Okanagan Basin Hydrologic Modeling

July 6th, 2009

DHI Water & Environment
&
Summit Environmental Consultants

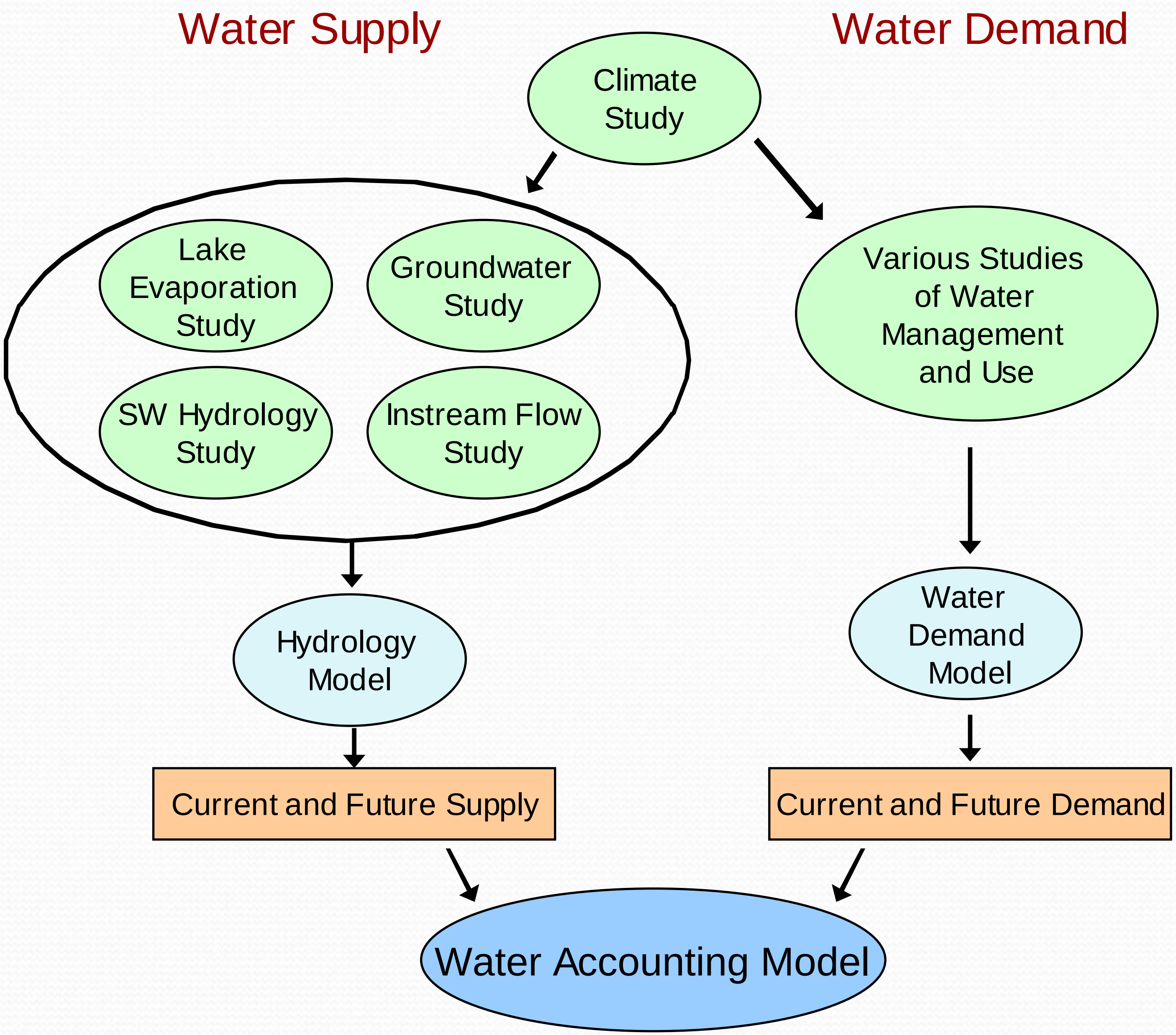
Outline

- Background/Objectives
- Model Overview
- Model Construction
- Previous Hydrology Model Calibration
- Addressing Comments/Improving Calibration
- Water Accounting Model Calibration
- Summary
- Next Steps

Background

Phase II of the Okanagan Basin Water Supply & Demand Project:

- A study of current water management and use
- A climate study
- Development of an Okanagan Water Demand Model
- A lake evaporation study
- A groundwater study
- An instream flow requirements study
- A surface water hydrology and hydrologic modeling study
- Development of a water accounting model


Water Supply
Water Demand
Climate Study
Lake Evaporation Study
Groundwater Study
SW Hydrology Study
Instream Flow Study
Various Studies of Water Management and Use
Hydrology Model
Water Demand Model
Current and Future Supply
Current and Future Demand
Water Accounting Model

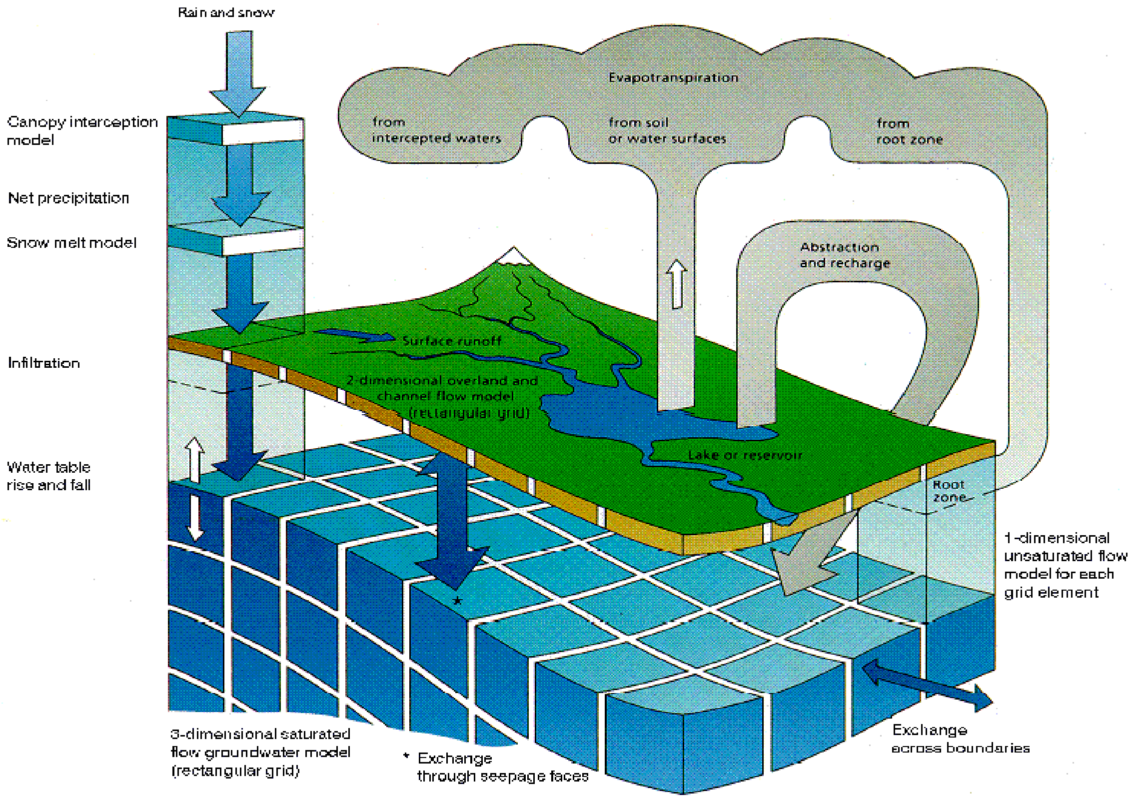
Objectives

- Develop a distributed hydrologic model of the Okanagan Basin to simulate naturalized conditions
- Calibrate and compare the model results with measured data and estimates from other studies
- Incorporate water use data to develop water accounting model
- Calibrate water accounting model to available measured data
- Estimate naturalized and historical weekly streamflows for the period 1996-2006 at 81 surface water nodes
- Upload results to the OKWater Database

Model Overview

MIKE SHE

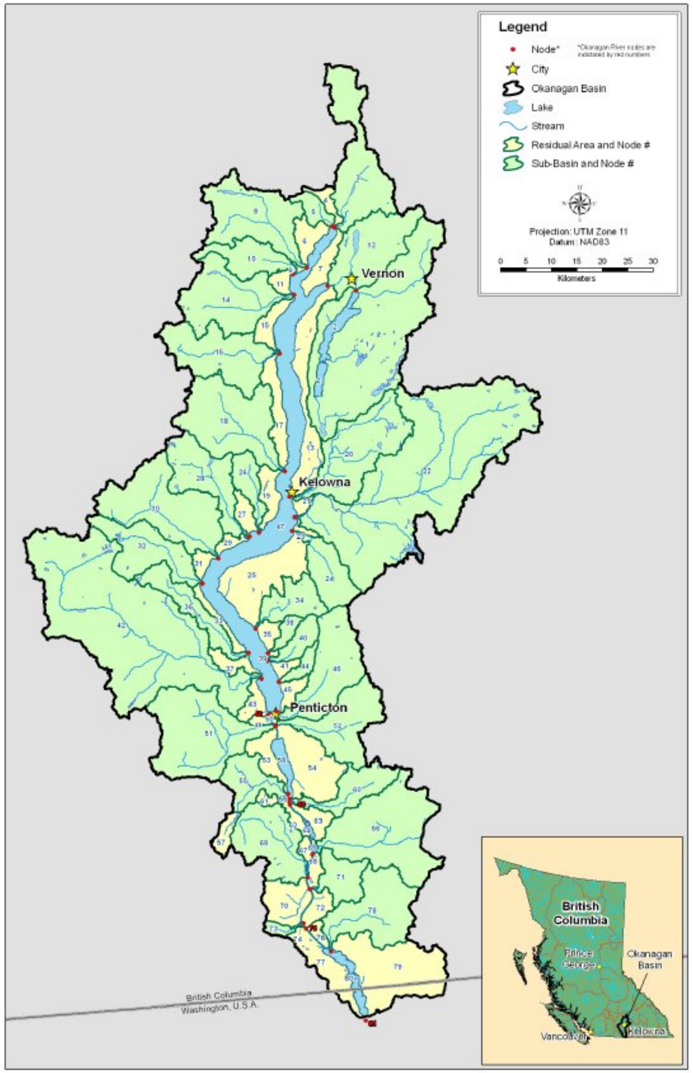
an Integrated Hydrological Modelling System
that covers all land-based phases of the hydrologic cycle



Model Overview

- Snowmelt – modified degree-day method
- Overland flow – 2-dimensional finite-difference method
- Unsaturated flow and ET – 2-layer water balance approach
- Groundwater flow – linear reservoir approach
- Channel flow – 1-dimensional hydrodynamic/routing approach

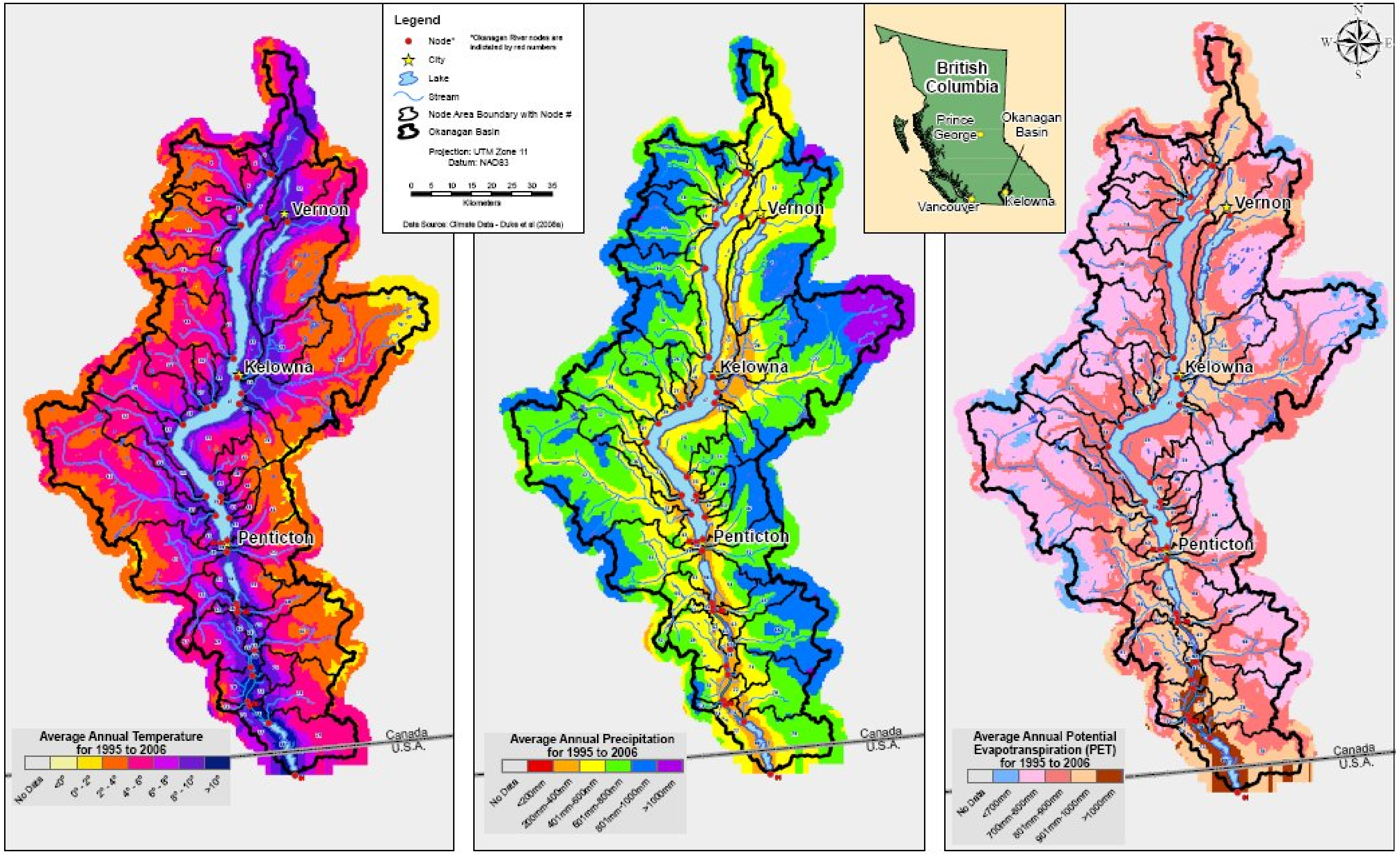
Model Overview



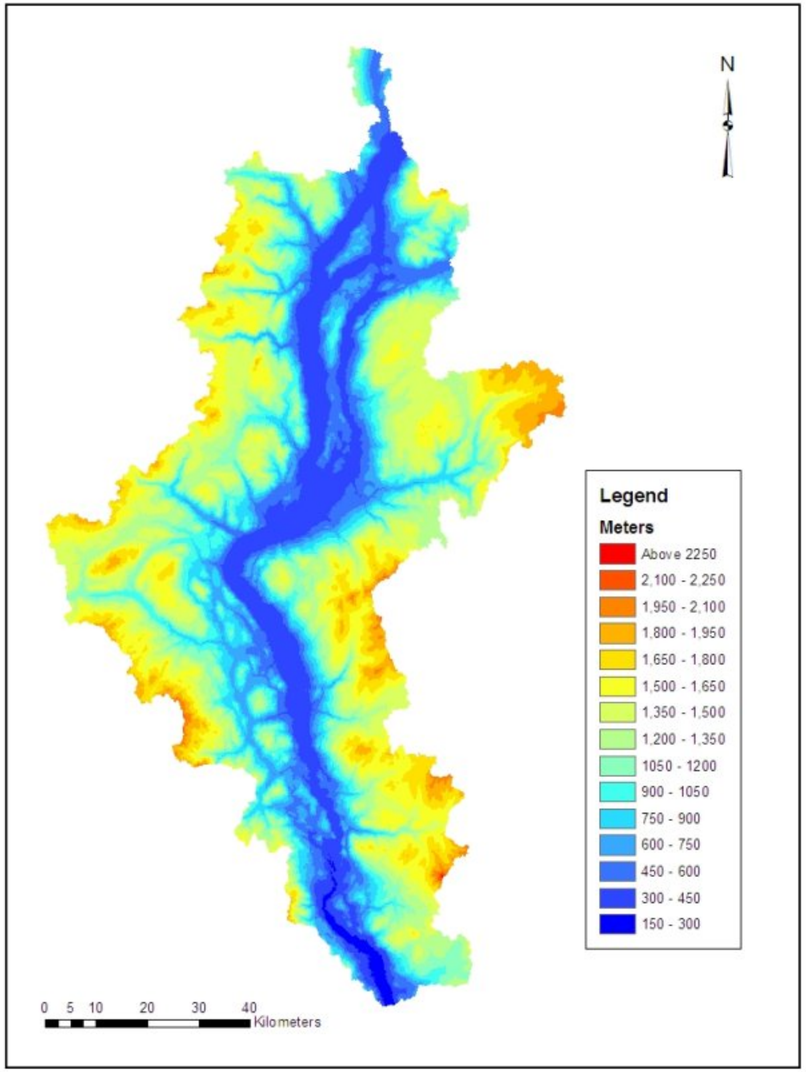
- Domain: Full Okanagan River Watershed upstream of Zosel Dam (Osoyoos Lake)
- Area: ~8,024 km^2
- Simulation Period: 9/1/1995 – 12/31/2006
- Resolution: 500-m by 500-m square grid cells
- Coordinate system: BC Albers projection, NAD 1983 datum

Model Construction – Climate

- Okanagan Climate Data Interpolator (Duke et al., 2008)
- 500 x 500-m grid resolution, daily time scale

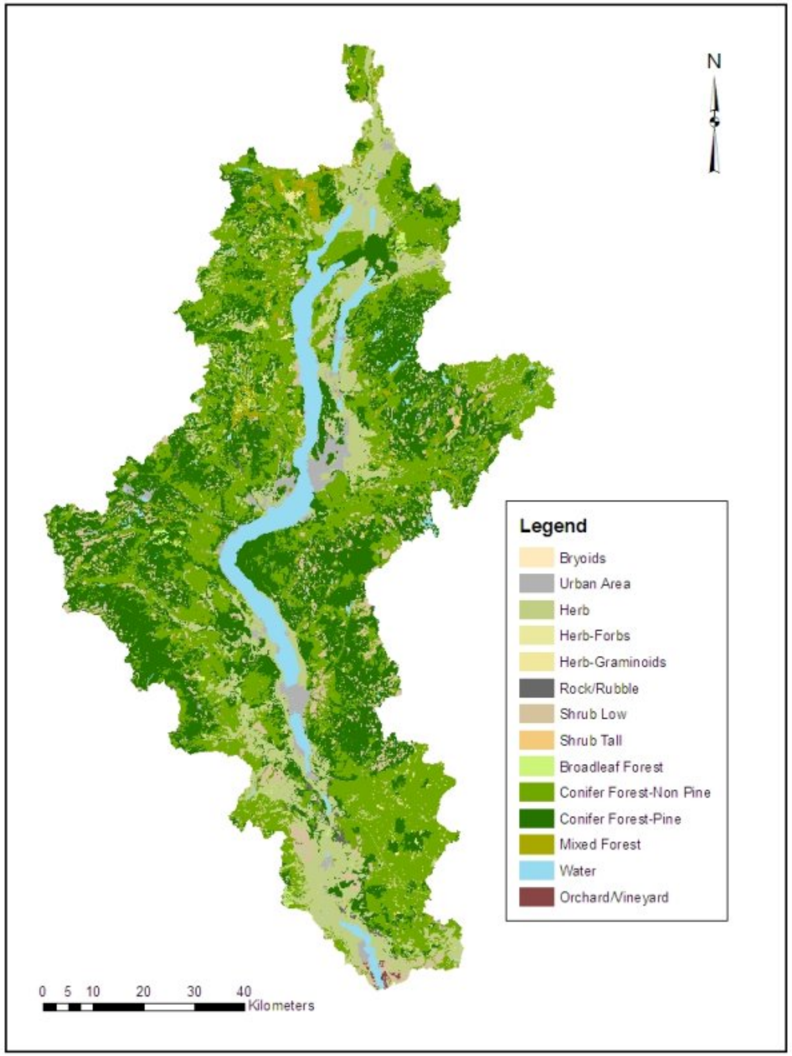


Model Construction - Topography



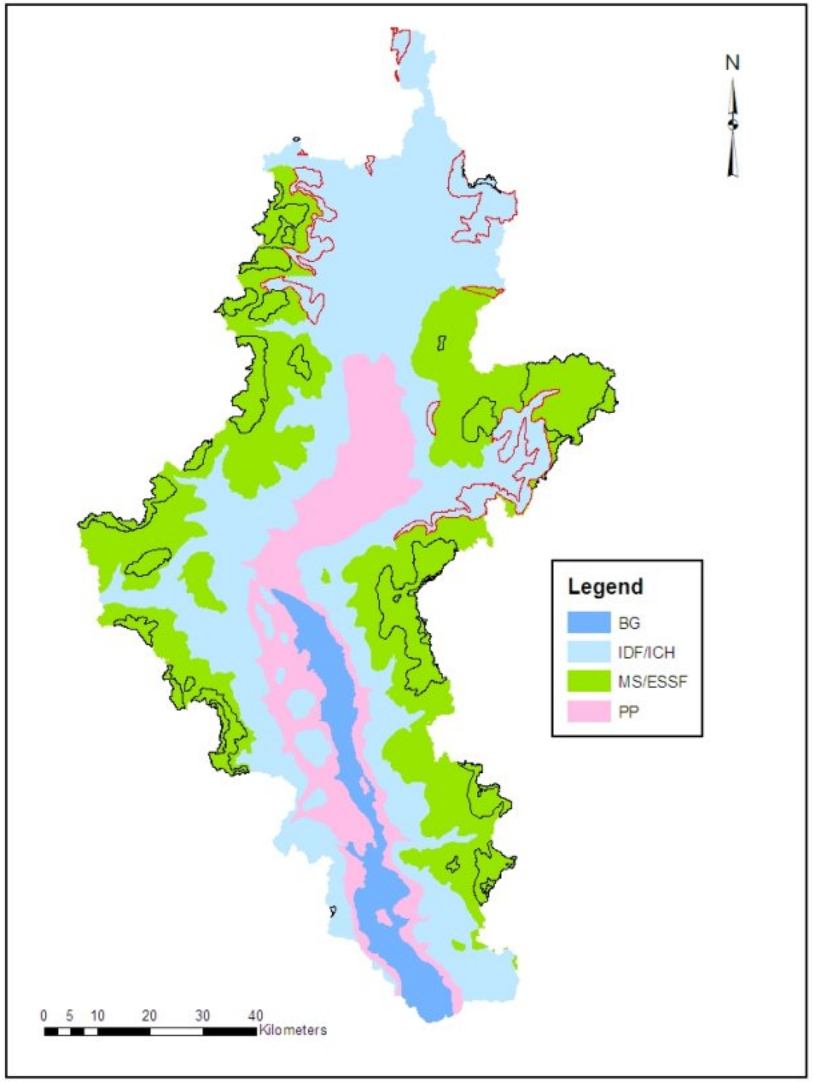
- Drives the overland flow component of the model
- 30-m resolution Canadian DEM (Geobase) and 100-ft resolution US DEM (WA Dept. of Natural Resources) merged and re-sampled to 500-m resolution

Model Construction – Land Cover



- Used to distribute vegetation properties (ET component) and roughness and detention storage values (overland flow component)
- Combination of data sources:
  - Base land cover maps (14)
  - Biogeoclimatic zones (4)
  - Disturbance areas (4)
  - Total of 67 zones

Model Construction – Land Cover



- Further subdivided by biogeoclimatic zones
- Categories:

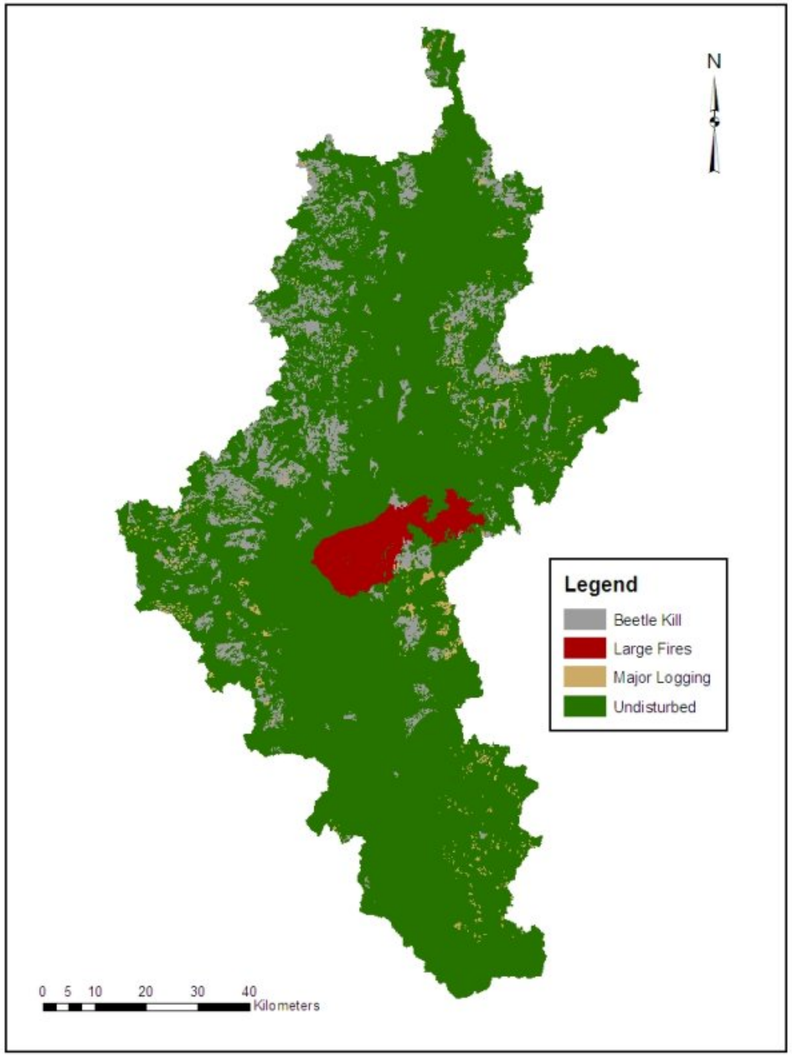
BG – Bunchgrass

IDF/ICH - Interior Douglas Fir / Interior Cedar - Hemlock

MS/ESSF - Montane Spruce / Engelmann Spruce – Subalpine Fir

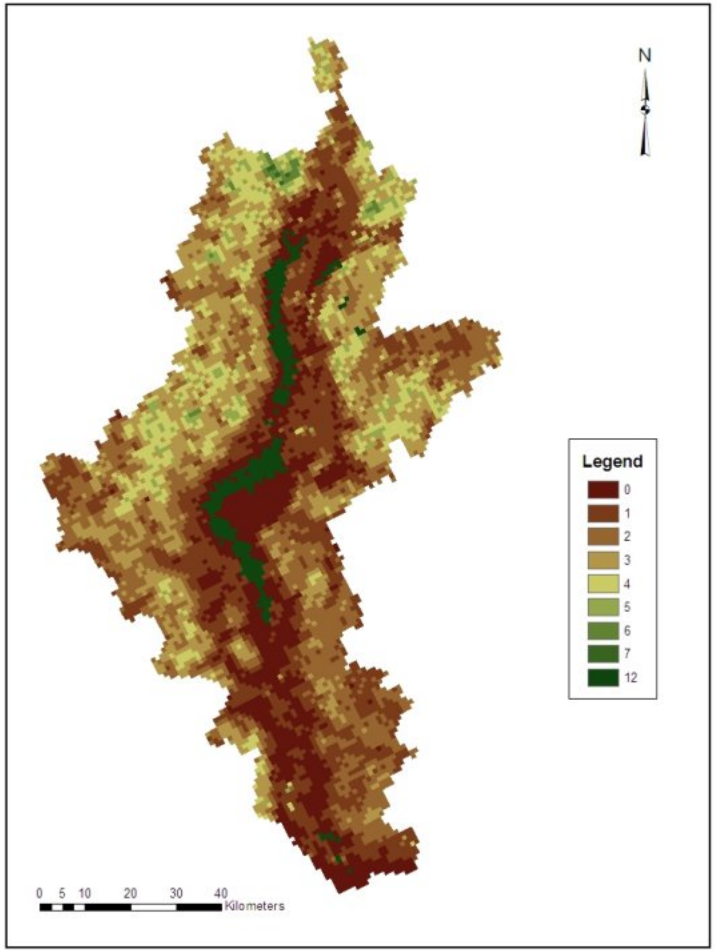
PP - Ponderosa Pine

Model Construction – Land Cover



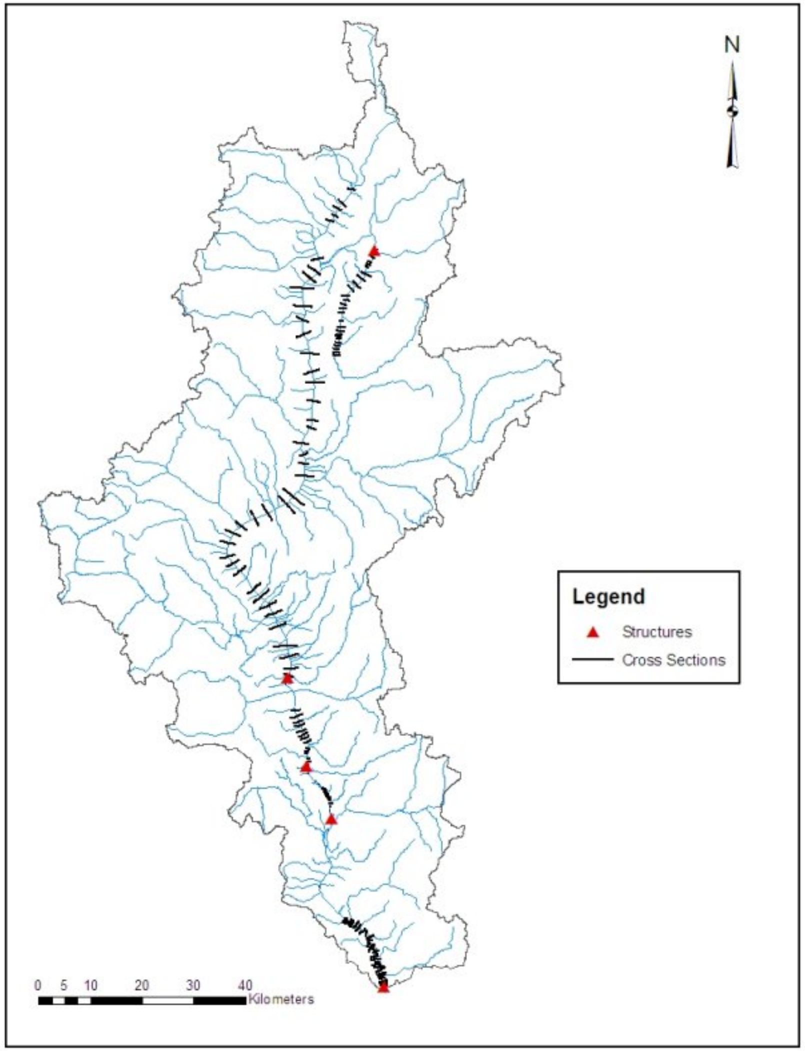
- Further subdivided by disturbance zones
- Mountain Pine Beetle
  - Annual gridded map with 400-m resolution
- Large Fires
  - Annual polygon map
  - 2003 Kelowna Fire
- Major Logging
  - Annual polygons from the VRI
- Undisturbed

Model Construction – Leaf Area Index



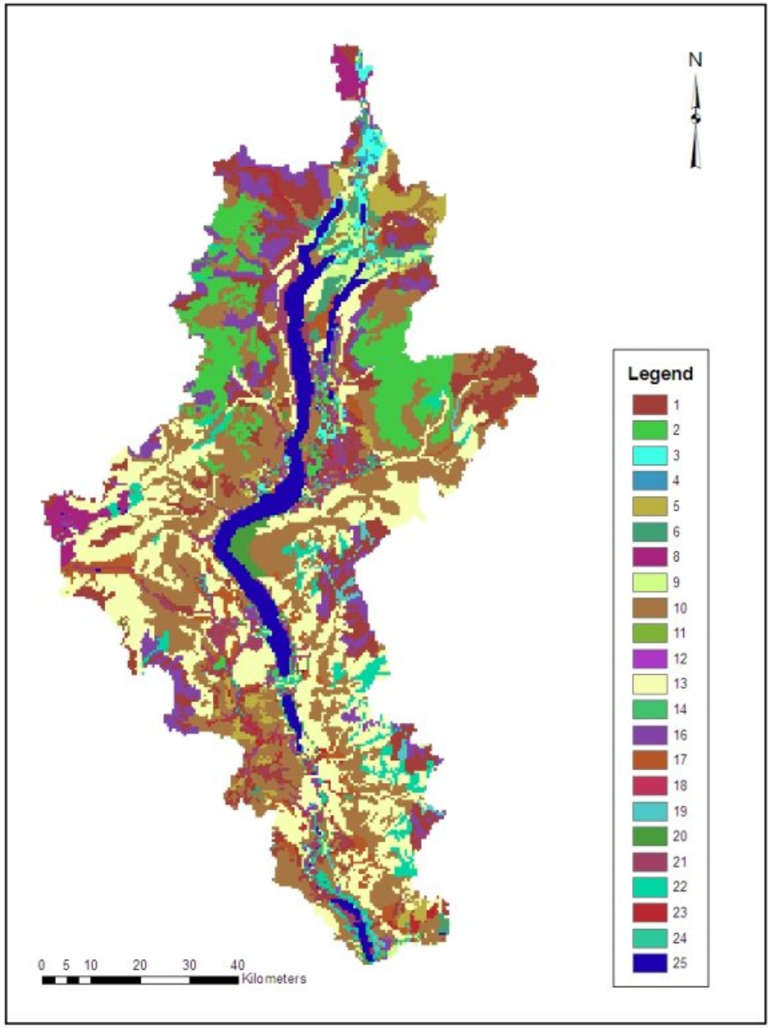
- 1-km resolution 10-day interval gridded data from 1998-2005
- Used to construct time-series for each of the 67 land cover categories

Model Construction – Streams and Lakes



- 176 river branches
- 146 cross sections (lake bathymetry surveys, flood control surveys for Okanagan River)
- 5 control structures (lake operations)

Model Construction – Soils



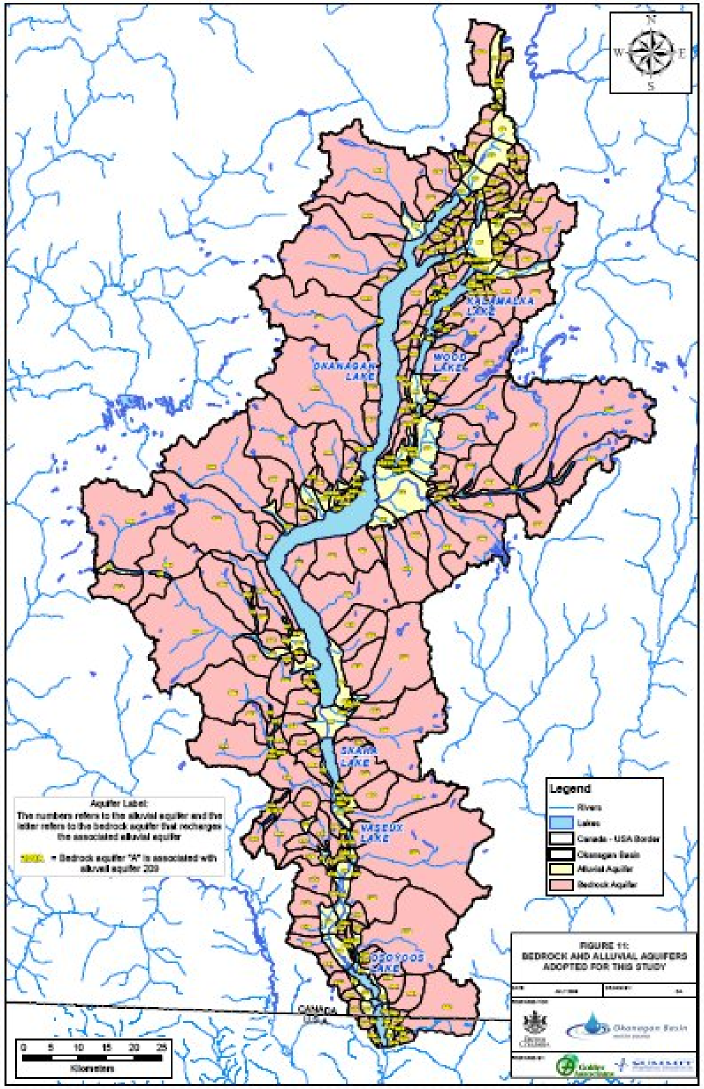
- Used to distribute soil properties (unsaturated flow and ET components)
- Four soil maps were merged and aggregated into 25 classes
- Depth-averaged soil properties computed from horizon data:

2-Layer UZ Soil properties

Profile ID: OK Soil10

Water content at saturation	0.421	
Water content at field capacity	0.211	
Water content at wilting point	0.098	
Saturated hydraulic conductivity	9.96e-008	[m/s]
Soil Suction at wetting front	-0.2	[m]

Model Construction – Groundwater

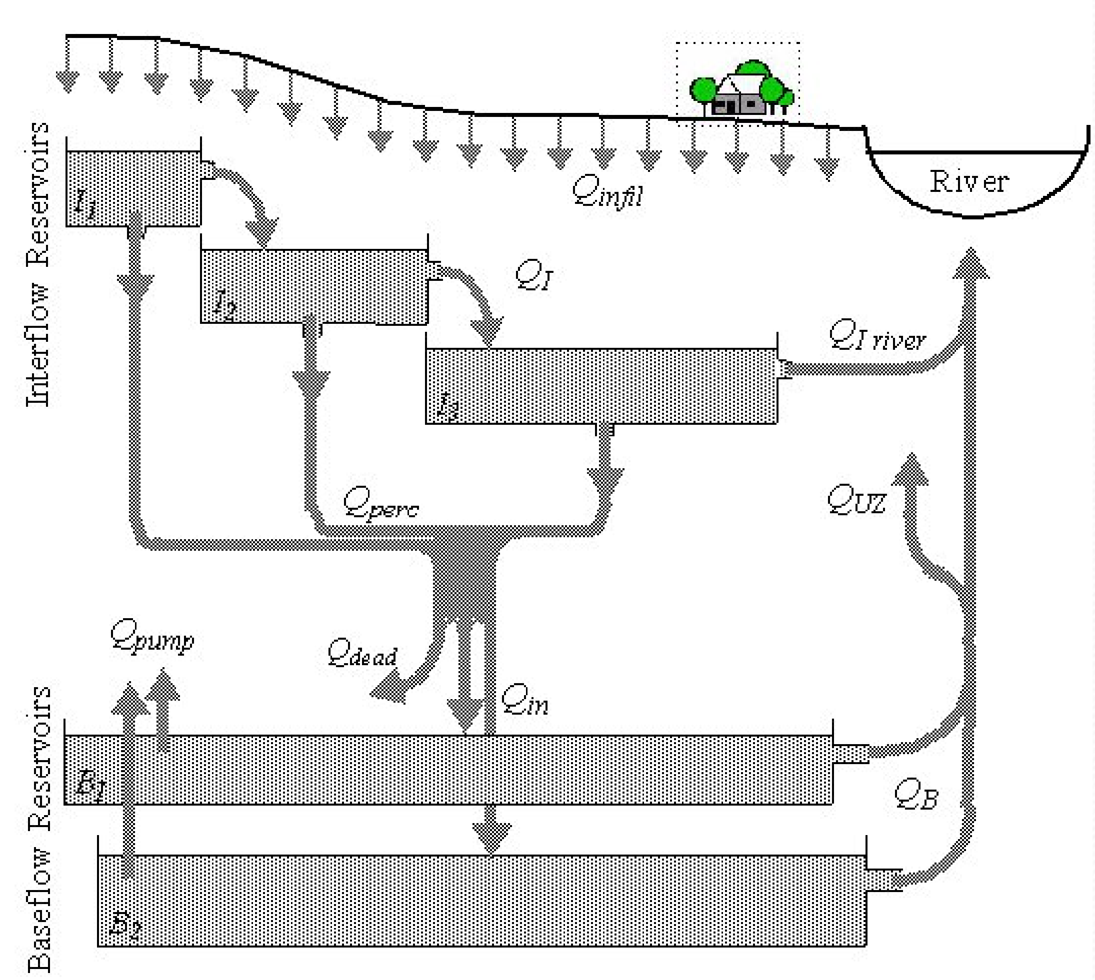


<u>Golder Groundwater Study</u>

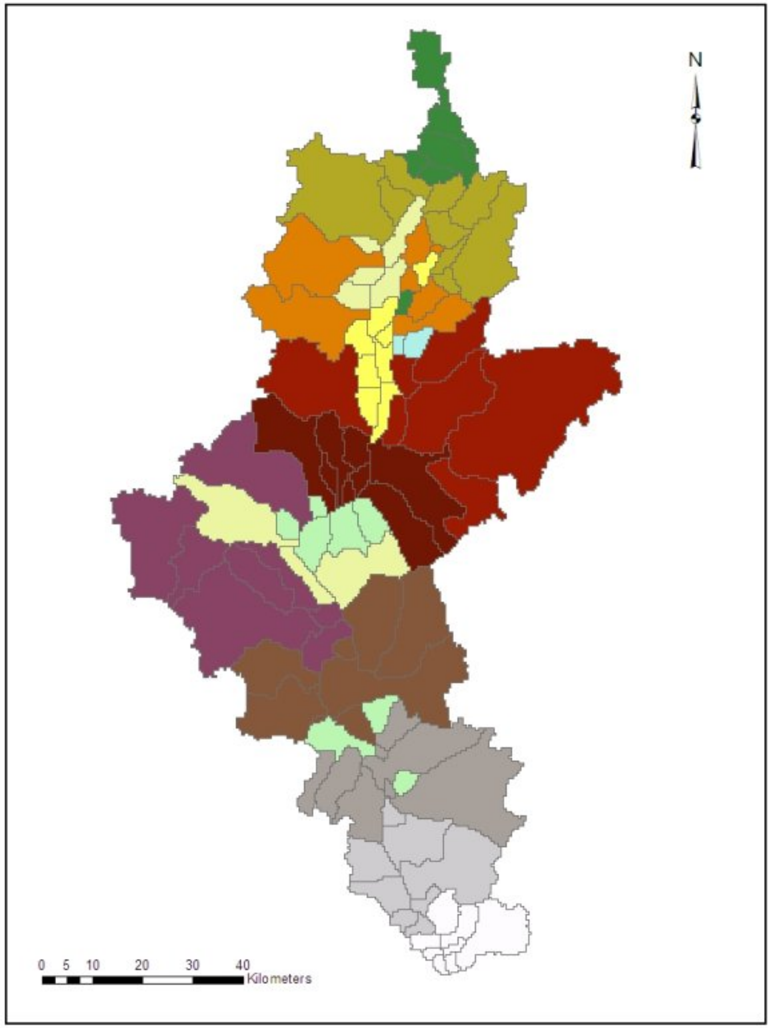
- 324 aquifers (79 alluvial aquifers)
- Recharge occurs primarily in the upland bedrock areas
- The bedrock system consists of a shallow interflow zone and a deeper fractured zone
- ~85% of the upland recharge reports to the shallow interflow zone and flows laterally to recharge down-gradient alluvial aquifers

Model Construction – Groundwater

- MIKE SHE Linear Reservoir Groundwater Method



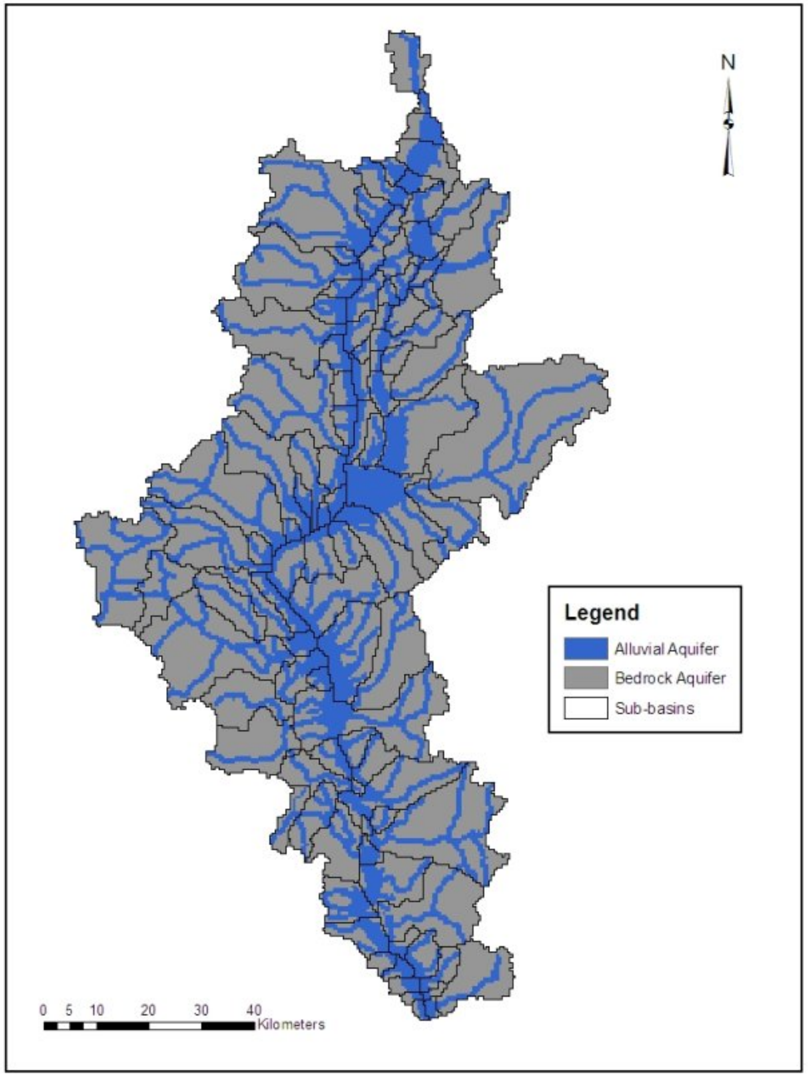
Model Construction – Groundwater



Baseflow Reservoirs

- Analogous to the deeper bedrock system
- Merged Golder bedrock aquifers with corresponding down-gradient alluvial aquifers

Model Construction – Groundwater



Interflow Reservoirs

- Analogous to the shallow bedrock system
- Upland reservoir – Golder bedrock aquifers
- Lowland reservoir – Golder alluvial aquifers plus a buffer around major streams

Hydrology Calibration – Overview

<u>Available Data</u>

- Overall basin water balance from previous studies
- Snow surveys (19 stations)
- Natural hydrographs (8 stations)
- Naturalized hydrographs (8 low-uncertainty, 15 moderate-uncertainty, and 49 high uncertainty)
- Lake evaporation estimates (5 lakes)

Calibration – Parameters

- Detention Storage – regulates magnitude and timing of runoff and indirectly effects infiltration and ET
- Riverbed Leakage Coefficient – regulates surface water / groundwater exchange
- Soil Moisture Contents – influences transpiration, infiltration, and groundwater recharge
- Saturated Hydraulic Conductivity (soils) – controls infiltration and recharge
- Degree Day Coefficient – Controls the rate at which snow is melted and converted to runoff
- Manning's Coefficients – Controls timing and magnitude of runoff
- Interflow and Baseflow Time Constants – controls timing and magnitudes of interflow and baseflow discharge to streams

Calibration – Water Balance

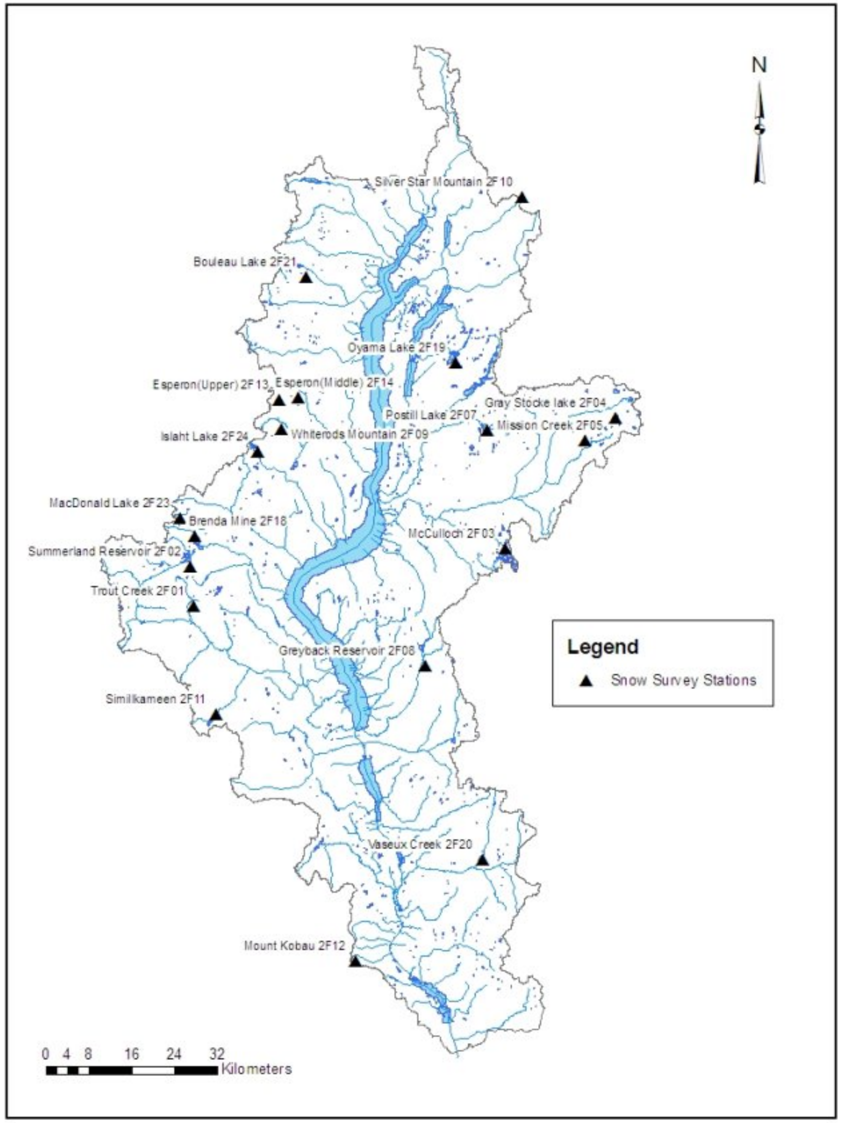
- ET - 71 - 77% (1974 Study)
  - 60 – 85% (various sub-areas)
- Recharge - 3% - 15% (various sub-areas)
- Runoff - 18% - 25% (State of the Basin & 1974 Study)

Water Balance Term	Total Depth (mm)	Mean Annual Depth (mm)	Relative to Precipitation (%)
Precipitation	7113.78	646.71	
ET	5757.74	523.43	80.9%
Recharge	459.62	41.78	6.5%
Runoff	846.46	76.95	11.9%

Results – Recharge Animation

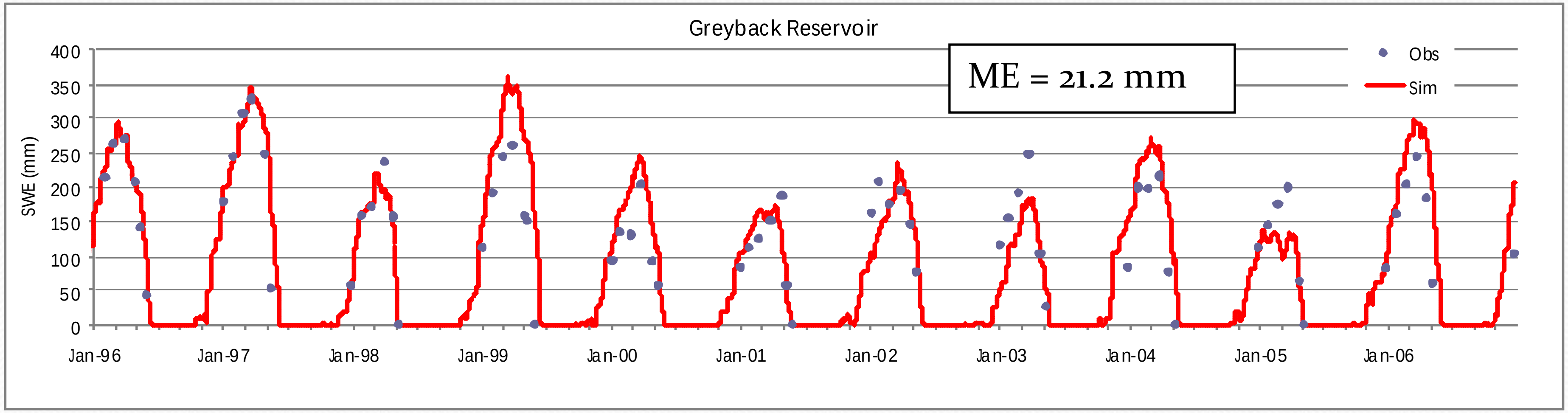
Recharge Sept-96 – Sept 98

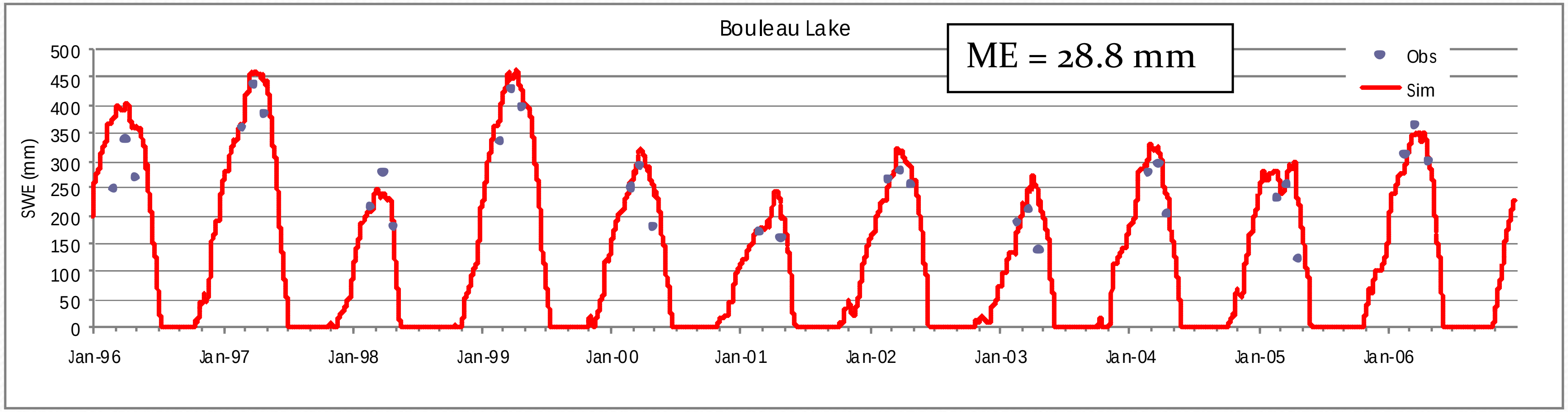
Calibration – Snow Surveys



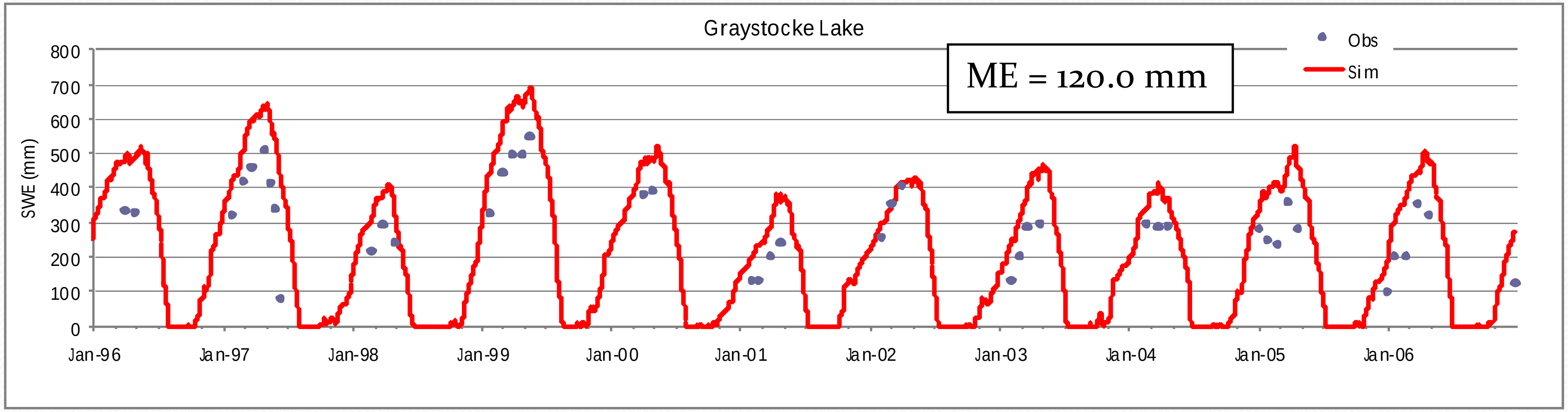
- 19 Stations with Snow Water Equivalent (SWE) data
- Ranging in elevation from 1266 to 1834-m
- Collected between December and June

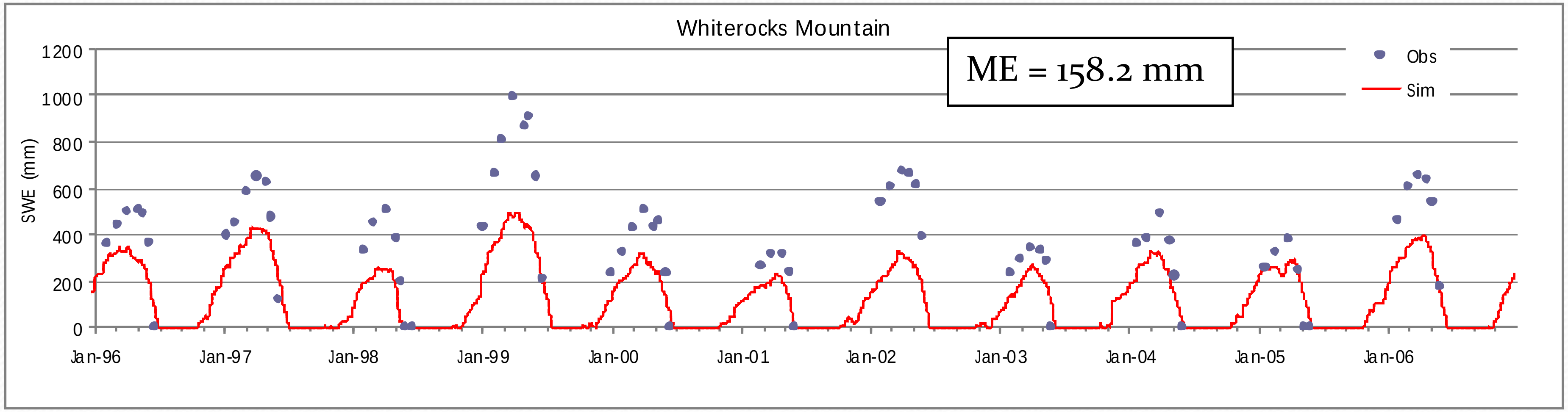
Calibration – Snow Surveys



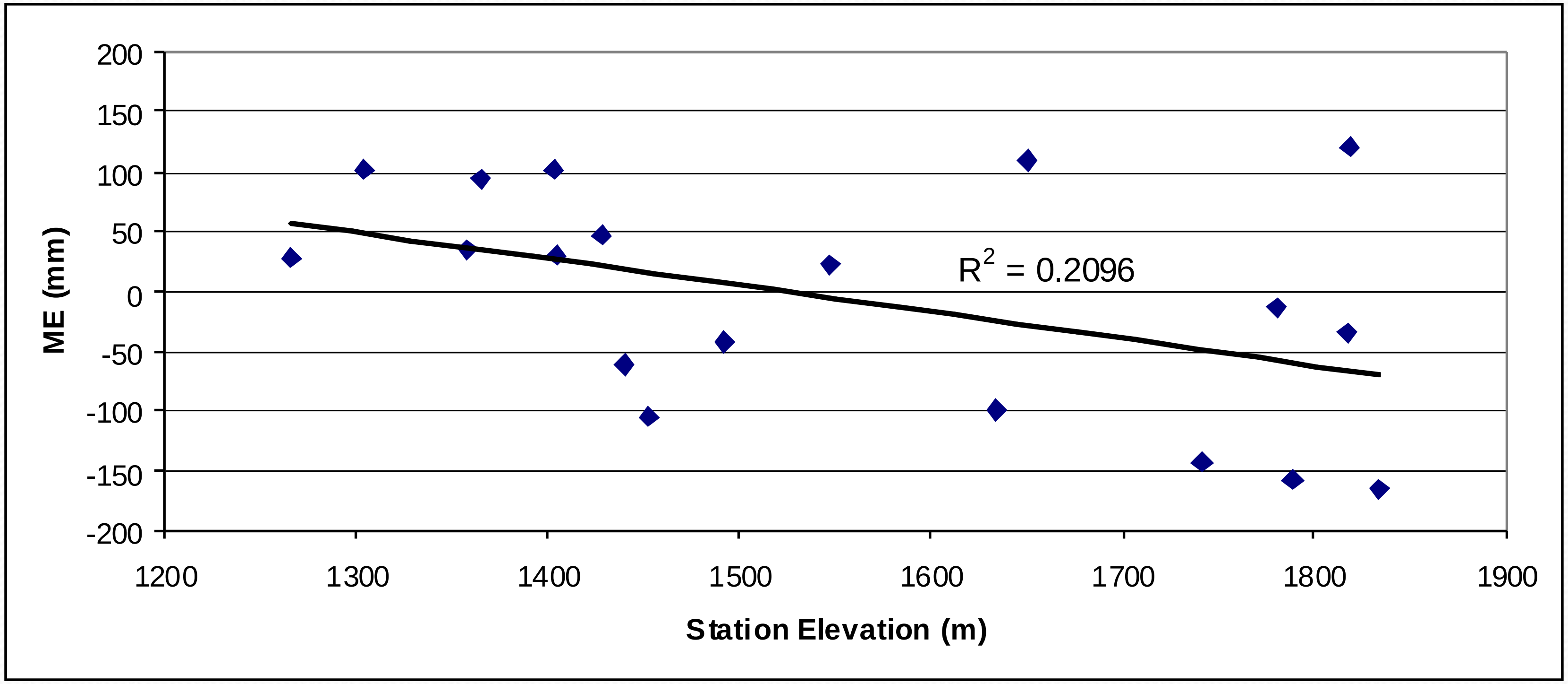


Calibration – Snow Surveys





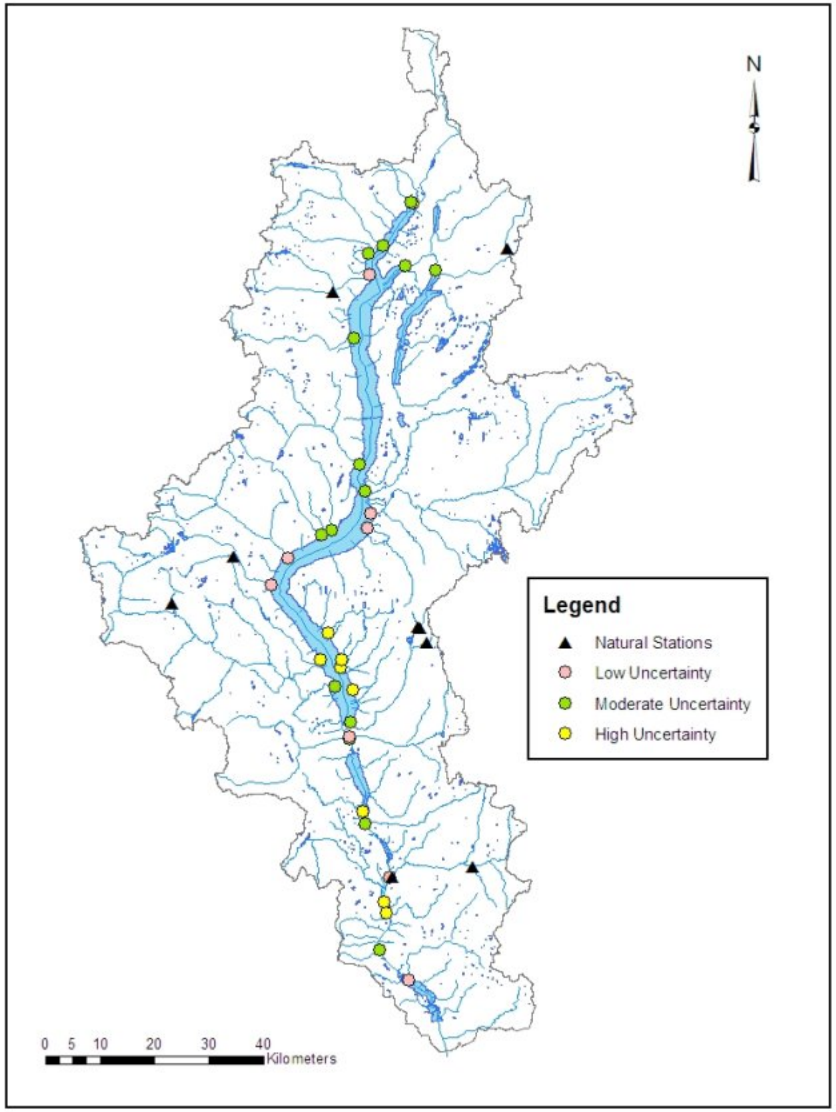
Calibration – Snow Surveys



Results – SWE Animation

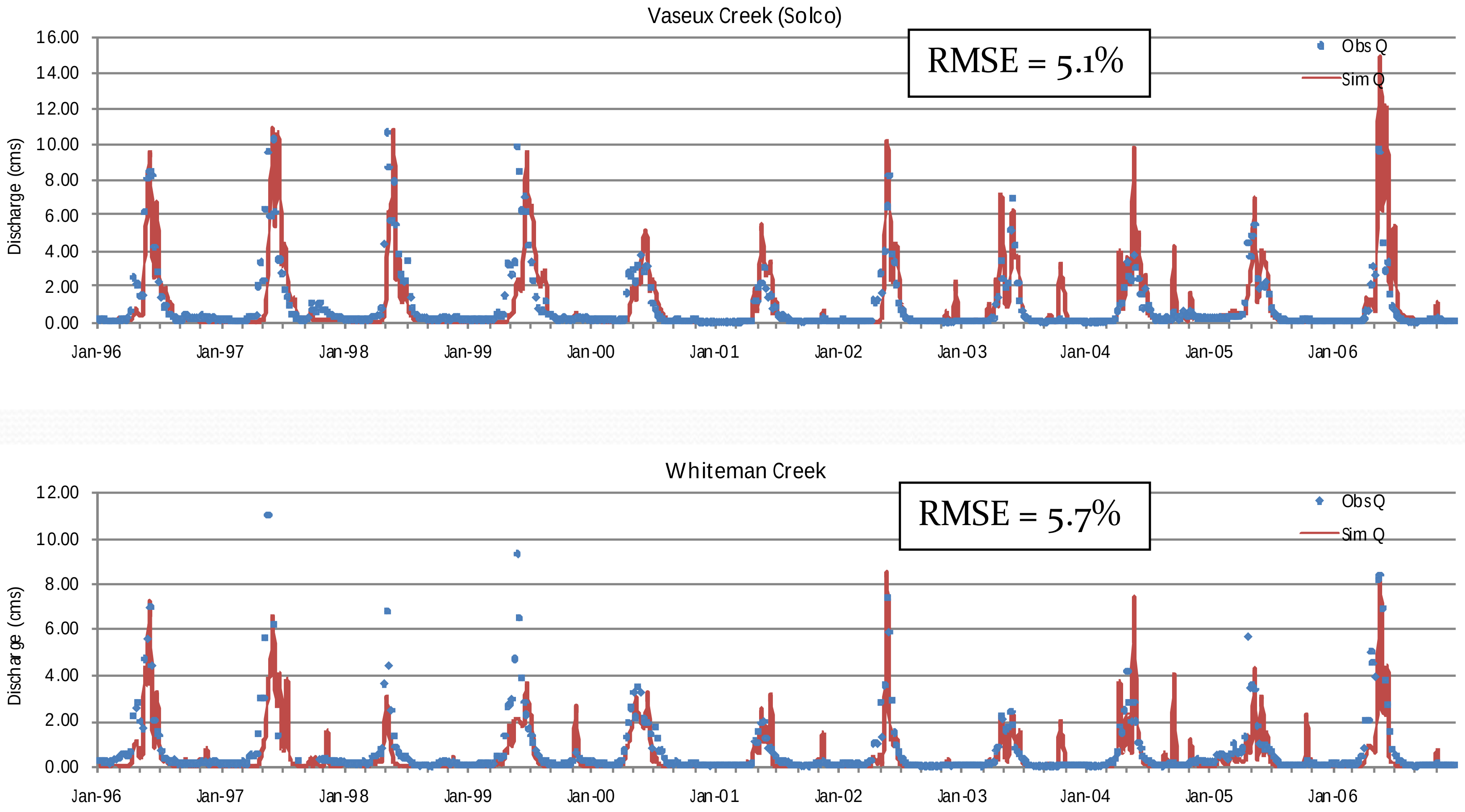
SWE Sept-95 – Sept 97

Calibration – Hydrographs



- 8 Natural Stations
- 8 Low Uncertainty
- 15 Moderate Uncertainty
- 49 High Uncertainty

Calibration – Natural Hydrographs

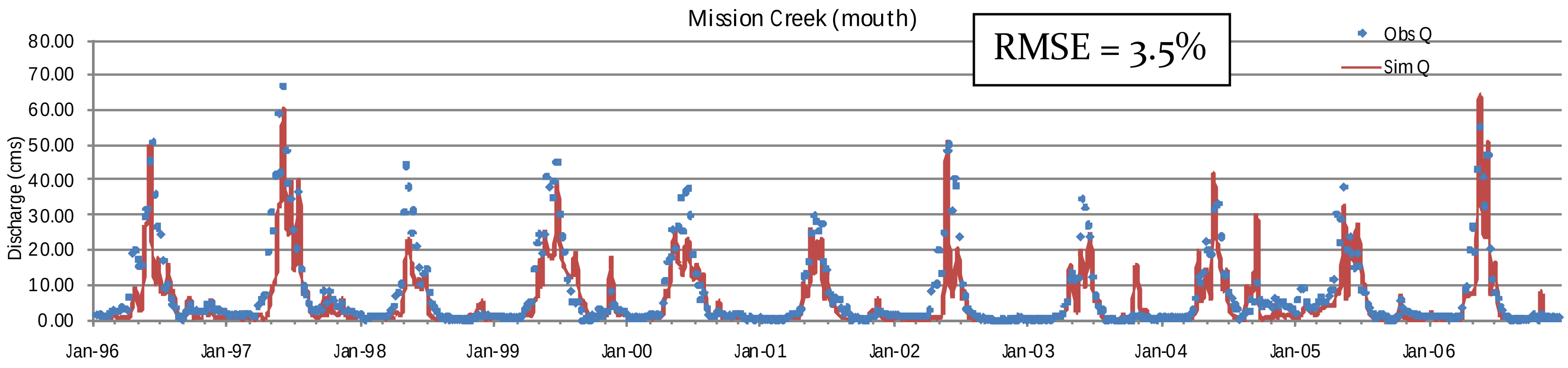


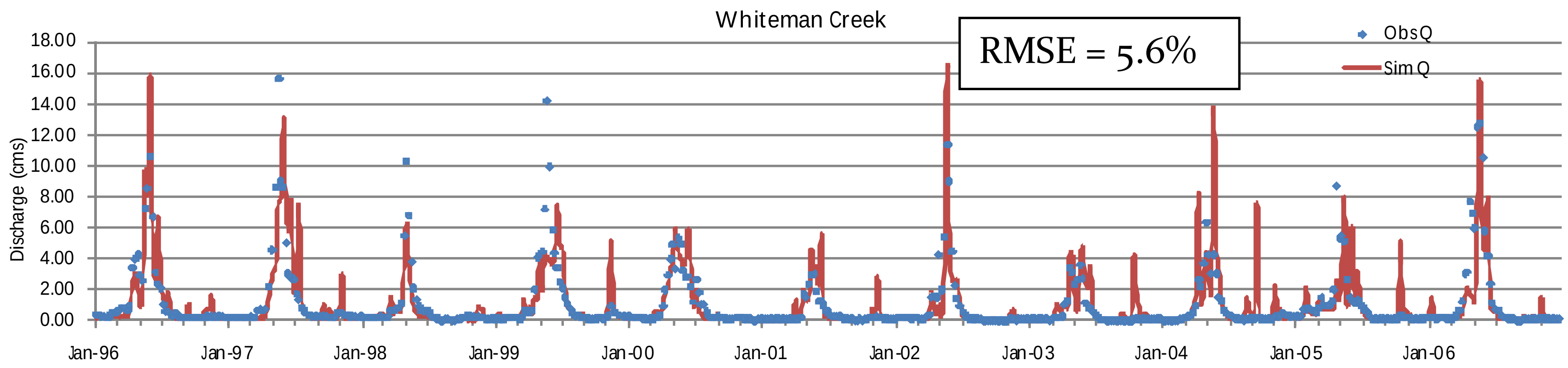
Calibration – Natural Hydrographs

- Total flow volume and high flow period volume match very closely
- Low flow period volume over-predicted as a result of simulated autumn runoff events

		Natural Stations	
		Total Volume (cm)	% Difference
Total	simulated	8.21E+08	2%
	observed	8.07E+08	
April - August	simulated	6.89E+08	-2%
	observed	7.03E+08	
Sept - March	simulated	1.32E+08	27%
	observed	1.04E+08	

Calibration – Low Uncertainty Naturalized

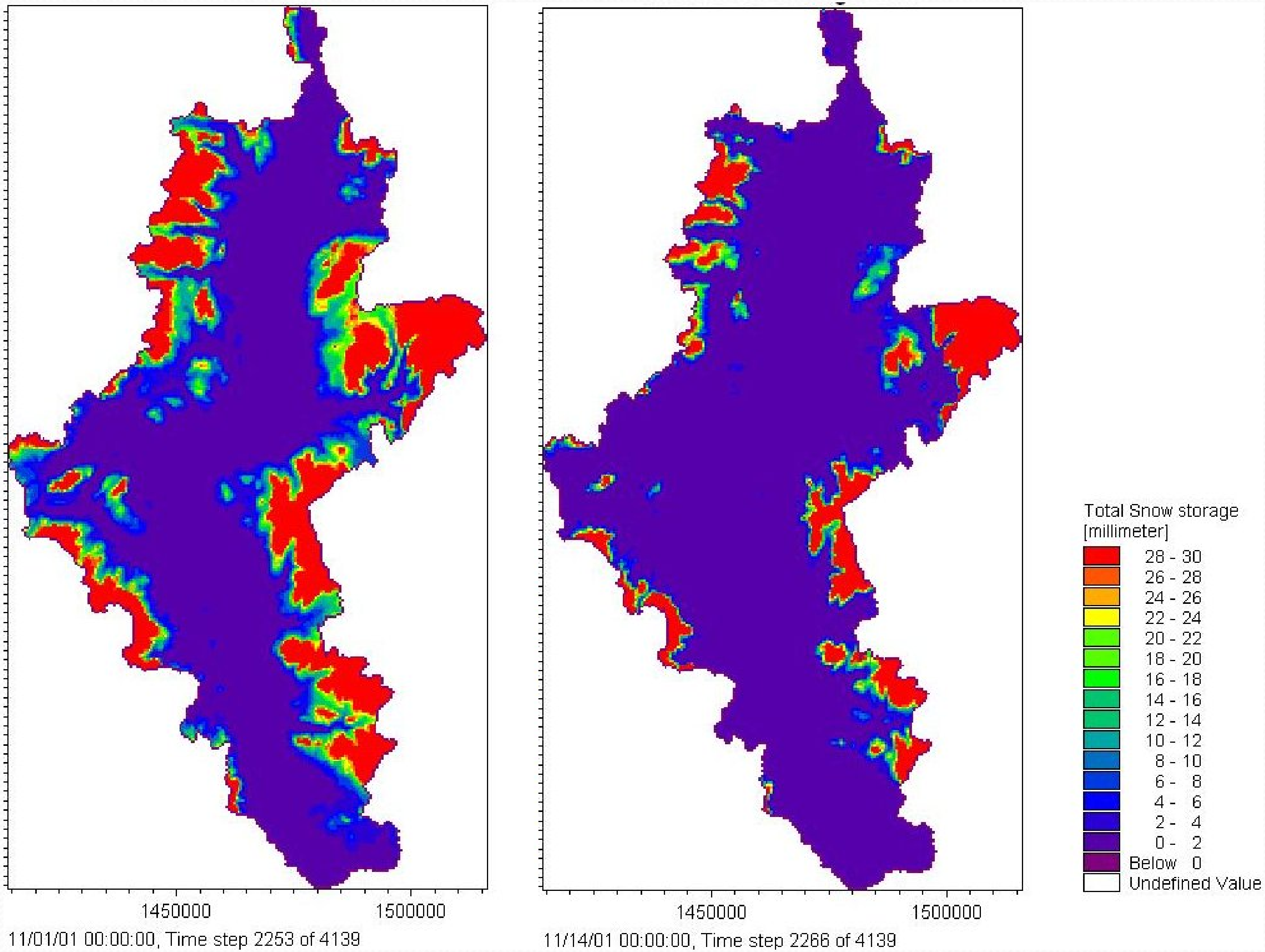




Calibration –Naturalized Stations

		Low Uncertainty Stations		All Stations	
		Total Volume (cm)	% Difference	Total Volume (cm)	% Difference
Total	simulated	4.22E+09	-10%	1.29E+10	18%
	observed	4.69E+09		1.10E+10	
April - August	simulated	3.38E+09	-13%	9.29E+09	4%
	observed	3.87E+09		8.93E+09	
Sept - March	simulated	8.37E+08	2%	3.61E+09	78%
	observed	8.22E+08		2.03E+09	

Revised Calibration – Reducing Fall Runoff



Revised Calibration – Reducing Fall Runoff

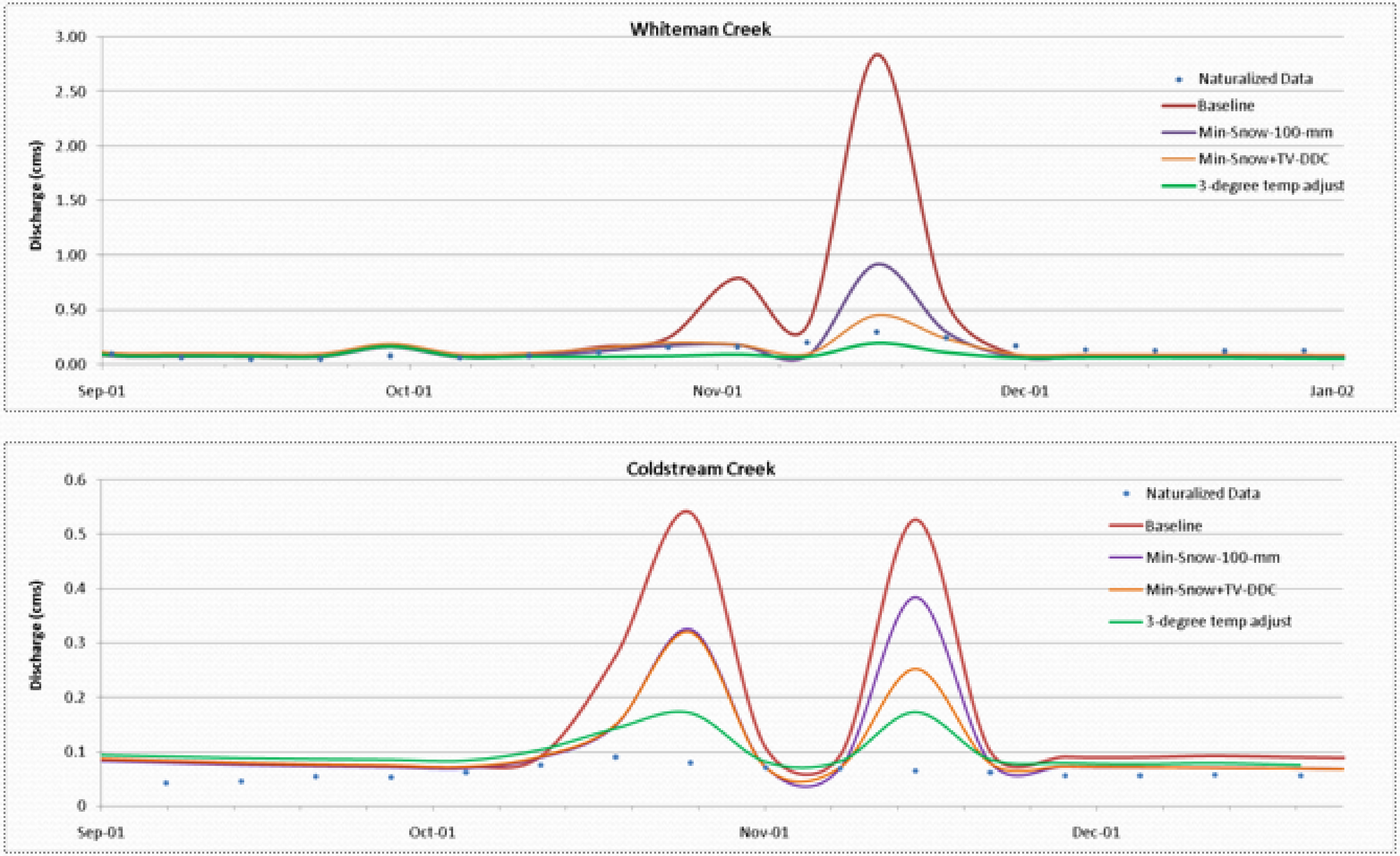
Potential Causes

- Inaccuracies in the temperature data
  - Inherently difficult time of year to capture
  - Inversions
- Limitations of the degree-day method
  - Temporal changes in melt energy
  - Sub grid-scale effects

Revised Calibration – Reducing Fall Runoff

- Uniform temperature adjustment
- Revised inversion period methodology
- Overland roughness coefficients
- Detention storage
- Soil infiltration rates
- Minimum snow storage for full coverage
- Time-varying degree day coefficient

Revised Calibration – Reducing Fall Runoff



Revised Calibration – Reducing Fall Runoff

- Reduced low flow volumes substantially
- Small improvement to high flow volumes
- Baseflow under-predicted

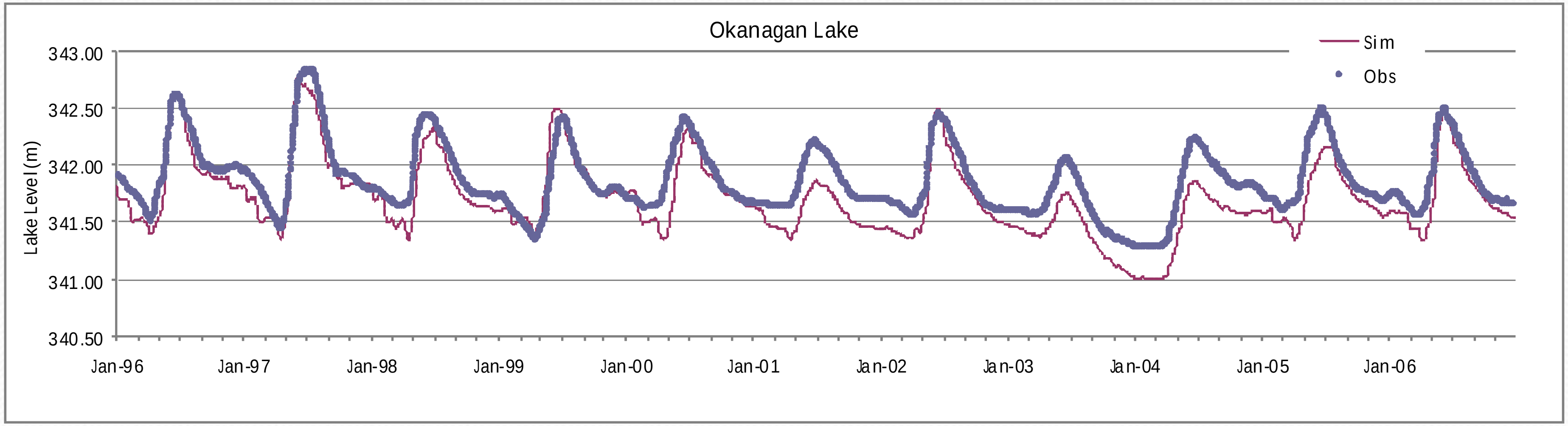
		Natural Stations		Low Uncertainty Stations	
		Original Difference	Revised Difference	Original Difference	Revised Difference
Total	simulated / observed	2%	1%	-10%	-12%
April - August	simulated / observed	-2%	2%	-13%	-9%
Sept - March	simulated / observed	27%	-6%	2%	-30%

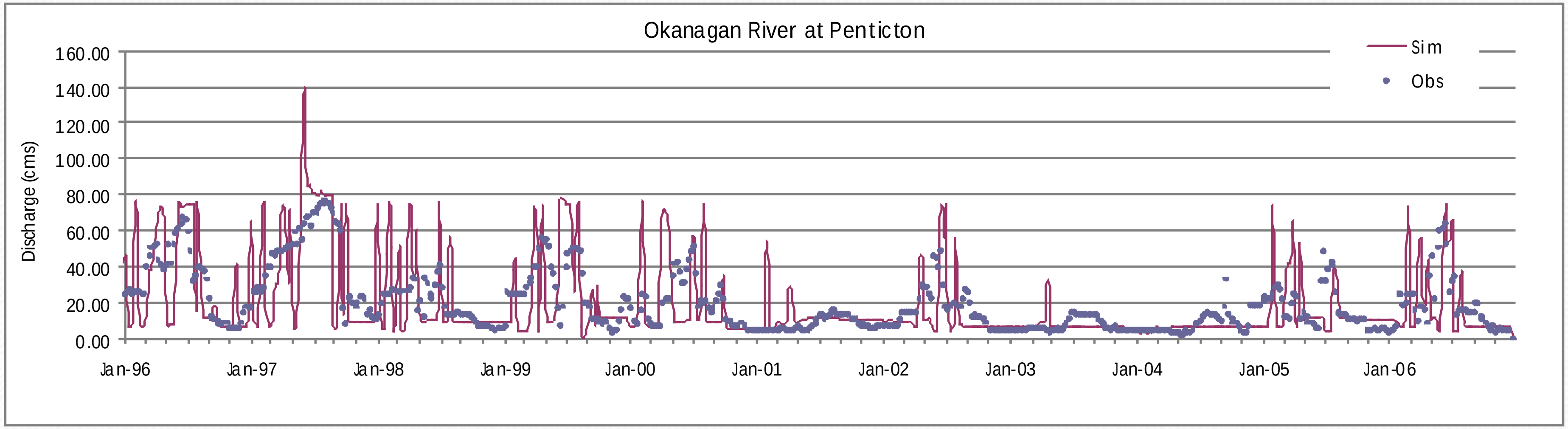
Calibration – Lake Operations

- Simplified model constructed to isolate lake operations - Okanagan Lake inflows from the FWMT specified as a boundary condition
- Various rule priority schemes based on the lake operation plan and the FWMT tested against historical water-levels and OK River discharges

Operational rules	Source	#1	#2	#3	#4
Maximum lake level	FWMT	1		1	1
Minimum lake level	FWMT	2		2	2
Minimum flow requirement downstream	FWMT			3	3
Maximum flow capacity at Penticton	FWMT	4			4
Maximum flow capacity at Oliver	FWMT	3			
Monthly lake level targets	operation plan	7	1	4	5
Flow requirement at Oliver from May 1 to Nov. 1 for Sockeye	FWMT	6		5	6

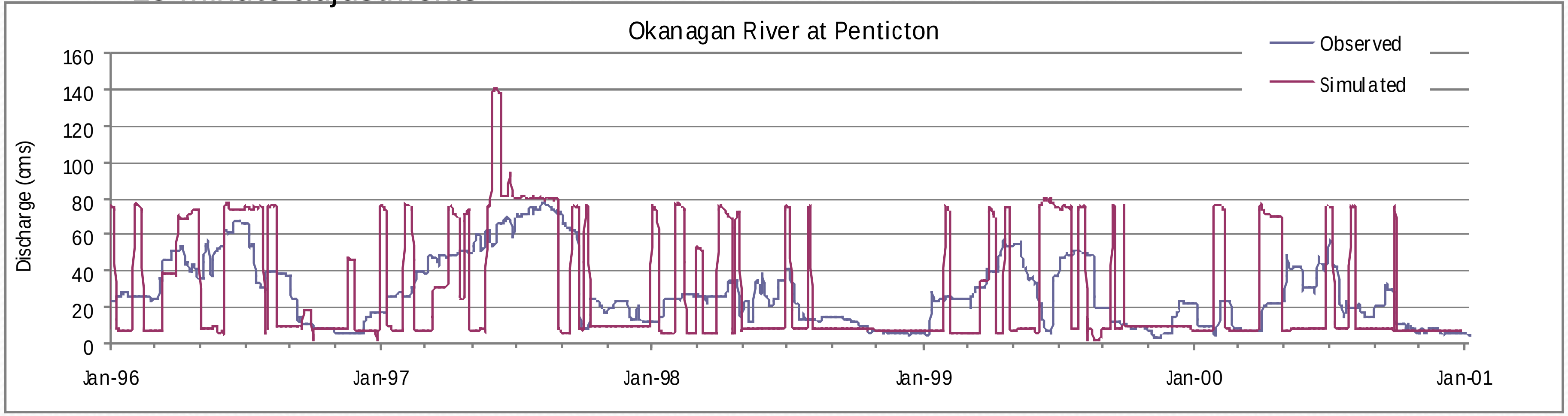
Calibration – Lake Operations



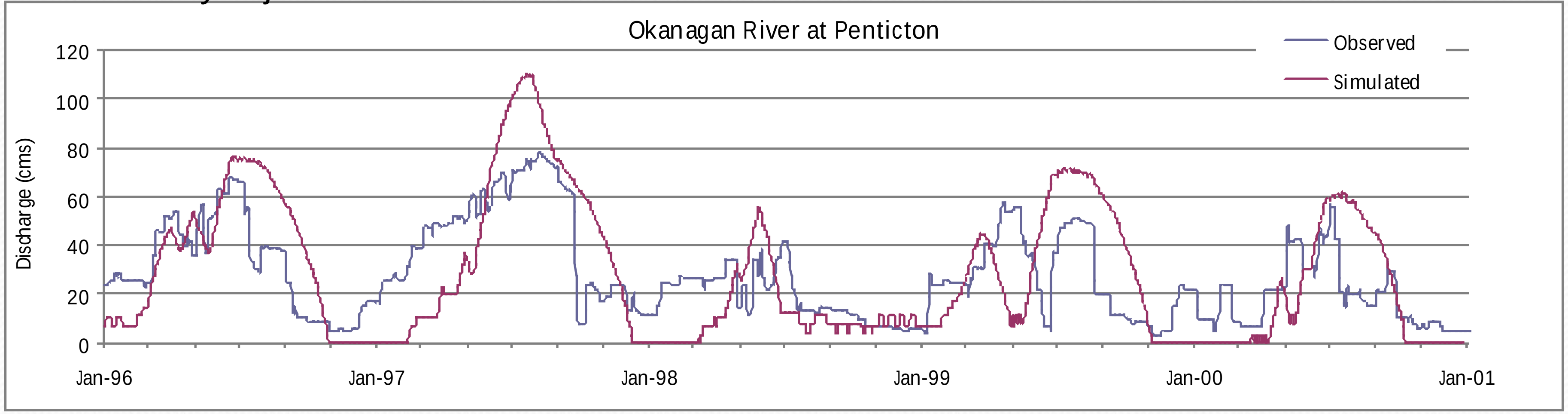


Revised Calibration – Lake Operations

15-minute adjustments

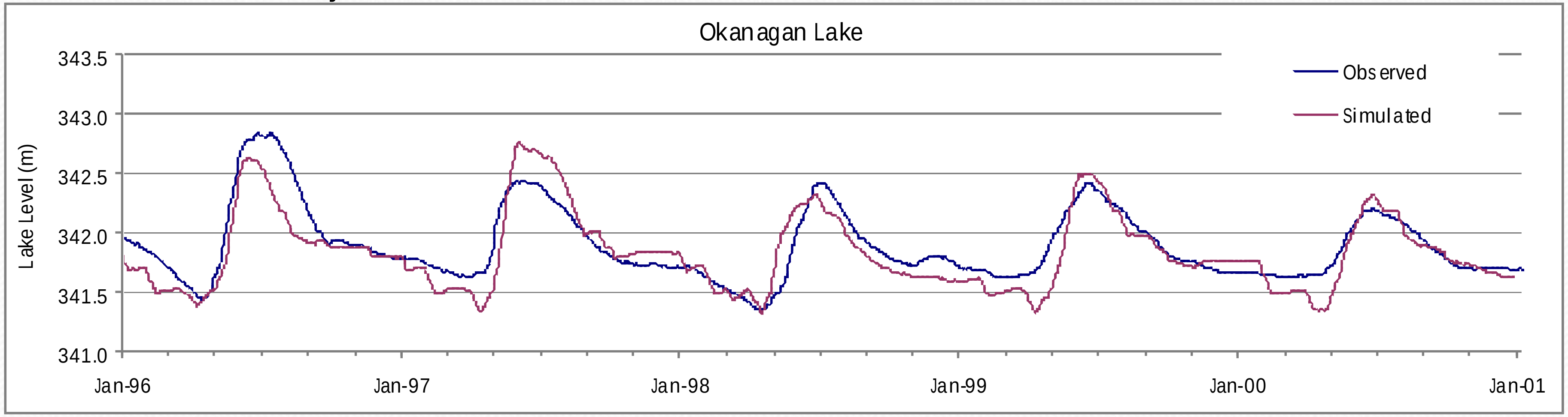


2-day adjustments

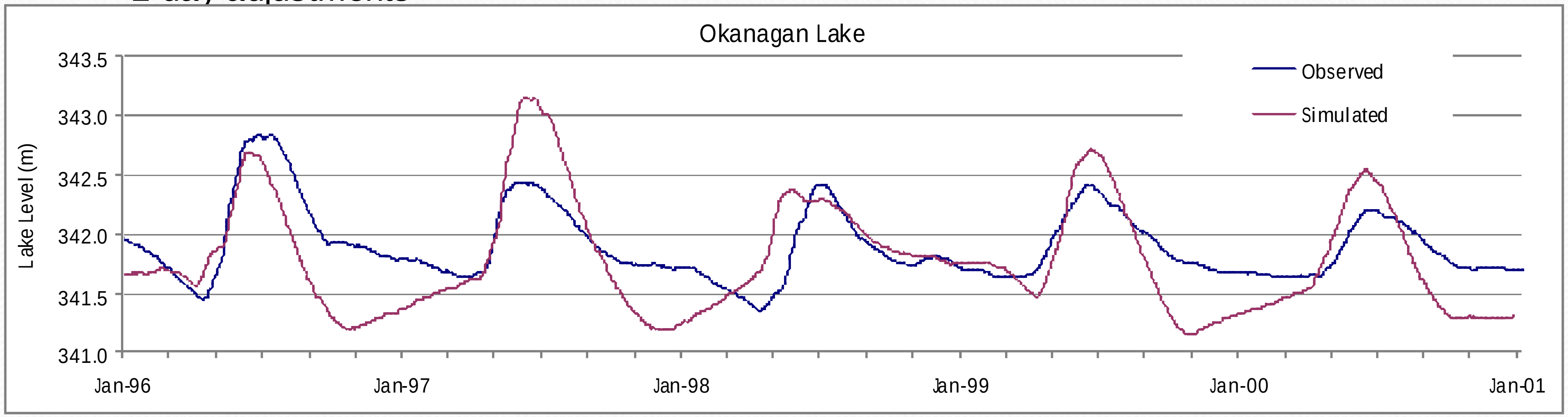


Revised Calibration – Lake Operations

15-minute adjustments



2-day adjustments



Results – Lake Evaporation

- MIKE SHE does not include a separate module for lake evaporation (simulated evaporation equals PET under moisture un-limited conditions in the absence of vegetation)
- Previous results influenced by drying lake cells – revised values shown below

	MIKE SHE Mean Annual Evaporation (mm)	Evaporation Study Mean Annual Evaporation (mm)	% Difference from Evaporation Study
Okanagan Lake	908.30	475.16	91%
Kalamalka Lake	918.21	270.53	239%
Skaha Lake	972.75	449.90	116%
Vaseux Lake	1008.69	363.27	178%
Osoyoos Lake	1065.86	368.85	189%

Water Accounting Model

- Incorporate timeseries of net water-use at each node into the hydrology model as boundary conditions
- Water-use terms:

$$Q_{WUnet} = (Q_{R\,i,t} + Q_{T\,i,t})\Delta t + RF_{S\,i,t} + RF_{G\,i,t} - E_{S\,i,t} - E_{G\,i,t} - (\Sigma R_{RH\,j})_{i,t}\,\Delta t$$

Q_R = Upstream reservoir component of streamflow

RF_S = Surface water component of return flow due to human activity

RF_G = Groundwater component of return flow due to human activity

Q_T = Rate of transfer from outside the natural contributing area

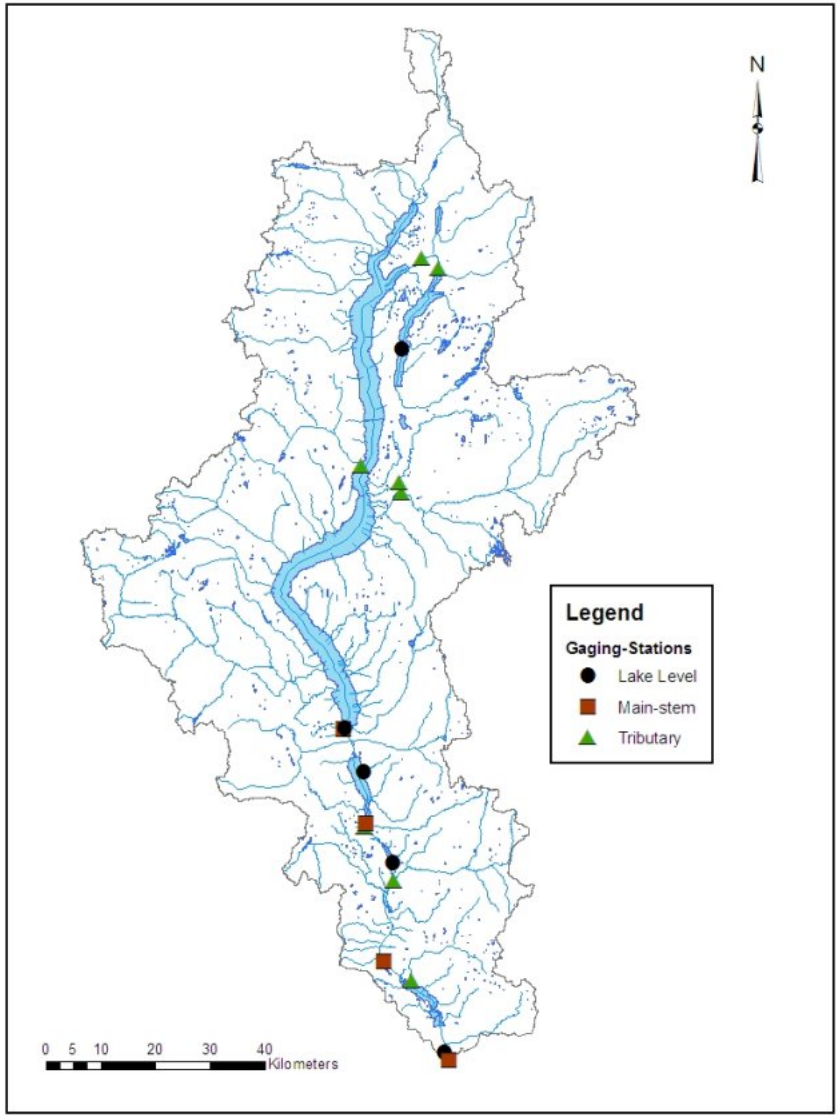
E_S = Rate of extraction from surface water sources

E_G = Rate of extraction from GW sources that would have discharged to streams

R_{RH} = Human-affected rate of loss from rivers to aquifer

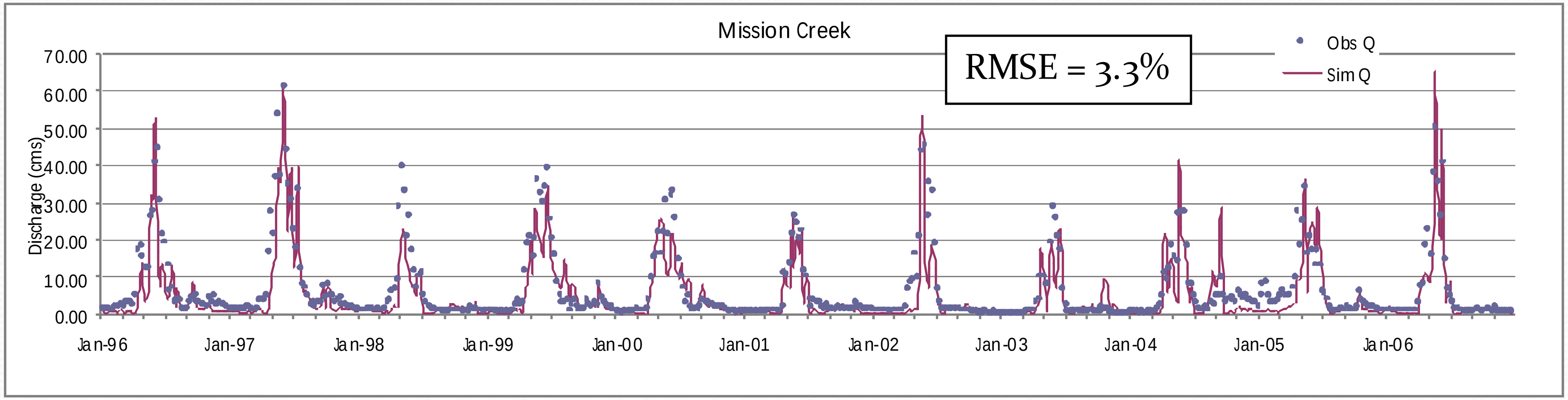
R_{LH} = Human-affected rate of lake/pond/wetland seepage loss

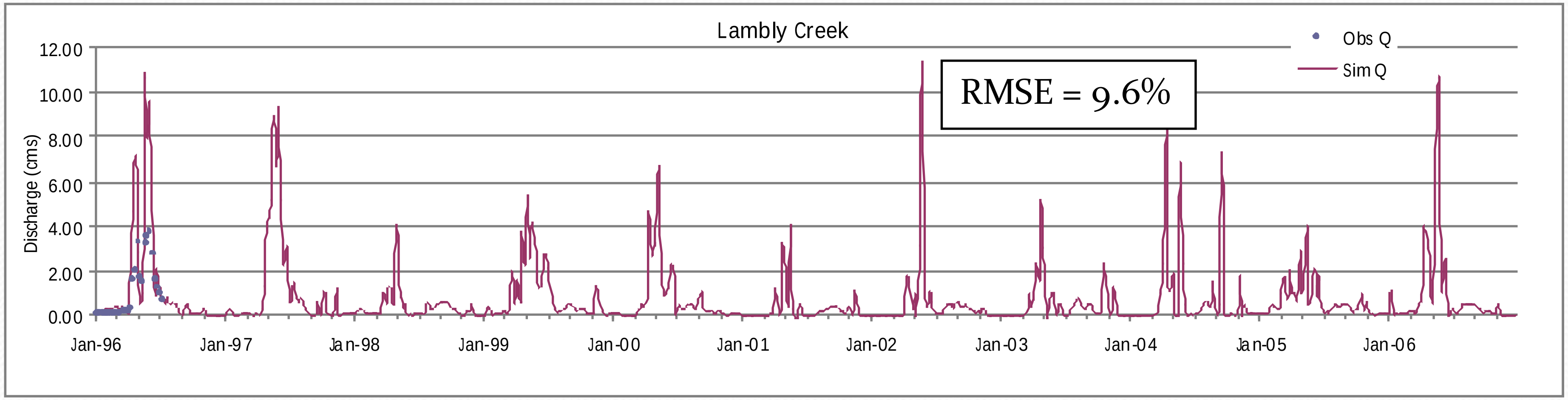
Water Accounting Calibration – Available Data



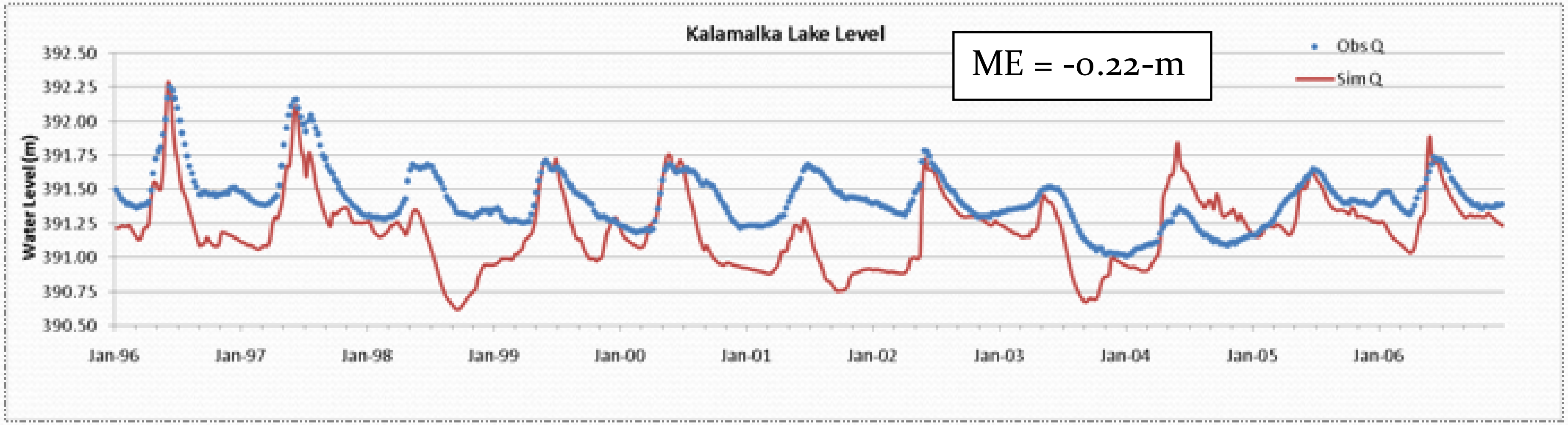
- Lake level – 5 lakes
- OK River – 4 locations
- Tributaries – 8 locations
  (+ 3 MOE stations?)

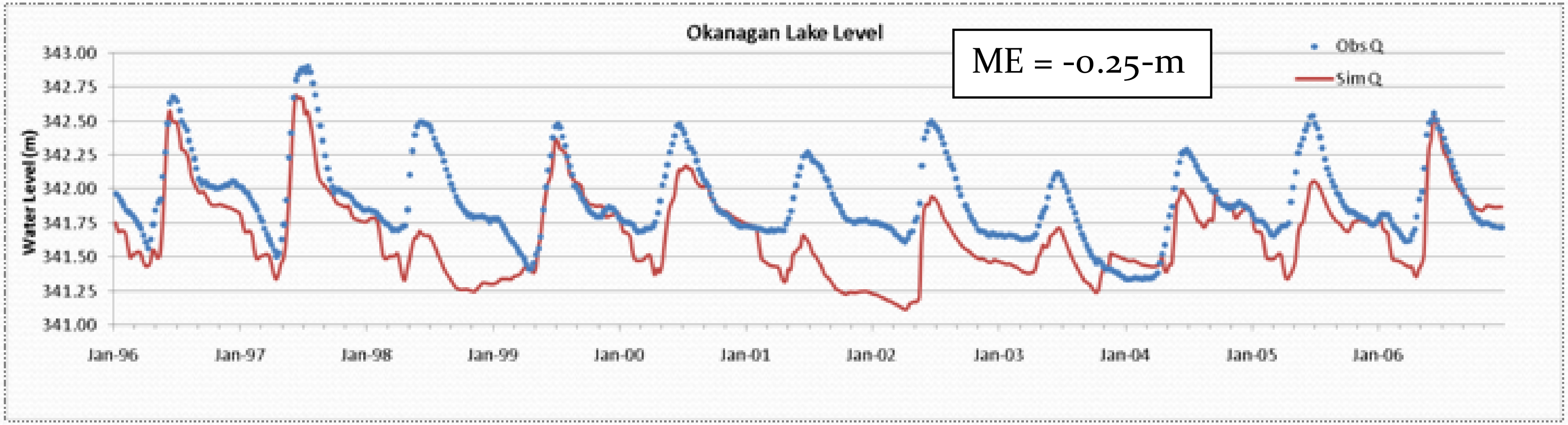
Water Accounting Calibration – Tributaries



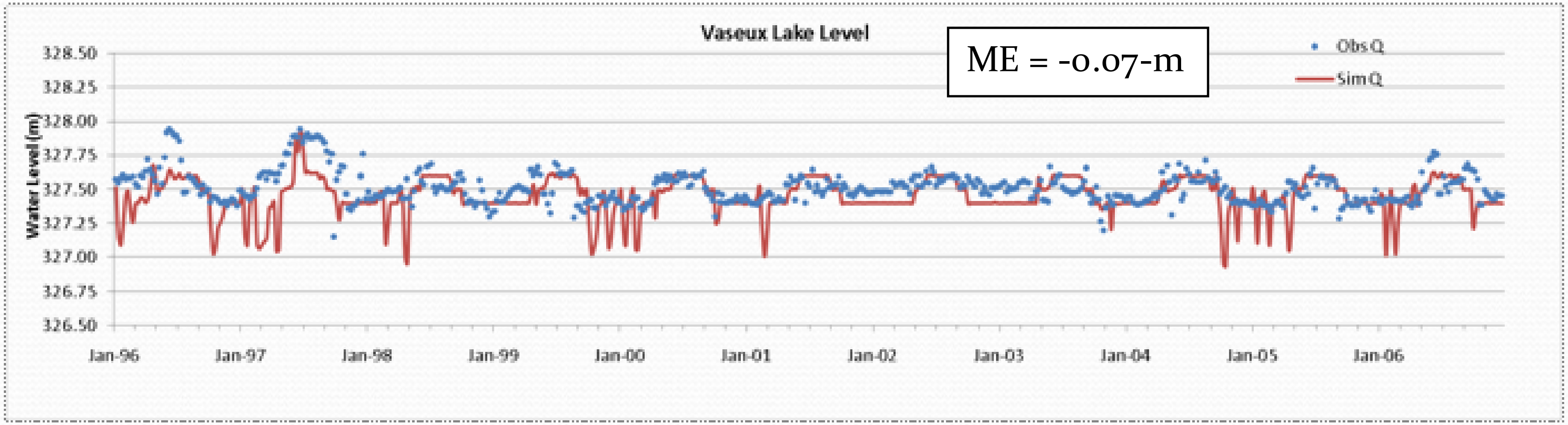


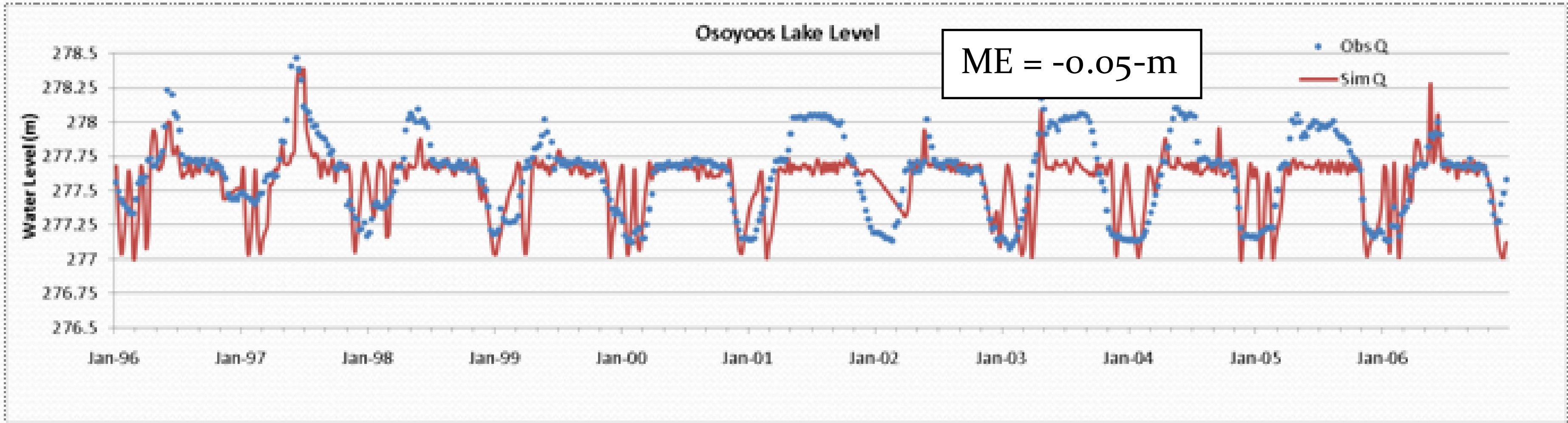
Water Accounting Calibration – Lake Level



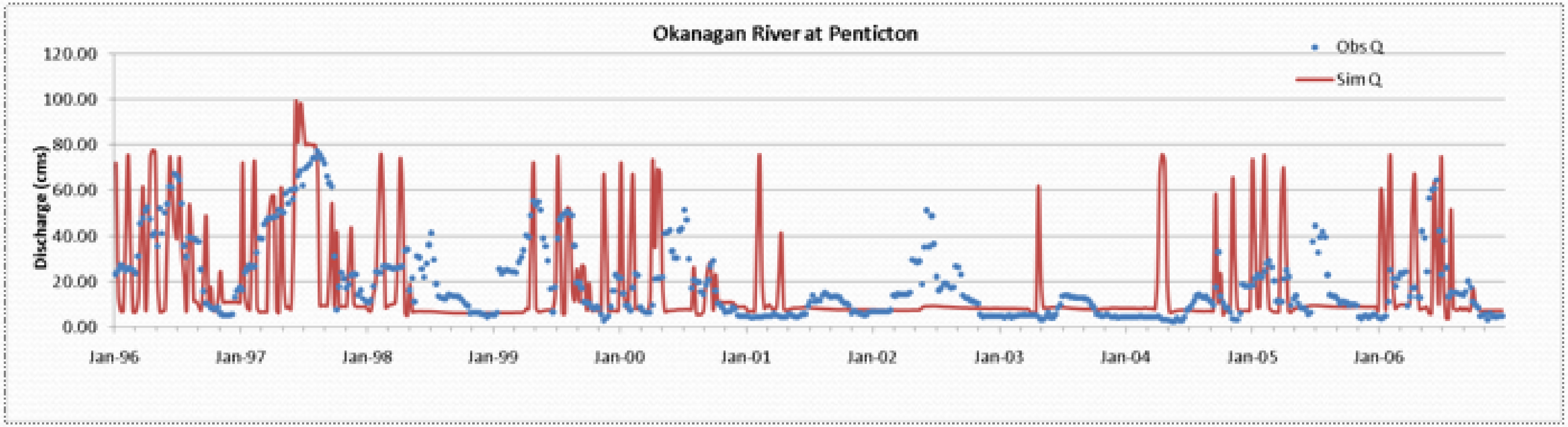


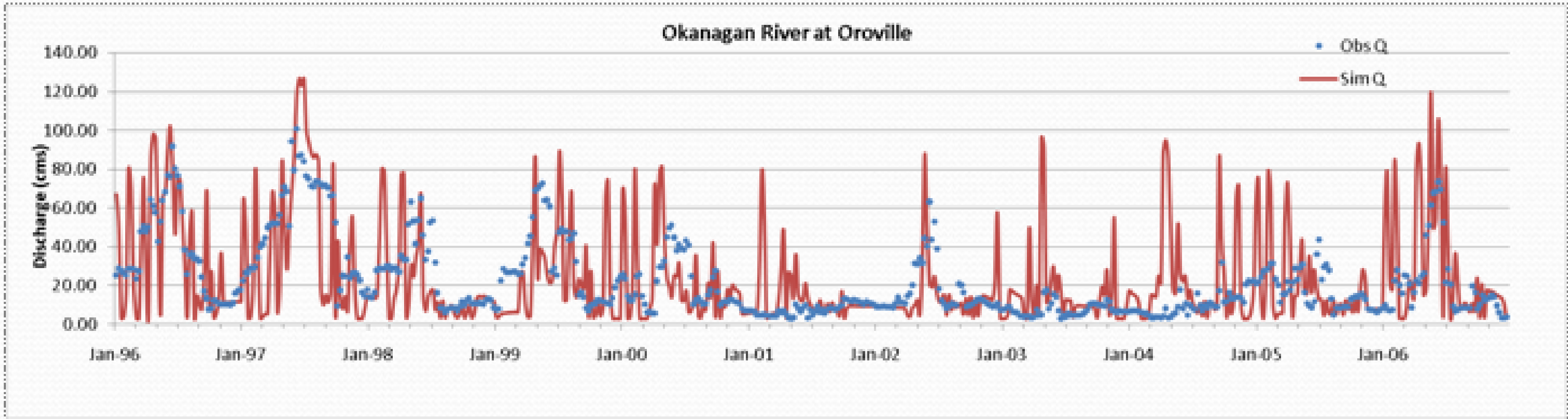
Water Accounting Calibration – Lake Level



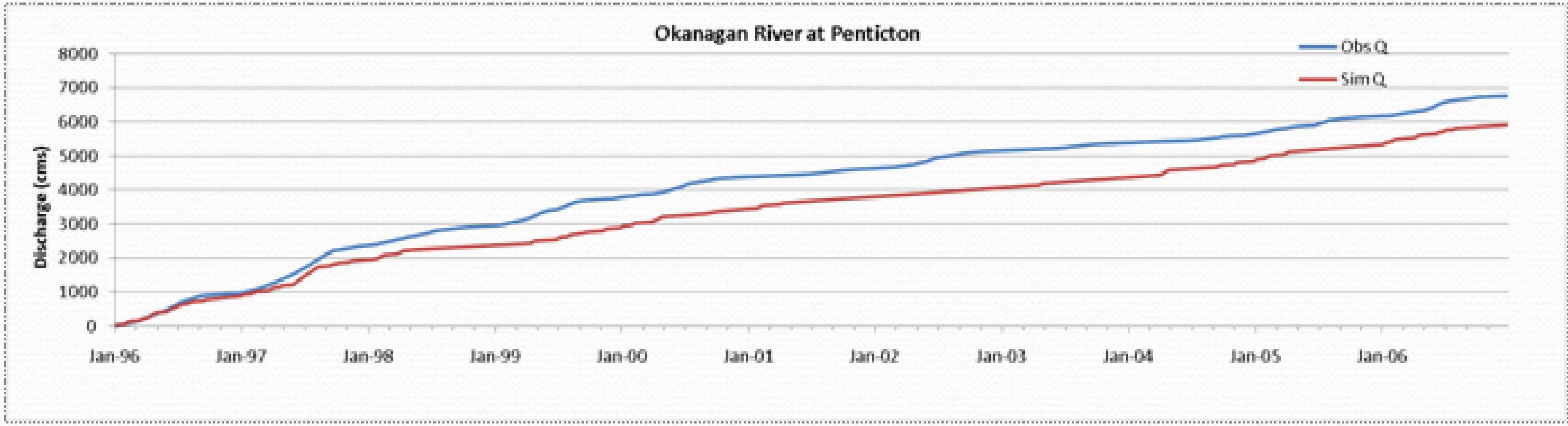


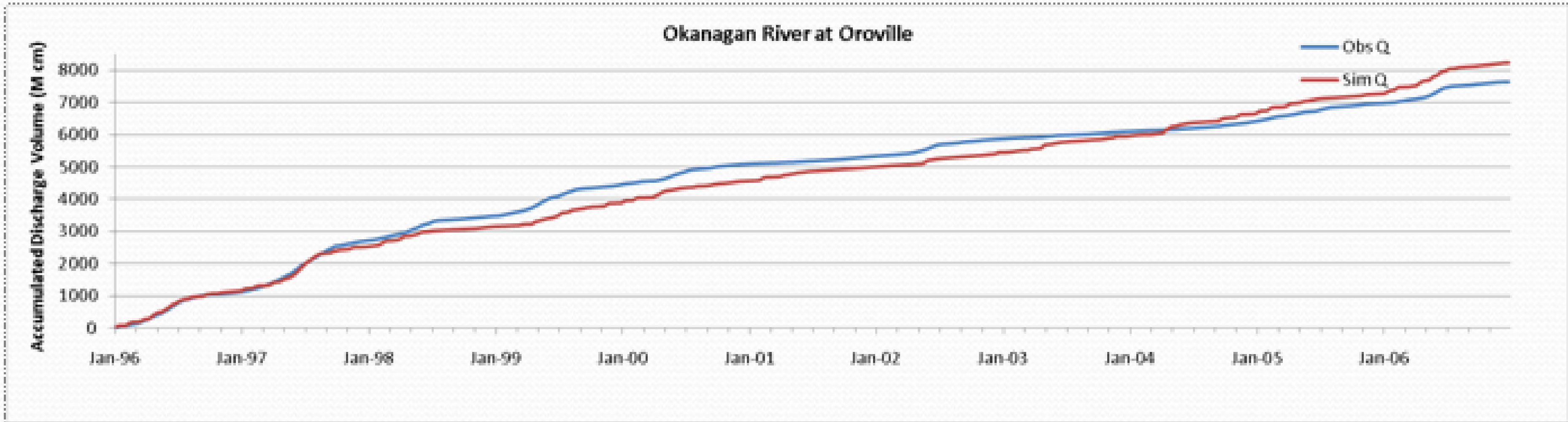
Water Accounting Calibration – OK River Discharge





Water Accounting Calibration – OK River Discharge





Summary

- Overall water budget agrees reasonably well with previous estimates - ET somewhat higher and runoff lower
- Snow accumulation and melt agrees well with observed data - tendency to over-predict snow accumulations at lower elevations and under-predict at higher elevations
- Tributary hydrographs agree well with naturalized and measured hydrographs for the most part
  - Freshet signal well-predicted
  - Fall runoff problem greatly reduced but still present
  - Under-predicted low flow period volume due to under-predicted baseflow

Summary

- Lake operations need improvement
  - Okanagan discharges fluctuate too rapidly
  - Skaha, Vaseux and Osoyoos lake levels fluctuate too rapidly
  - Decreased operation frequency improves pattern but reduces lake level calibration accuracy
  - More detailed information about operations needed

- Lake levels and outflows
  - Under-predicted lake levels for Kalamalka and Okanagan lakes but not for Skaha, Vaseux, and Osoyoos
  - Under-predicted OK river discharge volumes at Penticton and OK Falls but not at Oliver or Oroville

Next Steps

- Finalize water accounting model calibration
- Compare recharge and baseflow results with groundwater study estimates
- Perform a sensitivity analysis
- Estimate uncertainty of simulated hydrographs
- Upload results to the OK Water Database
- Scenario analysis