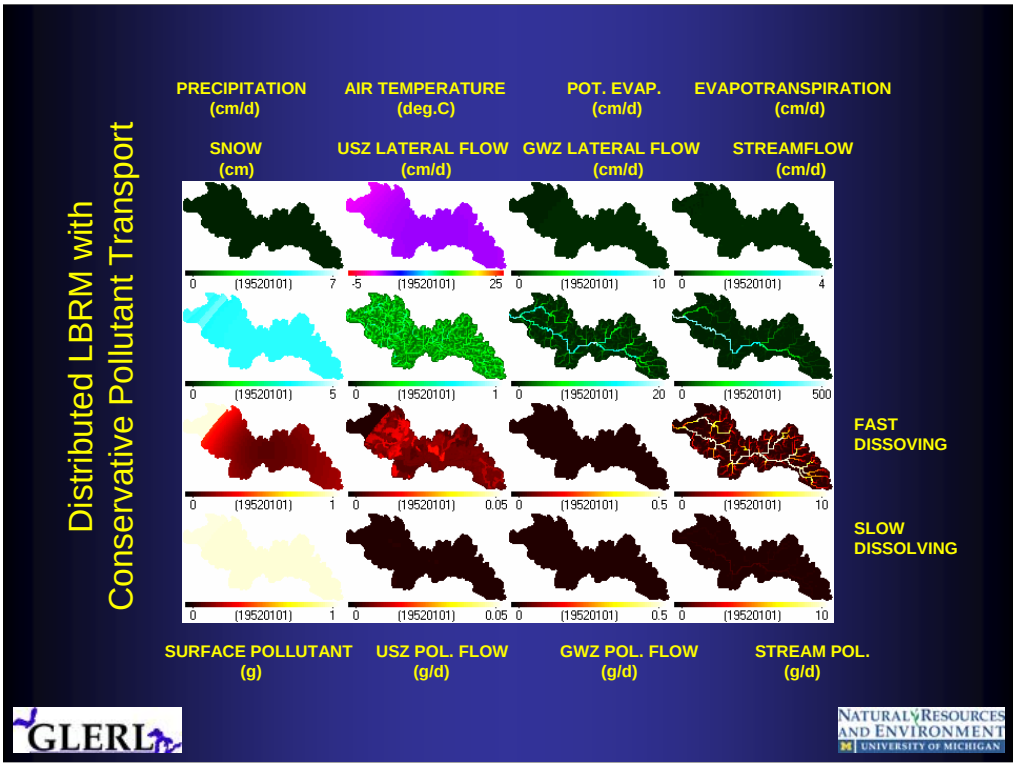
Let's look the performances of the hydrologic module for the AuGress-Rifle River. The calibration procedure was the same used for the Saginaw River:

The charts and table shows that the recalibrated model (Calib. 99-02) performances are very good. The 1950-64 parameters (Calib 50-64) are still more than acceptable, although there are clearly some differences.

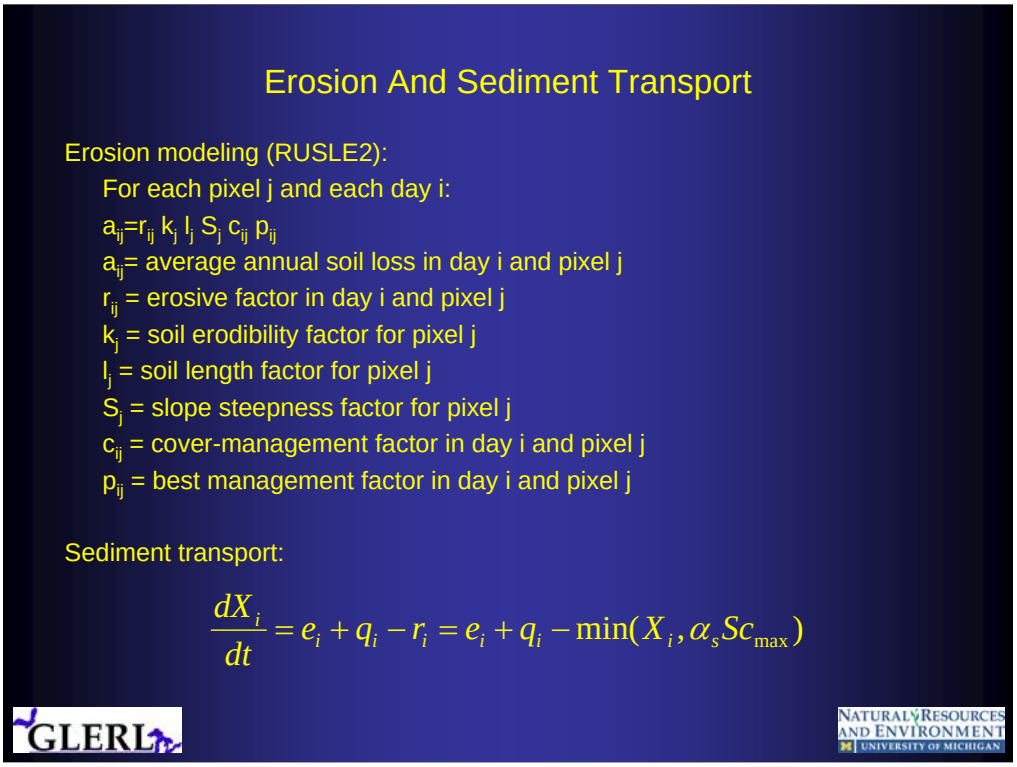
Even in this case, the model is resilient and still able to represent well the runoff from a watershed even after 35 years.



Input data for water quality simulation were determined from census data and Restricted Use Pesticide databases. We are also determining the parameters for erosion modeling from USDA.



Currently, DLBRM supports the simulation of the movement of conservative substances. Here we see the dynamics of a rapidly dissolving pollutant and of a slowly dissolving pollutant as well as of the hydrologic components.



We are currently adding the soil erosion and sediment transport components to DLBRM. Simulation of sediment generation and transport is important because sediments cause turbidity, destroy spawning habitats in the slow parts of the river, obstruct navigation channels, and carry pollutants.

Erosion is modeled by adapting the Revised Universal Soil Loss Equation protocol to the continuous simulation.

Sediment is the transported along the river system using a simple model that accounts for deposition and resuspension. For each pixel i, the variation of the sediment concentration is a result of the in-pixel erosion (e_i), input from upstream (q_i), and output (r_i). The output is the minimum between X and the river discharge times the sediment carrying capacity of the river, which is a function of the water velocity.

Current GLERL's Projects in the Saginaw Bay Basin

- Genetic characterization of Microcystis populations in Saginaw Bay
  PI: Juli Dyble
- Environmental factors controlling growth and toxin production of Microcystis in Saginaw Bay
  PIs: Juli Dyble and Gary Fahnenstiel
- Re-assessing the benthic macroinvertebrate (mayfly) community of Saginaw Bay
  PI: Tom Nalepa
- Dreissenid mussels as homeostatic filter feeders and nutrient excreters: Implications for harmful algal blooms (HABs) and nutrient cycling across trophic gradients
  PI: Henry Vanderploeg

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CENTER OF EXCELLENCE FOR GREAT LAKES AND HUMAN HEALTH

MICHIGAN HARMFUL ALGAL BLOOM STAKEHOLDER WORKSHOP

May 8, 2007

Bay City Riverfront DoubleTree Hotel

The intention of this day long Focused Workshop is to bring together Michigan drinking water operators, public health officials, beach managers, wastewater operators, tribes, agriculturalists, and other Michigan residents interested in harmful algal blooms in order to determine the extent of the harmful algal bloom (HAB) issue, create a venue to understand and assess existing knowledge of HABs, and identify methods in which HABs are monitored for and reported to the public.

For more information about attending this workshop, please contact: sonia.joseph@noaa.gov or 734-741-2283.

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