Building a picture of a watershed

Modeling with a computer simulation program

Watershed models – simulations of water quality and surface hydrology – help the Minnesota Pollution Control Agency (MPCA) better understand water quality and predict how it could change under different land management practices. The MPCA is using the Hydrological Simulation Program – FORTRAN (HSPF) model for this purpose. (FORTRAN is the computer language used by the model.) HSPF can simulate water flow rates as well as sediment (including sand, silt, and clay), nutrients, and other substances found in a water body. The model uses real-world observed data to ensure it properly mimics these interconnected processes. After confirming the model's accuracy, with a process called calibration, agency scientists and local partners can use it to model different scenarios of land-use change and how those changes might affect water quality.

The MPCA calculates Total Maximum Daily Loads (TMDLs) that help to protect the state's lakes, streams, and other water resources. TMDLs are the maximum amount – or load – that a water body can accept and still meet water quality standards. TMDLs are incorporated into the more comprehensive watershed protection and restoration strategies in each of Minnesota's 81 major watersheds. HSPF models give us greater insight into watershed processes to aid in TMDL development and to better safeguard Minnesota waters.

Why did the MPCA choose HSPF?

HSPF models help the MPCA protect the environment in many ways, including a variety of TMDL types:

- Conventional parameter TMDLs (turbidity, etc.)
- Dissolved oxygen TMDLs
- River nutrient TMDLs
- Point source effluent limits (individual facilities)
- Pollutant trading (point source for point source or point source for non-point source)
- Municipal separate storm sewer systems (MS4) permitting
- Support of stressor ID development
- Priority management zone support
- Non-point land-use planning
- General uses such as statewide nutrient reduction efforts

Benefits of HSPF include:

- Options to adjust physical processes and watershed characterization
- U.S. Environmental Protection Agency developed and supported
- Consistent record of peer-reviewed successes in multiple watersheds throughout the United States

How are HSPF models developed?

HSPF models are developed by acquiring and combining many sources of data. These datasets together represent the combined characteristics of a watershed necessary for the model to run a simulation. HSPF models are created with the following process:

1) Spatial Data from GIS layers

- Using land surface data (digital elevation models from LiDAR[1]) for accurate topography
- Sub-basin boundaries within watershed, water body locations and cross-sections
- Land-cover data (agriculture, urban use, etc)
- Soil type data

2) Incorporation of time-series data

- Hourly hydrological data from MDNR[2], MPCA, USGS[3], etc.
- Meteorological records (precipitation, air temperature, etc) from NWS[4] and MN State Climatological Office
- Water quality data collection (nutrients, sediments, etc.)

3) Point source data

- Adding loads from points sources in a watershed, specifically from facilities such as wastewater treament plants

4) Data Calibration

- Determine water balance for each land-cover category
- Researching appropriate sediment transport for the watershed
- Adjusting model so simulated hydrology, nutrient, and sediment match **OBSERVED** data

5) Data Validation

- Ensuring that model predictions are accurate by comparing to observations from different time periods

6) Scenario Simulations

- Running simulation with BASINS software
- Adjusting characteristics (land use, etc) to simulate changes to the watershed
- Determine how these changes would affect nutrients, sediment transport in the watershed

Figures 1 & 2 on page 3 show calibration/validation examples

1. Laser-based remote sensing satellite images. 2. Minnesota Department of Natural Resources. 3. U.S. Geological Survey. 4. National Weather Service.

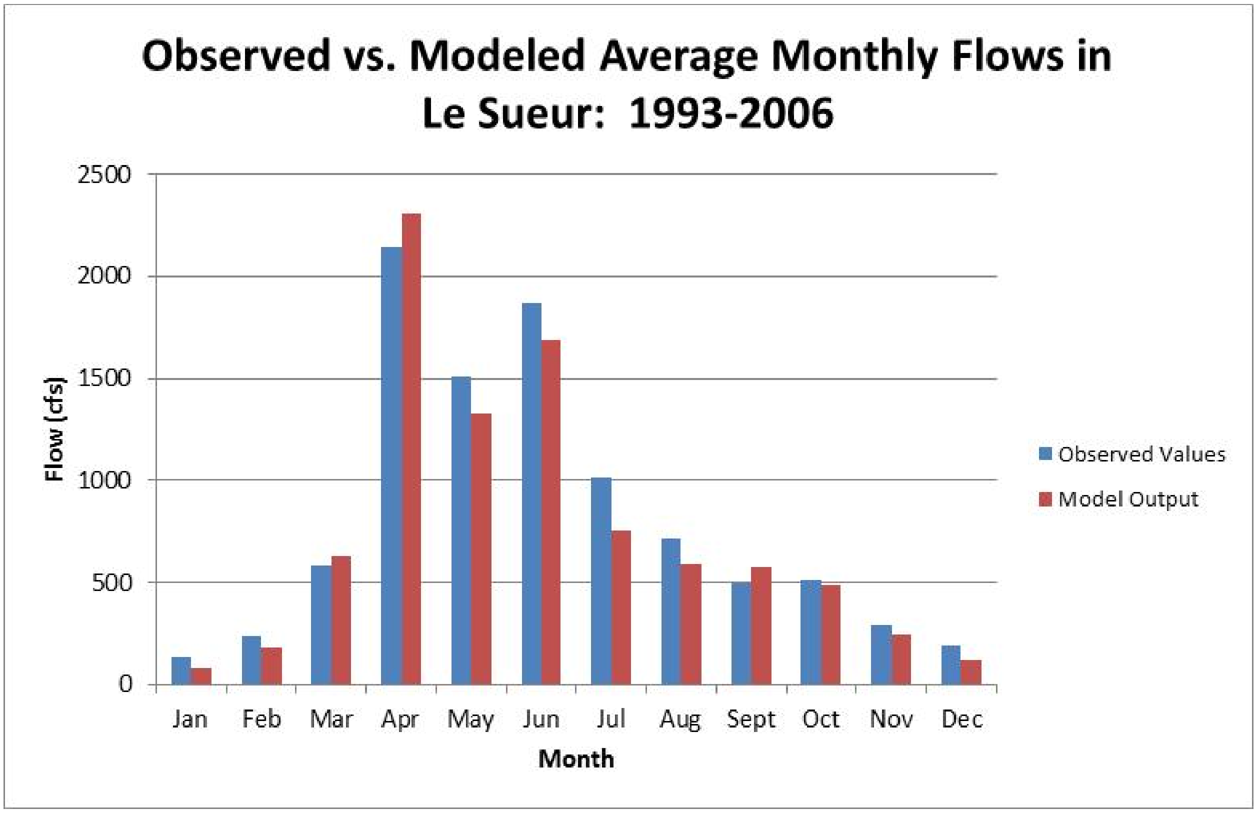

Figure 1: Comparison of observed streamflow data to that simulated by HSPF for calibration/validation quality assurance.

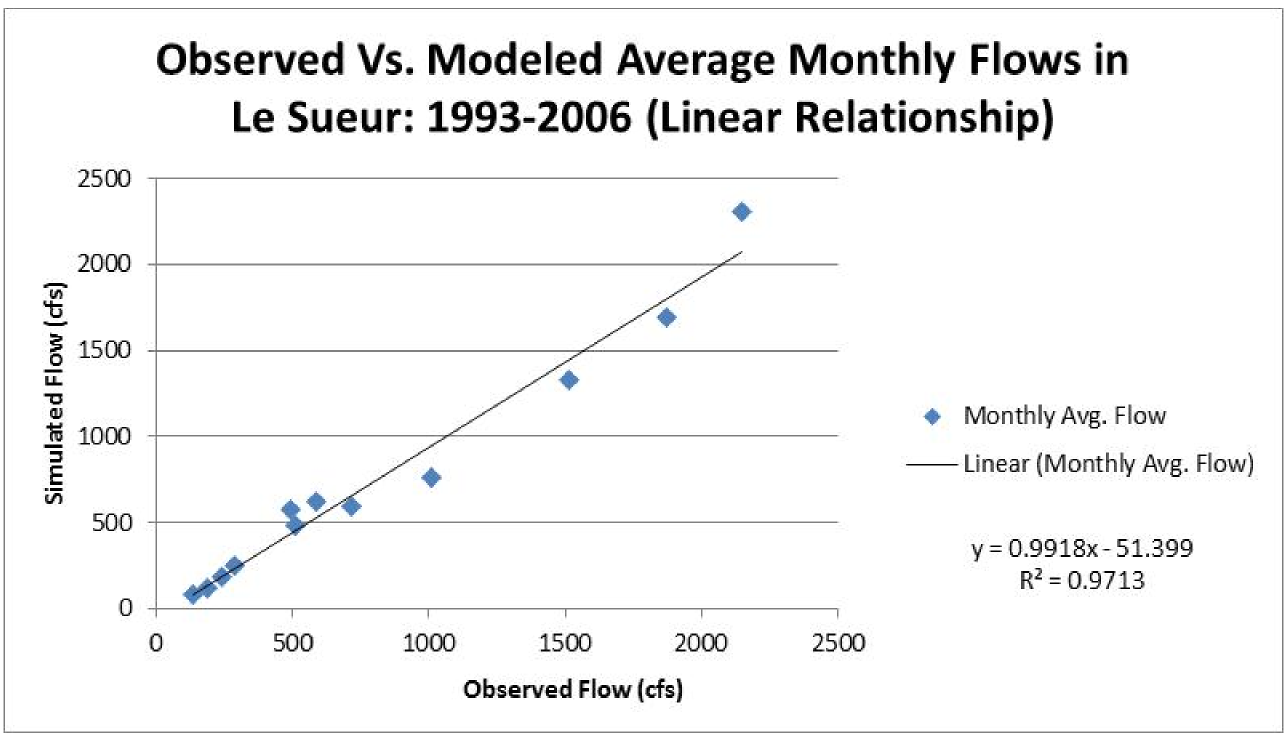

Figure 2: Statistical testing of similarities between observed and simulated streamflow. Note the R^2 value of 0.9713, a statistic indicating high correlation and therefore confirming the model's ability to accurately simulate streamflow.

Common questions about HSPF specifications:

How many locations within the watershed are used for calibration and validation?

- **For hydrology:** Hydrological and stream flow calibration/validation uses all available and reliable data within a watershed. Sometimes this means one calibration/validation station at the watershed outlet, but for some models, such as the Le Sueur watershed, eight stations are available. Figure 3 shows the locations of the Le Sueur's meteorological calibration points.
- **For water quality:** Water quality calibration/validation uses as much watershed data as possible. Water quality datasets are highly variable with multiple data sources, sampling locations, sampling times, and parameters differing in each watershed. For example, the number of calibration points can range from two in the Little Fork watershed to 117 in the Sauk.

Over what periods of time does model calibration and validation take place?

- MPCA models currently simulate data from 1995 – 2009 or 1995 – 2012. As more data becomes available, it will be incorporated into future modeling projects. Generally, model calibration occurs during the latter half of the time period (where there is likely more data available) and then validation in the first half. Both validation and calibration periods should contain "wet" and "dry" years in terms of precipitation totals.

Can atmospheric deposition data be added to the model?

- Contributions from the atmospheric deposition of nutrients have been added to each model using records from the nearest available data collection points. Both wet and dry atmospheric deposition are added directly to other nutrient time-series data.

What equations are being used to simulate physical processes (erosion, etc.)?

- Erosion: Sheet and rill erosion from agricultural fields are simulated by an expanded Revised Universal Soil Loss (RUSLE) -type equation. (RUSLE is a mathematical model developed by the U.S. Department of Agriculture to simulate soil erosion). In-stream, bluff, gullying, and channel widening erosional processes are also included in HSPF modeling.
- Snow: Mixed empirical/physically-based parameters are used to simulate the impacts of precipitation as snow. This includes processes such as snow melt, evaporation from snow and compaction.

How are farming practices simulated?

- Agricultural fertilization: Fertilization practices are not specifically a part of the model. Instead, nitrogen and phosphorus loadings are set on a per-acre basis based on water quality data in the nearest downstream water body. In other words, nitrogen and phosphorus application is back-calculated based on what is observed in streams. Simulated per acre loading rates are compared to the range of values reported in scientific literature for reasonableness.
- Tillage: Types of tillage are simulated not by one tillage parameter but by changing model terms relating to infiltration, surface roughness, and other land-cover factors that mirror the effects of a tillage type. Combined, these terms are analogous to the empirically-developed RUSLE.
- Artificial drainage: Tile drainage, stormwater, and other artificial drainage features are simulated by parameters that determine the speed water enters shallow groundwater and the amount of time those water inputs are maintained in the shallow groundwater after a storm event.

How does HSPF deal with forested regions?

- HSPF can also be used with confidence in parts of Minnesota that are heavily forested. Many model algorithms are already compatible with forest hydrology or can be easily adjusted for a forested watershed. Hydrology of forest harvesting areas can also be simulated by adjusting localized characteristics, including changes in hydrology.

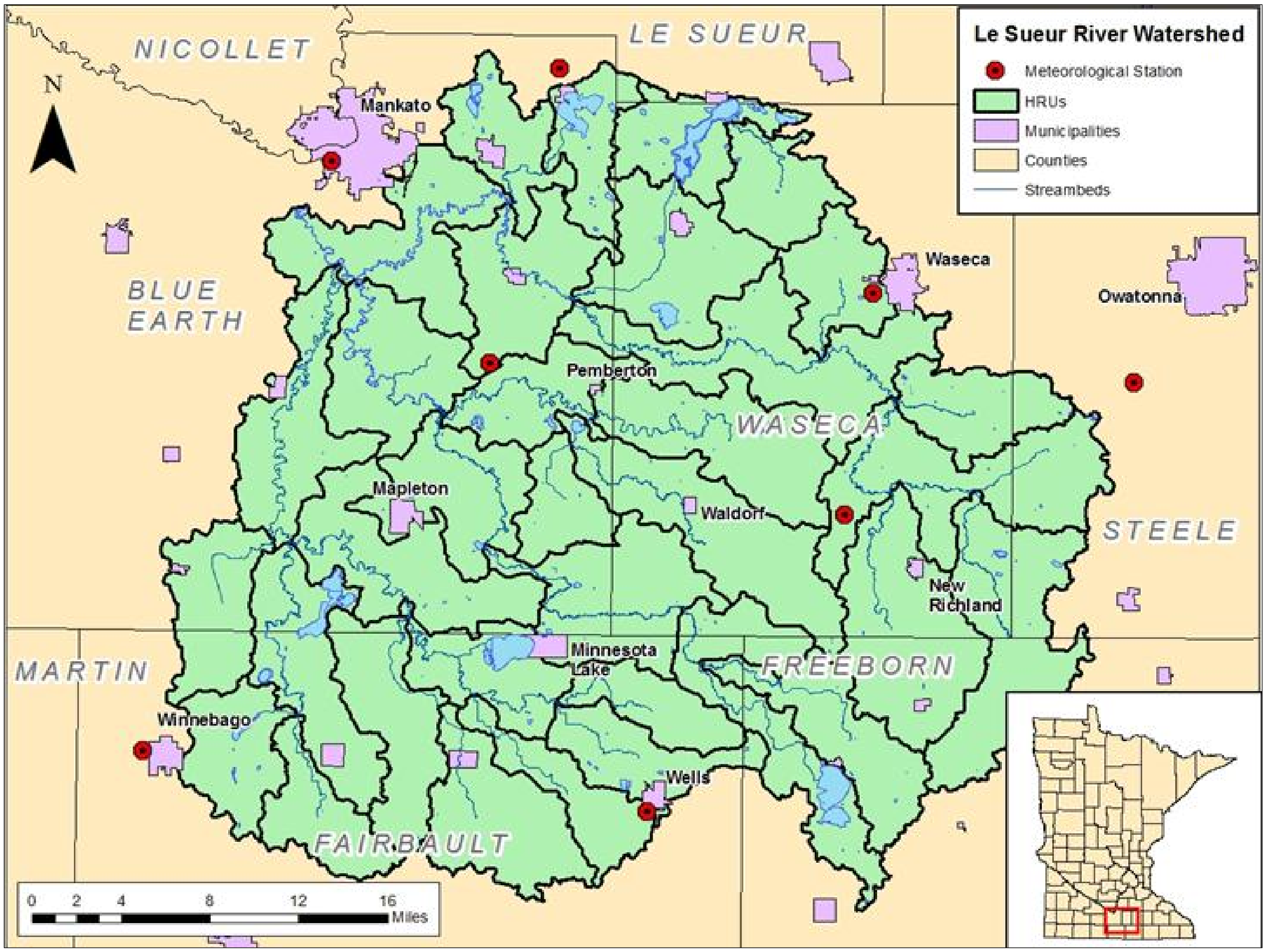

Figure 3: Le Sueur River watershed with meteorological calibration/validation points.

What assumptions go into HSPF model development?

As with any mathematical model, there are assumptions that are accounted for in model creation. Two major assumptions exist for HSPF: There is no interaction over the boundaries between sub-basins. Processes for each stream or river cross-section are homogeneous and thus the stream can be treated as a one-dimensional flow path for water, nutrients, and sediments. These assumptions have proven acceptable in appropriately simulating watershed hydrology.

How does the MPCA use HSPF output data?

Data produced from modeling allows MPCA scientists to accurately estimate the total amount of a substance (i.e. suspended sediments, dissolved oxygen, total phosphorus) produced in a watershed. With this data, it is then possible to calculate more accurate TMDL figures. These data are then used to administer appropriate stormwater, wastewater discharge, and other permits.

Overall, HSPF provides a complete picture of watershed physical, biological, and chemical processes. We can use this picture to determine which changes in watershed management, such as new land management practices, could be enacted to maintain or improve water quality of lakes, streams, and groundwater.