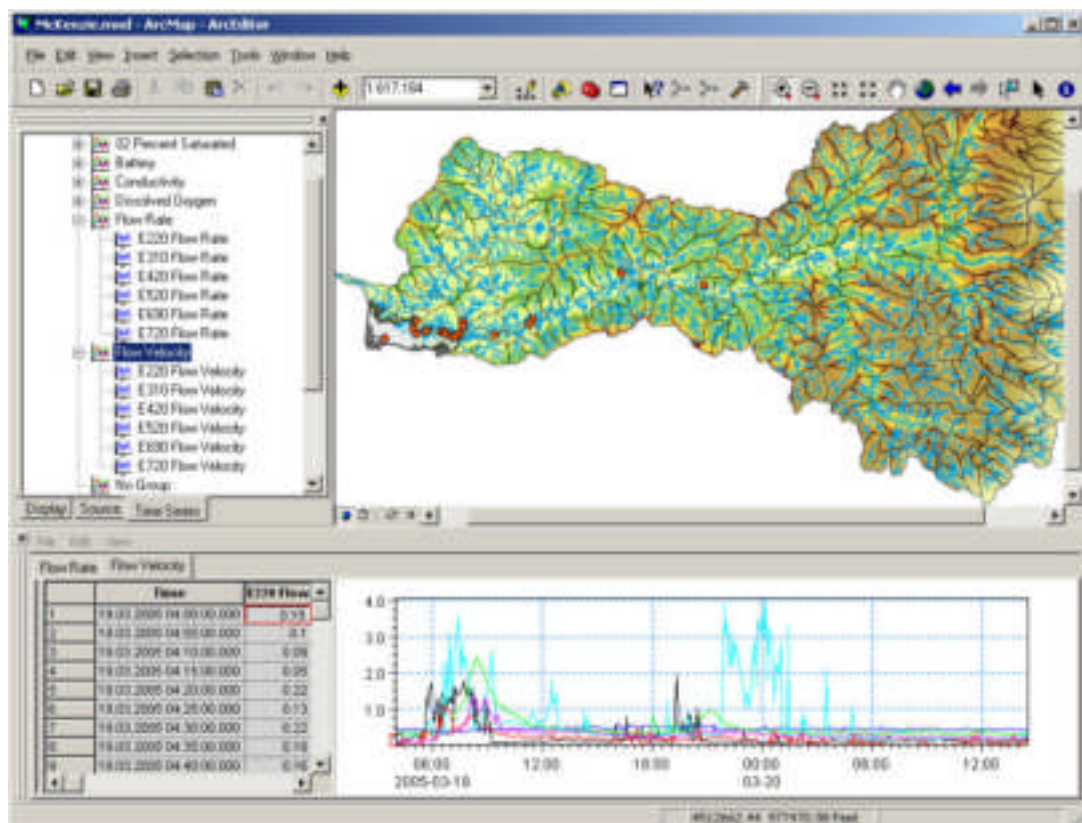


McKenzie River MIKE BASIN Model

Prepared for the:
Eugene Water & Electric Board

Prepared by:
DHI Water & Environment, Inc.
and Lane Council of Governments

June, 2008







© DHI Water and Environment , Inc. 2008

The information contained in this document produced by DHI Water and Environment, Inc. is solely for the use of the Client identified on the cover sheet for the purpose for which it has been prepared and DHI Water and Environment, Inc. undertakes no duty to or accepts any responsibility to any third party who may rely upon this document.

All rights reserved. No section or element of this document may be removed from this document, reproduced, electronically stored or transmitted in any form without the written permission of DHI Water and Environment, Inc.

All hard copies of this document are "UNCONTROLLED DOCUMENTS". The "CONTROLLED" document is held by DHI Water and Environment, Inc.



CONTENTS

1	INTRODUCTION.....	6
1.1	Background.....	6
2	METHODOLOGY.....	7
2.1	Model Descriptions.....	7
2.1.1	NAM.....	7
2.1.2	MIKE BASIN.....	8
2.2	NAM.....	10
2.2.1	Model Domains.....	10
2.2.2	Timeseries Data.....	12
2.3	MIKE BASIN.....	14
2.3.1	Channel Network.....	14
2.3.2	Catchments.....	14
2.3.3	Water Users.....	17
2.3.4	Reservoirs.....	18
3	CALIBRATION AND RESULTS.....	20
3.1	NAM.....	20
3.2	MIKE BASIN.....	26
4	CONCLUSIONS.....	35
4.1	Recommendations.....	36
5	REFERENCES.....	40



LIST OF TABLES

Table 1: Catchments included in the MRMBM.....	11
Table 2: Water Users by Catchment.....	18
Table 3: Mohawk River NAM Model Calibration Parameters.....	22
Table 4: Flow Volume Calibration Metrics and Water Budget Summary for the Mohawk River NAM Model.....	23
Table 5: Comparison of the Willamette River Basin Water Budget (Conlon, et al., 2005) with the Water Budget Simulated with the Mohawk River NAM Model.....	24
Table 6: Lookout Creek NAM Model Calibration Parameters.....	25
Table 7: Flow Volume Calibration Metrics and Water Budget Summary for the Lookout Creek NAM Model.....	25
Table 8: Comparison of Water Budget Estimates from a Variety of Sources with the Water Budget Simulated with the Lookout Creek NAM Model.....	26



LIST OF FIGURES

Figure 1: Meteorological Station Locations and Precipitation Polygons used in the MRMBM.	12
Figure 2: Channel Network and Locations of Nodes and Water Users Included in the MRMBM.	15
Figure 4: Relationships Between Temperature and Elevation Used to Determine Lapse Rates For Use in the NAM Models.	21
Figure 5: Mohawk River Simulated vs. Observed Flow Comparison.	23
Figure 6: Lookout Creek Simulated vs. Observed Flow Comparison.	26
Figure 7A-D: Comparison of the simulated versus observed hydrographs prior to applying reach gains/losses.	28
Figure 8A-D: Comparison of the simulated versus observed baseflow hydrographs and the reach gains/losses computed from the baseflow residue.	30
Figure 9: Average applied reach gains/losses by reach and cumulative reach gains.	32
Figure 10A-D: Comparison of the final simulated versus observed hydrographs.	32



1 INTRODUCTION

This document describes the initiative by the Eugene Water and Electric Board (EWEB) to develop a surface water budget model for the McKenzie River Basin in western Oregon. The model was constructed using DHI's MIKE BASIN model for the mainstem McKenzie River and major tributaries. In this text the term 'MRMBM' is used to refer to the McKenzie River MIKE BASIN model. The MRMBM Model includes a series of rainfall-runoff models constructed using DHI's NAM model in order to provide catchment inflows to the model.

The MRMBM will enable EWEB and other stakeholders to better quantify and represent sources and uses of streamflow throughout the entire McKenzie River Basin. This report documents the process by which the MIKE BASIN model and the rainfall-runoff models were developed. Model construction was a collaborative effort between EWEB, LCOG, and DHI and took place between December 2006 and April 2008.

This memorandum provides an overview of the methods and data used in the construction and calibration of the model. Specifically, the memorandum includes:

- A brief description of the numerical model codes
- Summaries of the data and assumptions that went into the model setup
- A description of the rainfall-runoff model
- Information about the model calibration process and calibration results
- Limitations of the modelling effort
- Results of the modelling effort
- Remaining data gaps that need to be filled
- Recommendations regarding further refinement of the model

1.1 Background

The McKenzie River is the sole source of drinking water for over 200,000 customers in the Eugene, Oregon metropolitan area. In order to protect this valuable resource from potential threats, the Eugene Water and Electric Board (EWEB) has developed a Drinking Water Source Protection Program. As part of this program, EWEB has contracted with DHI and LCOG to develop a watershed modeling system to assist in evaluating watershed health, quantifying anthropogenic influences in the watershed, and developing a program to insure a sustainable drinking water source.

The regional watershed model described in this document is designed to provide a quantitative assessment of water distribution and allocation within the watershed while giving EWEB an overall

water balance and general understanding of water movement throughout the basin. In order to better understand and manage the complex water resources within the McKenzie River Basin, EWEB and LCOG will continue to operate and maintain the model in order to evaluate various “what if” scenarios involving changes in water use and allocation and the impacts of climate change. The rainfall-runoff models may also be used to help evaluate the best times to collect additional field data during large rainfall events. A subsequent modelling effort will add a water quality component to the MRMBM model, and boundary conditions from the MRMBM model will be extracted for use in the development of a more detailed hydrodynamic model of the lower McKenzie River during a subsequent modelling phase.

2 METHODOLOGY

2.1 Model Descriptions

2.1.1 NAM

DHI’s Nedbør-Afrstrømnings-Model (NAM) is a lumped conceptual model for simulating streamflow based on precipitation at a catchment scale. Since its creation in 1973, NAM has been used worldwide in a variety of climatic and hydrologic settings to simulate runoff from precipitation events. The model can be used independently, dynamically with MIKE 11, or to develop input timeseries for MIKE BASIN catchment nodes.

NAM is a rainfall-runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow, and baseflow (DHI, 2003). As NAM is a lumped model, it treats each sub-catchment as one unit, therefore the parameters and variables considered represent average values for the entire sub-catchments. Precipitation in the form of snow is modelled as a fourth storage unit. For catchments with snow falling over a wide elevation range, the storage unit representing snow can be divided in up to ten subunits to represent different elevation zones. Water use associated with irrigation or groundwater pumping can also be accounted for in NAM. The result is a continuous timeseries of the runoff from the catchment throughout the modelling period. Thus, the NAM model provides both peak and base flow conditions that account for antecedent soil moisture conditions over the modelled time period.

Basic data requirements for the NAM model include catchment area, initial conditions, and concurrent timeseries of precipitation, potential evapotranspiration (ET), and stream discharge. When snowmelt is included in the model, temperature is required and radiation is optional. If the catchment is divided into elevation zones for the snowmelt calculation, also required are elevation of the precipitation gage, wet and dry adiabatic lapse rates (the rate of decrease of temperature with increasing altitude in the atmosphere), precipitation accumulation per zone, and maximum accumulation per zone.

Calibration of the NAM model involves adjusting the coefficients for the exchange of water between storage units and the storage unit depth so that simulated and observed discharges match as best as possible. A minimum of 3 years including periods of above-average precipitation is recommended for calibration, with longer periods resulting in a more reliable model. Disparity between simulated and observed discharge arise due to quality of timeseries data or other attributes. For ungaged streams, parameters developed for another catchment with similar topographic, climatic, geologic, vegetative, and land use characteristics can be applied.

2.1.2 MIKE BASIN

MIKE BASIN is an integrated water resource management and planning computer model that integrates a Geographic Information System (GIS) with water resource modelling (DHI 2006). In general terms, MIKE BASIN is a mathematical representation of the river basin, including the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing as well as potential major water use schemes and their various demands for water.

MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. Branches represent individual stream sections while the nodes represent confluences, diversions, locations where certain water activities may occur (municipal, industrial, reservoir, and hydropower water uses), or important locations where model results are required. The river system is represented in the model by a digitized river network that can be generated in ArcMap 9.2 (a GIS software package). All information regarding the configuration of the flow simulation network, location of water users, reservoirs and intakes, and outlets of return flow are also defined by on-screen editing.

Catchment inflows can be simulated using the rainfall-runoff model, NAM. The NAM model is a lumped, conceptual rainfall-runoff model which simulates overland flow, interflow and baseflow as a function of the moisture content in each of four mutually interrelated storages: snow storage, surface storage, root zone storage, and groundwater storage. Given rainfall and evaporation data, NAM calculates a runoff timeseries that can then be assigned to MIKE BASIN for use in the river flow simulation.

MIKE BASIN has extensive reservoir modelling capabilities. For individual reservoirs, the performance of specified operating policies using associated operating rule curves can be simulated. Rule curves define the desired storage volumes, water levels and releases at any time as a function of existing water level, the time of the year, demand for water and possibly expected inflows. For periods of drought, release from reservoirs can be reduced a certain factor for each of several critical (also termed reduction) water levels. Evaporation from the reservoir, precipitation into it, and leakage losses from it are accounted for given a height - volume - area table.

Two types of reservoirs, and natural lakes, can be modelled. The standard reservoir has a physical storage that all users are drawing water from a common storage and operation rules for each user applies to the same storage. The allocation pool reservoir also has a physical storage, but the individual users have been allocated a certain storage right ("water banking"). An accounting procedure keeps track of the actual water storage in one pool for downstream minimum flow releases (water quality pool) and in the individual pools allocated for water supply users. Lakes have no operation rules, but a water level-dependent outflow.

Basic model inputs are timeseries data for catchment run-off, diversion, and allocation of water for the off-river nodes. Catchment runoff can be specific runoff data (from the RR Module or user defined) or gage data. Diversion nodes require either a timeseries of water allocation to each branch or an equation partitioning flow to each branch based on incoming flows to the diversion node. Irrigation nodes require timeseries data for demand, fraction of the demand satisfied by ground water, fraction of the demand returning to the river branch, and lag time for the return fraction to re-enter the stream. Water demand can be specified directly from an input timeseries or indirectly from agricultural use information.

Once the water usage has been defined, the model simulates the performance of the overall system by applying a water mass balance method at every node. The simulation takes into account the water allocation to multiple usages from individual extraction points throughout the system. Results from the model can be viewed as:

- A timeseries or monthly summary in graphic or tabular form.
- A map of visualized groups of results for the entire or any specified part of the model network in the ArcMap Graphical User Interface (GUI). Map views can be stepped through time to generate animation files. The GUI can help create graduated color result presentations for many combinations of results. Several result groups can be animated simultaneously (e.g. flow in the mainstem of the stream and extractions by users). Animations can be saved as a Windows movie (*.avi file) and imported into PowerPoint presentations.
- Model results are stored in a database that can be queried using Microsoft Access. The user can create programs in Microsoft Access to automatically generate reports to display results.

MIKE BASIN has additional capabilities, including the ability to simulate municipal, industrial, and hydropower water users; apply priorities to water distribution; simulate ground water use; and simulate transport and degradation of substances affecting water quality in rivers and reservoirs. Water quality substances that MIKE BASIN simulates include ammonia/ammonium, nitrate, oxygen, total phosphorus, and organic matter. Organic matter is represented in terms of biological oxygen demand and chemical oxygen demand. A more complete description of the capabilities and applications of MIKE BASIN can be found at <http://www.dhisoftware.com/mikebasin/>.



2.2 NAM

2.2.1 Model Domains

NAM models were constructed for each of the 25 (later expanded to 30) NAM catchments shown in Figure 3 in order to predict hourly and daily inflows for the MRMBM catchments that were not represented by gaged flow data or by reach gains/losses. Table 1 lists the catchments included in the MRMBM, including the type and drainage area of each catchment. Catchments were also defined (but not listed) along the McKenzie River valley floor to correspond to the six mainstem McKenzie River USGS gaging stations at Hayden Bridge, Walterville, Leaburg, Vida, South Fork McKenzie (Rainbow), and Trailbridge Reservoir. Catchment types other than NAM catchments are discussed in greater detail in section 2.3.2.

Catchment Name	Type of Input Model	Area (sq km)	Catchment Name	Type of Input Model	Area (sq km)
Anderson Creek	Gaged Spring	17.7	Lookout Creek	Gaged Streamflow	63.6
Bear Creek	NAM - WT	11.4	Lost Creek	Gaged Spring	199.8
Blue River	Gaged Streamflow	138.8	Lower Blue River	NAM - CC	12.3
Boulder Creek	Gaged Spring	35.1	Marten-Gale Creek	NAM - WT	39.8
Boulder Creek - Walterville	NAM - WT	10.4	McKenzie Above South Fork	Reach Gain/Loss	115.1
Camp Creek	NAM - WT	67.8	McKenzie Above Vida	Reach Gain/Loss	50.0
Cedar Creek	NAM - WT	26.7	McKenzie At Hayden Bridge	Reach Gain/Loss	29.8
Clear Lake Catchment	Gaged Streamflow	47.9	McKenzie at Walterville	Reach Gain/Loss	65.6
Cogswell Creek	NAM - WT	13.7	McKenzie Confluence	Reach Gain/Loss	36.5
Deer Creek	NAM - CC	59.1	McKenzie Leaburg Reservoir	Reach Gain/Loss	89.8
Deer Creek_Vida	NAM - WT	39.8	Mohawk River	NAM - WT	463.3
Elk Creek	NAM - CC	18.1	Olallie Creek	Gaged Spring	20.5
Ennis Creek	NAM - WT	22.0	Osborn Creek	NAM - WT	6.7
Finn Creek	NAM - WT	10.6	Quartz Creek	NAM - CC	108.9
Frissell Creek	NAM - CC	8.4	Quartz Creek Blue River	Gaged Streamflow	23.7
Gate Creek	NAM - CC	123.9	Ritchie Creek	NAM - WT	23.7
Haagen Creek	NAM - WT	8.6	Scott Creek	NAM - CC	29.8
Hackleman	Gaged Streamflow	37.1	Smith Below Dam	Gaged Streamflow	18.8
Hatchery Creek	NAM - WT	5.5	South Fork Above Cougar Dam	Gaged Streamflow	404.1
Holden Creek	NAM - WT	11.2	South Fork Below Cougar Dam	NAM - CC	22.4
Horse Creek	NAM - CC	405.0	South Fork Cougar Reservoir	NAM - CC	131.3
Indian Creek	NAM - WT	16.1	Tamolitch Creek	Gaged Streamflow	140.6
Johnson Creek	NAM - WT	20.5	Toms Creek	NAM - WT	8.5
Kink Creek	Gaged Streamflow	31.4	Trail Bridge Reservoir	Gaged Streamflow	6.6
Lane Creek	NAM - WT	7.3	Trout Creek	NAM - WT	9.7
Leaburg Canal	Reach Gain/Loss	1.1	Upper Smith River	Gaged Streamflow	40.3
			Walterville Canal	NAM - WT	25.2

CC = combined catchment, WT = weighted timeseries

Table 1: Catchments included in the MRMBM.

2.2.2 Timeseries Data

Timeseries data required for the NAM models include concurrent precipitation, temperature, and evapotranspiration (ET) data. Available flow data at the downstream-most point of a subset of the catchments were used to calibrate the models. The McKenzie River Basin is located in the western Cascade Range and in the upper portions of the basin, most of the precipitation falls as snow during the winter months, whereas in the lower portions of the basin, most of the precipitation falls as rain. Due to the mountainous nature of the basin, the precipitation and temperature measurements around the basin vary greatly. Precipitation and/or temperature data were available from three NRCS SNOTEL sites located in or near the basin (NRCS, 2007), six gages from the HJ Andrews Experimental Forest, seven NOAA/NWS cooperative observer network stations, four Remote Automated Weather (RAWS) stations, and one Lane Regional Air Pollution Authority (LRAPA) station. ET data were available from three AgriMet stations and two RAWS stations. The location of each meteorological station is shown in Figure 1 below.

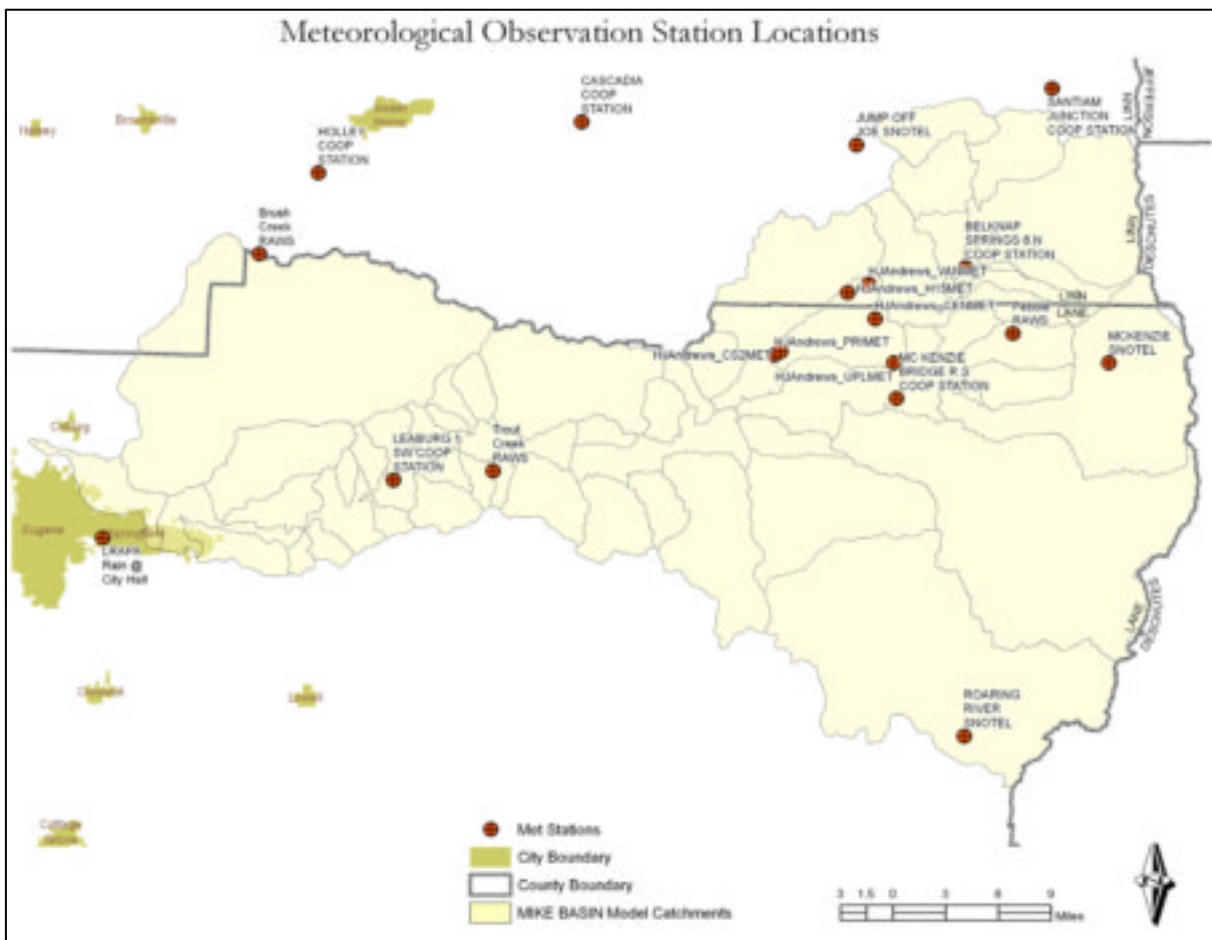


Figure 1: Meteorological Station Locations and Precipitation Polygons used in the MRMBM.



In addition to meteorological station data, spatially modeled continuous monthly and annual precipitation and temperature data is available for the U.S. at a resolution of 2.5 arc-minutes from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset (PRISM, 2006). An examination of the PRISM data indicates that precipitation varies widely within the McKenzie River Basin from approximately 40 to 130 inches/yr largely as a function of elevation; both annual precipitation and elevation generally increase from west to east across the watershed. Rain shadow effects are also a factor in controlling the variation of precipitation within the basin.

In order to obtain a precipitation distribution for the NAM models, the PRISM mean annual precipitation data from 2000 – 2005 was aggregated into ten-inch precipitation zones. One or more precipitation gages were assigned to each of the resulting seven PRISM precipitation zones by comparing the mean annual precipitation from the gage record with the aggregated zone value. For the PRISM zones where more than one gage was assigned, a Thiessen Polygon method was used to determine the portions of each zone that correspond to each gage. For the PRISM zones where only one gage was assigned, that gage was simply assigned to represent the entire PRISM zone. The various sets of Thiessen Polygon datasets were then merged with the simplified PRISM precipitation zones to produce a series of polygons with each polygon being associated with one of the 21 precipitation gage sites (Figure 1).

In most cases the NAM catchments crossed two or more of the precipitation polygons and the standard approach employed by the NAM model engine is to determine a single timeseries of precipitation and temperature based on the relative proportion of the catchment represented by each precipitation polygon. During the initial calibration process of the NAM model for the Lookout Creek catchment, it was determined that the area-weighted distribution of temperature timeseries data would not work well for catchments at higher elevations which receive greater amounts of snowfall because such an approach smoothes out differences in temperature within the catchment potentially resulting in lower snow accumulations and faster melting in higher-elevation areas and higher accumulations and slower melting in lower-elevation areas. Because the accumulation and subsequent melting of snow is the primary factor controlling discharge from the higher elevation (2,500 feet and above) catchments in the middle portion of the watershed, a decision was made to model these higher elevation catchments differently using a “combined catchment” approach. This approach utilizes sub-catchments (smaller areas of catchments defined by elevation zones) which are delineated and modeled separately then combined to estimate total catchment discharge. These delineations were created by examining elevation data from 10 meter DEMs, and dividing catchments into the following “snow zones”:

- Snow Zones
- 0 – 2500 feet
- 2500 – 3500 feet
- 3500 – 5000 feet
- 5000+ feet

The elevation break points were derived through an examination of snow survey data acquired from the HJ Andrews Experimental Forest. This dataset consisted of snow depths measured periodically over a period of approximately ten years at 40 locations of varying elevation along a roadside course

in the HJ Andrews Experimental Forest. For combined catchment NAM models, instead of assigning values of temperature, precipitation, and ET at each time step by averaging several different timeseries datasets, data for each sub-area are derived from a single elevation appropriate timeseries dataset. In this manner we were able to better represent the temperature variations in these catchments, which resulted in a significantly improved calibration result.

ET data were available at only two locations within the basin (three additional nearby ET stations were utilized.) The spatial variation of ET throughout the basin is much less significant than the variation in precipitation and temperature; thus a single ET gage was assigned to each model catchment based solely on proximity.

2.3 MIKE BASIN

2.3.1 Channel Network

The river network for the McKenzie River and its tributaries included in the MIKE BASIN model was developed by using the previously existing ArcHydro geodatabase encompassing the watershed. In general, the planar course of the rivers was copied directly from the hydrography feature classes in this database to serve as the MIKE BASIN model network (Figure 2). The model includes the mainstem of the McKenzie River as well as portions of 34 tributary streams. In addition to the McKenzie River and its tributaries, the model also includes two diversion canals, Walterville Canal and Leaburg Canal (Figure 2) as well as the complex Carmen-Smith diversion and hydropower generation system, though its operational characteristics are not yet simulated.

2.3.2 Catchments

Catchment runoff nodes represent locations in the model where water is introduced directly to the stream network system. For the MRMBM, the catchment inflows can be divided into four categories: simulated inflows from NAM, gaged spring inflows, stream gage inflows, and reach gain/loss inflows. Figure 3 shows the division of the catchments into these four categories.

The majority of the catchments were simulated with the rainfall-runoff model, NAM. Development of these models and generation of these inflow data are described in section 2.2 of this report. The upper portions of the basin are spring-flow dominated and proper simulation of the groundwater processes responsible for generating the inflows from these basins is beyond the capabilities of the NAM model which only allows for a very simplistic representation of groundwater processes. Due to the complexity of the groundwater processes in these spring-flow dominated basins, measured spring flows were applied, where available, as the inflow timeseries for these catchments. These flow timeseries datasets were provided by researchers at Oregon State University, who set up flow gages on

fifteen spring-dominated basins in the upper McKenzie watershed which recorded daily average flow between 2003 and 2005. The available flow data was extended to the full calibration time period by averaging available daily flow and using these results to expand the time series to cover the entire calibration period.

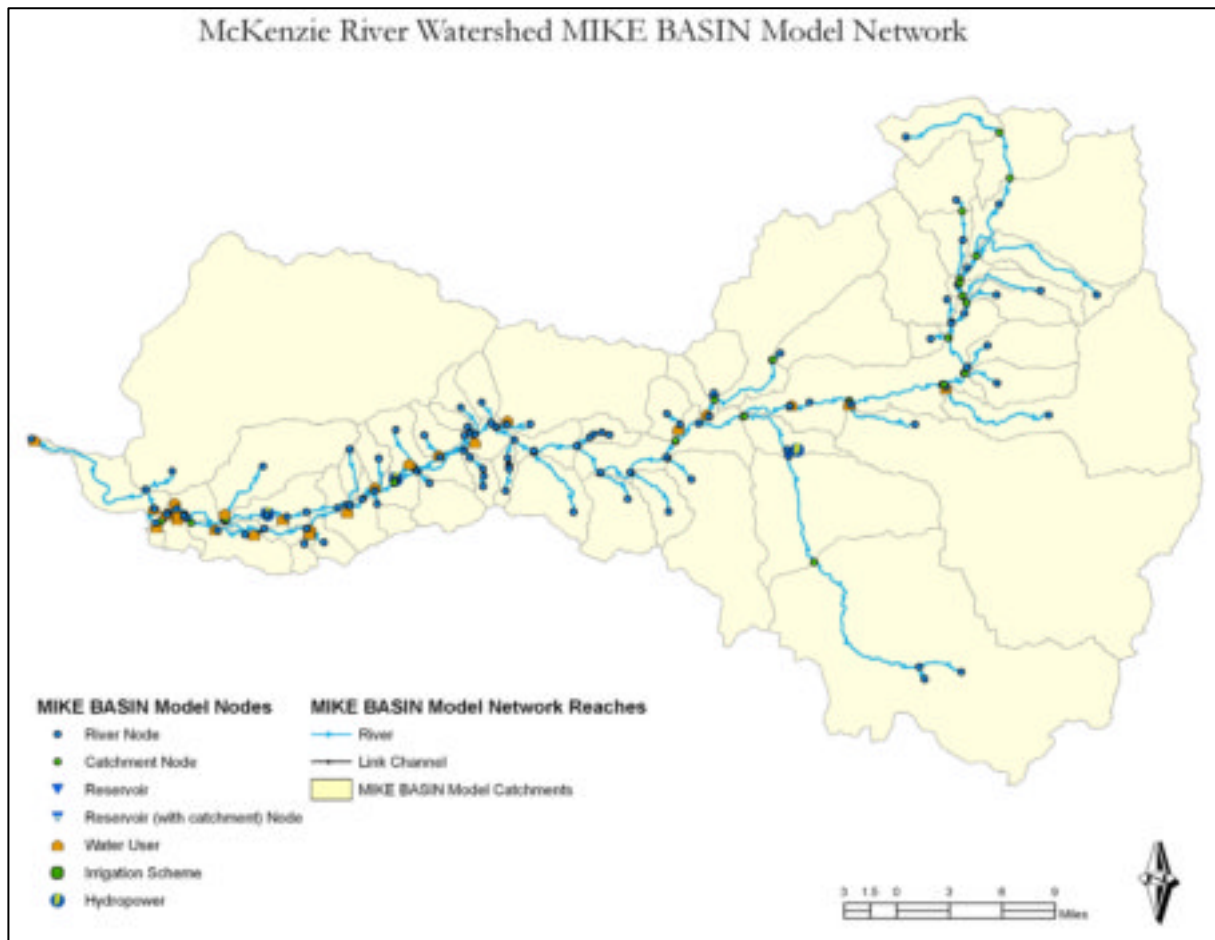


Figure 2: Channel Network and Locations of Nodes and Water Users Included in the MRMBM.

The upper-most portions of the watershed contain numerous high volume springs and examination of the spring-flow records revealed inconsistencies in the data. Thus the decision was made to lump all of the upper-most catchments together and add inflow to the MRMBM using the McKenzie River Below Trailbridge Dam USGS gage record. In essence, this gage location represents the upstream-most extent of the basin that is explicitly modelled for this study.

Adjacent to the main-stem of the McKenzie River there are portions of the basin drainage area that are not associated with a significant tributary stream. Runoff generated from this corridor along the main-stem is expected to be a relatively minor portion of the total basin runoff. Exchange between the surface water and groundwater systems is also expected to occur within this area, and simulation of the complex groundwater hydrology responsible for this exchange is beyond the scope of this study. Thus in order to account for the surface water/groundwater exchanges occurring along the main-stem, timeseries of reach gains/losses were determined by performing a hydrograph separation technique to the simulated and observed discharge timeseries at the six main-stem gages and assuming that the differences between the two baseflow hydrographs (residuals) represent the surface water/groundwater exchanges occurring in this area.

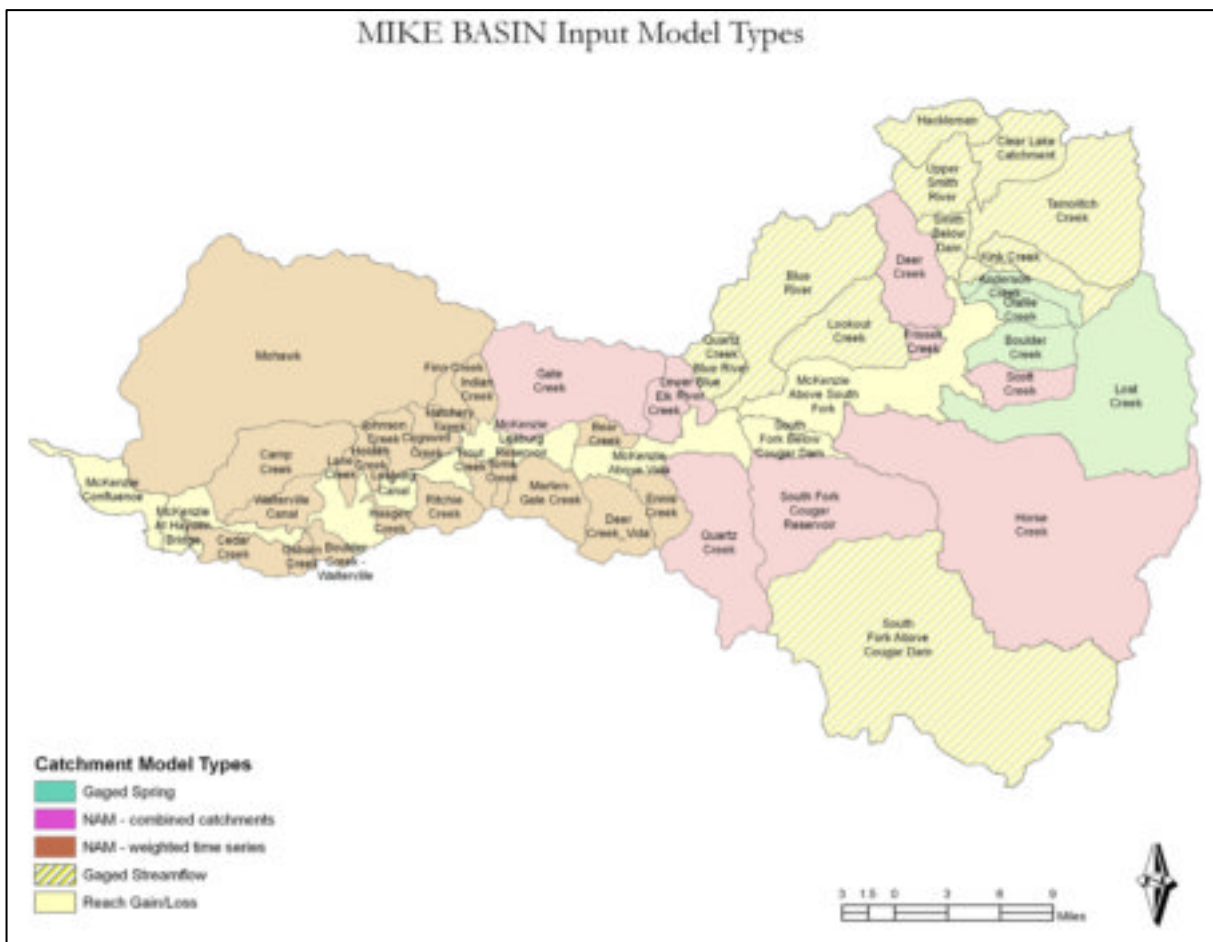


Figure 3: Catchments included in the MRMBM.

Best judgment and existing studies addressing surface water/groundwater exchange in the area were used to determine if the magnitudes of the reach gains/losses computed from the residuals at the gage



locations were reasonable. This was an iterative process whereby the flow at the gages was simulated and the reach gains/losses computed, and the NAM models were re-visited until the computed reach gains/losses were determined to be reasonable. This process is described in greater detail in section 3.2.

2.3.3 Water Users

An estimate of consumptive water use was included in the MRMBM. Data on water rights from the Oregon Water Resources Department (OWRD) were obtained and analyzed in order to synthesize the data into hourly time step timeseries files. These data were aggregated at the catchment level except for major water users including EWEB's drinking water intake at Hayden Bridge, Weyerhaeuser Corporation's Springfield plant, and the Springfield Utility Board. In order to estimate water-use timeseries data sets from the OWRD water-rights data, consumptive use factors described in *Determining Surface Water Availability in Oregon* (OWRD Open File Report SW 02-002) were followed (Cooper, 2002). The resulting hourly timeseries datasets were then assigned to the appropriate water user represented in the model. A summary of catchments where estimated water users were included is shown in Table 2 below.

Catchment Name	Number of water rights	Estimated Total Annual Use (cf)
Boulder Creek - Walterville	8	11,184,030
Camp Creek	20	44,151,327
Cedar Creek	32	119,799,801
Cogswell Creek	4	130,680
Elk Creek	15	784,080
Gate Creek	9	2,983,860
Holden Creek	6	5,194,530
Horse Creek	7	32,670
Johnson Creek	6	3,604,590
Lost Creek	2	65,340
Blue River	32	219,678,525
McKenzie Above SF	64	14,897,520
McKenzie Above Vida	35	2,727,945
McKenzie At Hayden Bridge	30	63,287,235
McKenzie Walterville	88	40,578,318
McKenzie Confluence	76	1,422,091,341
McKenzie Leaburg Reservoir	87	12,348,171
Mohawk River	201	231,396,165
Osborn Creek	3	969,210
South Fork Cougar Reservoir	29	219,580,515
Walterville Canal	32	46,625,535

Table 2: Water Users by Catchment.

2.3.4 Reservoirs

A total of six reservoirs exist within the McKenzie River watershed; two United States Army Corps of Engineers projects – Blue River and Cougar Reservoirs, and four EWEB projects; the Carmen Diversion, Smith River, Trailbridge, and Leaburg dams. While all of these facilities were initially included within the MRMBM, detailed operational data were not available for all of them. Because of this lack of detailed operational data and the fact that long-term USGS measured discharge data were available a short distance downstream of the Cougar, Blue River, and Trailbridge Reservoirs, a decision was made to omit these reservoirs from the model for this initial calibration phase. In a future enhancement phase of the modelling, the reservoirs will be added back in once more detailed operational data becomes available.

2.3.5 EWEB Power Canals

EWEB maintains two separate canals which divert water from the main-stem McKenzie River, flow parallel to the river for a distance, run through hydroelectric generation facilities, and then return flow back to the river. The upper canal, Leaburg Canal, starts at the Leaburg Dam and flows approximately



5.3 miles before returning to the river just downstream of the community of Leaburg. The Walterville Canal starts just upstream of the community of Walterville, flows 6.3 miles, and returns to the McKenzie River near the mouth of Camp Creek. In both cases USGS flow gages exist on the de-watered sections of the McKenzie River adjacent to these canals so for calibration purposes it was important to acquire a good source of high temporal-resolution flow data for these facilities. Unfortunately, reliable gage data was not available for either canal, however hourly hydro-electric generation data were available for both canals. These data were used to estimate canal flow at the power plants for the MRMBM using a well-established formula (provided by an engineer with EWEB's hydroelectric division staff):

$$\text{Flow (ft}^3\text{/s)} = P \times 11.98 \times 1000 / (n \times H)$$

where H = gross head, n = efficiency, and P = power (mW). For Walterville, H = 53.5 ft and n = 0.85 while for Leaburg, H = 88.5 ft and n = 0.80. For the Leaburg canal, NAM modelled discharge data for two small catchments that actually flowed into the canal above the hydropower generation facility were subtracted from the estimated flow in order to derive an estimated diversion flow time series data set.



3 CALIBRATION AND RESULTS

In order to calibrate the MRMBM, a two-step process was followed. First, NAM rainfall-runoff models were calibrated by LCOG for two tributary catchments within the model where long-term USGS gage data was available: Mohawk River and Lookout Creek. Once these models were calibrated, the NAM parameters determined for these two catchments were transferred to the models of the remaining catchments and the results from all of the NAM models were then imported into the MIKE BASIN model. The second and final phase of the calibration of the MRMBM model was then accomplished by DHI by comparing the simulated and observed hydrographs at the main-stem McKenzie River gages and computing reach gains/losses.

3.1 NAM

Besides being the only currently gaged, free-flowing, tributary catchments within the McKenzie River watershed, the Mohawk River and Lookout Creek catchments had the added benefit of being representative of two of the distinctly different climatological and topographical regions within the watershed. The Mohawk River catchment is a low-elevation, rainfall-dominated hydrologic unit characteristic of the western third of the McKenzie River watershed while Lookout Creek drains a higher-elevation, heavily-forested, steeply-sloped, winter snow-dominated region that is representative of the middle third of the watershed. As noted earlier in this report, the far eastern, highest portion of watershed is an area of relatively little surface runoff and heavy groundwater influence that was deemed unsuitable for simulation with the NAM rainfall-runoff model algorithm. Instead, measured flow data from a number of spring-dominated streams acquired from researchers at Oregon State University in addition to the USGS gage data at Below Trailbridge were used to represent the streamflow contribution from this area. A summary of the different input discharge models or data sources was shown in Figure 3.

The first step in the calibration of the NAM models was to acquire measured flow from the USGS gages 14161500 LOOKOUT CREEK NEAR BLUE RIVER, OR and 14165000 MOHAWK RIVER NEAR SPRINGFIELD, OR. Significant water withdrawal (primarily for irrigation) occurs upstream of the Mohawk River gage location, thus an estimation of water use was developed using data from OWRD. This estimated consumptive water-use timeseries was added to the gage record prior to performing the model calibration because the NAM model was set up to simulate only the natural processes responsible for runoff generation and it did not take into account anthropogenic water use.

For the initial simulations, rainfall-runoff parameters were set to default ranges with a number of notable exceptions. The NAM model contains a snow accumulation and melting component which, among other parameters, requires input values for temperature lapse rates. Based on previous research and discussions with Dr. Christopher Daly of the PRISM group at OSU, we knew that the default lapse rates (or $-1.0C/100M$ dry and $-0.6C/100M$ wet) were not appropriate. Location-appropriate lapse rates were determined by regression of the elevation and average daily high, low, and median temperature data from the 21 meteorological observation sites for which we had obtained timeseries data (Figure 4). Through this analysis, a revised value for the wet adiabatic lapse rate of $-2.7F/1000ft$

(or $-0.492C/100M$) was determined (a dry lapse rate of $-0.82C/100M$ was calculated using the proportional relationship of the default wet and dry rates). These values were adjusted downward by 25% in later calibration phases to better match observed snow values and final lapse rates were $-0.592C/100M$ (wet) and $-0.392C/100M$ (dry).

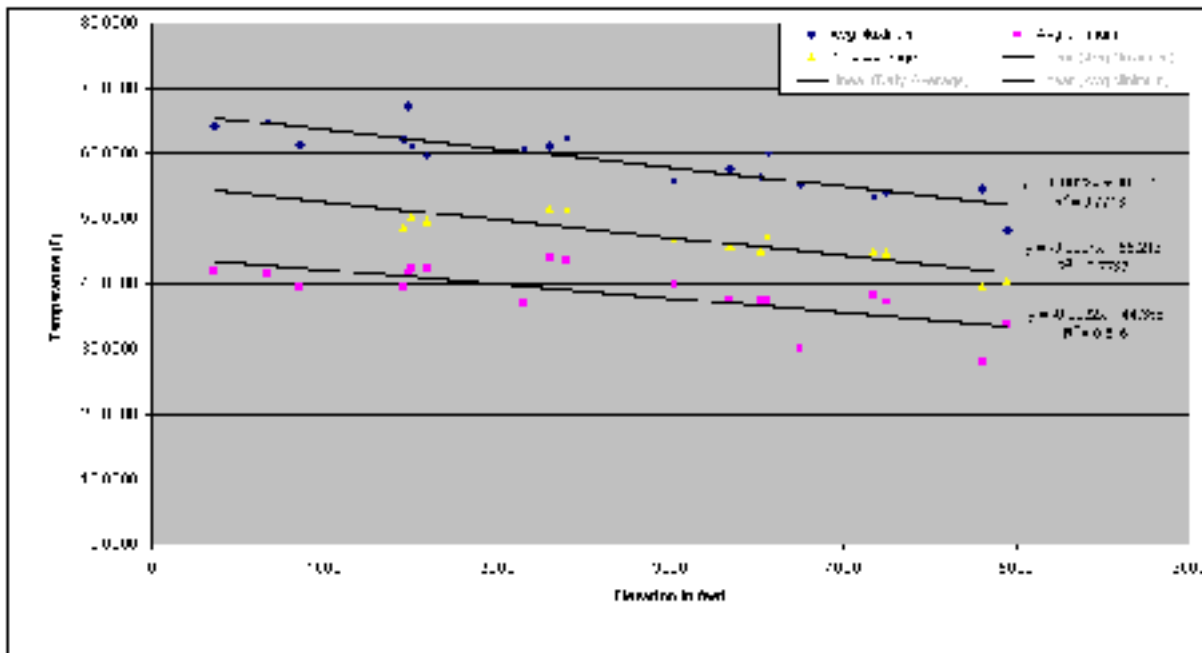


Figure 4: Relationships Between Temperature and Elevation Used to Determine Lapse Rates For Use in the NAM Models.

The next step in model development was to use the NAM model’s autocalibration module to estimate the remaining input parameters for the Mohawk River catchment. The calibration period of October 1, 2002 through January 1, 2006 was initially chosen for these autocalibration runs. This time period was later expanded to January 1, 2000 – November 3, 2006 in order to take advantage of additional available data. The autocalibration routine functions by varying a subset of the input parameters in the NAM model within a default range of parameter values in order to minimize the differences between the simulated hydrograph and the observed gage record. After examination of the initial results, modifications to the acceptable range of parameter values used by the autocalibration routine were made. After a second round of autocalibration, additional examination of the results was undertaken and it was determined that the model was under-predicting baseflow during the summer months. Manual adjustments to the NAM parameters affecting groundwater interaction were made until a satisfactory baseflow calibration was achieved. Final parameter values are shown in Table 3, a summary of the final calibration statistics and the components of the simulated water budget is included in Table 4, and a plot comparing the final simulated hydrograph with the observed record is shown in Figure 5. Upon completion of the Mohawk River NAM model calibration, the final NAM

parameters were then transferred to NAM models for the other lower-watershed catchments and modeled discharge timeseries were assigned to the appropriate catchment within the MRMBM.

The calibration results for the Mohawk River catchment were assessed on several levels. Overall annual water budget totals were compared with those described in the literature. Because there was no specific Mohawk River water budget study available, we looked at the hydrologic budget estimates for the Willamette River Basin that were described in *Ground-water Hydrology of the Willamette Basin, Oregon* (Conlon, et al, 2005). A summary of a comparison between the results of this study and those derived from the calibrated Mohawk River NAM model is shown in Table 5 below. While we would not expect the two budgets to agree precisely, given that the Willamette River Basin is a much larger basin with highly variable terrain, climate, and land-use characteristics relative to the Mohawk Basin, the comparison is useful to evaluate how well the NAM model is performing on a very general level. The Mohawk River water budget generally agrees with the budget estimates from the Willamette Basin study with slightly lower ET and overland flow and slightly higher groundwater recharge estimates for the Mohawk Basin when these budget terms are expressed as a percentage of precipitation.

The overall simulated discharge volume compares very well with the observed volume, with the simulated volume for the full calibration period (1/1/2000 – 11/3/2006) under-predicting the observed volume by 1.2%. A review of the plot showing simulated discharge vs. observed discharge reveals that the model tends to under-predict large flow events while slightly over-predicting low flow conditions. This is balanced against the fact that the model does an excellent job of predicting the timing of the peak flows and the overall shape of the hydrograph; rising and recession limbs are very close in shape and magnitude between the two hydrographs. Based on these analyses we feel confident in the ability of the NAM model to estimate catchment discharge given meteorological inputs for the Mohawk River catchment.

Parameter	Final Value	Lower Bound	Upper Bound
Umax	5	5	30
Lmax	130	25	450
CQOF	0.7	0.681	1
CKIF	118.7	100	2000
CK1,2	30	1	120
TOF	0.587	0	0.99
TIF	0.2	0	0.99
TG	0.1	0	0.99
CKBF	1400	100	4000

Table 3: Mohawk River NAM Model Calibration Parameters.

Period	Q-obs (million cm)	Q-sim (million cm)	%diff	Rainfall (mm)	Pot Evap (mm)	Actual Evap (mm)	Recharge (mm)	Overland Flow (mm)	Inter-Flow (mm)	Base-Flow (mm)
1/1/2000 – 1/1/2001	394.2	336.8	-6.8	1315.2	973.3	495.9	411.9	293.1	96.3	336.4
1/1/2001 – 1/1/2002	297.9	364.0	-10.3	1359.7	918.2	474.2	420.6	339.4	98.2	347.6
1/1/2002 – 1/1/2003	384.0	394.6	-1.3	1228.9	908.3	364.5	365.6	375.5	103.4	372.6
1/1/2003 – 1/1/2004	497.2	512.4	-1.4	1507	1013.1	406.2	439.2	545.7	121.3	438.6
1/1/2004 – 1/1/2005	397.8	368.6	-3.4	1205.1	999.3	500.3	335.8	285.2	107.9	402.4
1/1/2005 – 1/1/2006	350.1	345.6	0.6	1370.8	995.6	502.1	428	293.4	102.3	349.9
1/1/2006 – 11/3/2006	457.9	388.0	-7.1	1037.5	1031.4	457.6	256.9	367.2	71.9	398.3
1/1/2000 – 11/3/2006	2779.0	2710.0	-1.2	9024.1	6839.2	3200.6	2658	2499.6	701.2	2645.6

Coefficient of determination: R2 = 0.799

Standard Error: SE = -0.348 cfs, Root Mean Squared Error: RMSE = 248.7 cfs

Table 4: Flow Volume Calibration Metrics and Water Budget Summary for the Mohawk River NAM Model.

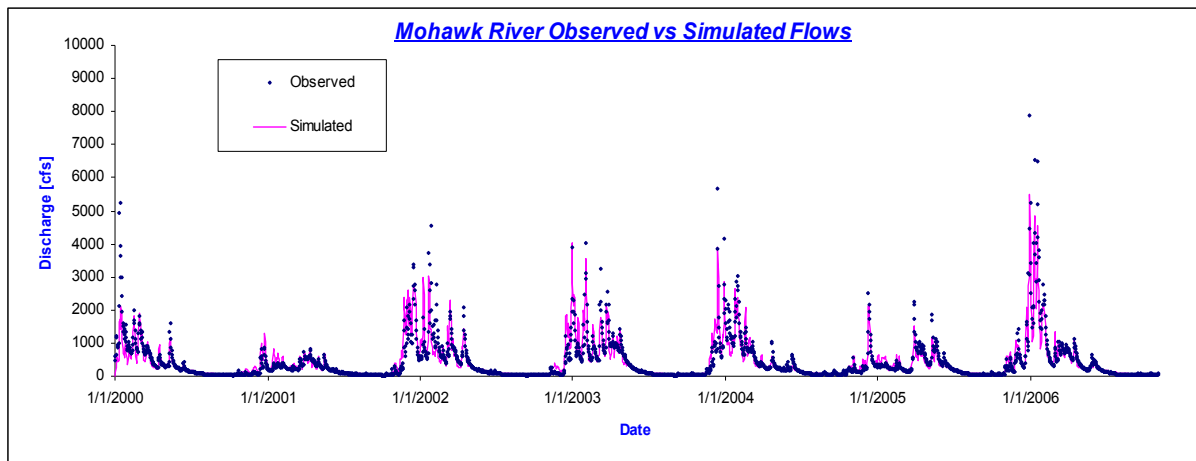


Figure 5: Mohawk River Simulated vs. Observed Flow Comparison.

Basin / Study	ET(% of precip)	Overland Flow (% of precip)	Total Streamflow (% of precip)	Recharge (% of precip)	Baseflow + Interflow (% of tot. Q)	Overland Flow (% of tot. Q)

Mohawk River	35.4	27.7	64.8	29.5	57.3	42.7
Willamette River	38.6	34.8		26.6		

Table 5: Comparison of the Willamette River Basin Water Budget (Conlon, et al., 2005) with the Water Budget Simulated with the Mohawk River NAM Model.

As discussed previously (section 2.2 above) for Lookout Creek, autocalibration using a weighted timeseries method across the catchment was initially attempted but produced poor results, especially in predicting spring snowmelt runoff. It was determined that in order to capture the effects of snowfall and melt, a “combined catchment” model was needed where the higher elevation catchments would be divided into smaller sub-catchments in order to more accurately account for temperature variations across the catchment. This method produced a much better calibration. Other adjustments involved the modification of parameters not included in the autocalibration routine such as the groundwater area to catchment area ratio (CAREA) utilized by the NAM model to define the size of the groundwater storage reservoir relative to the catchment size. For the Lookout Creek catchment, the default value of 1.0 was changed to 0.8 to account for the fact that the steep-sloped sections of this mountainous drainage have very little groundwater storage capacity. Final parameters and a summary of the final calibration statistics and simulated water budget are provided below in Tables 6 and 7 and a comparison plot of the final simulated hydrograph with the observed record is shown in Figure 6.

Results from the calibrated Lookout Creek catchment were examined in a similar manner to those from the Mohawk River model. Annual water budget information found in a literature search was compared to the water budget calculated from the calibrated model. Because of the existence of the HJ Andrews Experimental Forest Long-Term Ecological Research (LTER) Program within the Lookout Creek watershed, a wealth of data and research is available on this relatively small watershed. We were able to obtain a number of published studies describing some aspect of Lookout Creek’s annual water budget and compare those to the model’s estimates (Table 8). Literature estimates of the ET expressed as a percentage of the precipitation generally fall into a relatively narrow range from 24.5-28.8% with the exception of one reference which places it much higher at 44%. The simulated value of 25.2% compares very well with these literature estimates. Waichler et al. (2005) estimated that the baseflow contribution to the total streamflow was much higher than what the NAM model predicts although differences in the evaluation time period make it difficult to compare the values directly.

The overall discharge volume over the full simulation period (1/1/2000 – 11/3/2006) compares favorably with the observed record, with the model under-predicting the total volume by 2.5%. Comparison of the simulated and observed hydrographs reveals that the model generally predicts the magnitudes of the storm peaks quite well with some of the larger peaks over-predicted and some of the smaller peaks under-predicted. The model generally over-predicts base flow slightly and tends to melt off the accumulated snow pack earlier in the year relative to the observed data..

Parameter	Final Value	Lower Bound	Upper Bound
Umax	14.8	5	30
Lmax	132	25	450
CQOF	0.8	0	1
CKIF	224	100	2000
CK1.2	25	1	120
TOF	0.61	0	0.99
TIF	0.12	0	0.99
TG	0.3	0	0.99
CKBF	5000	100	2.00E+04

Table 6: Lookout Creek NAM Model Calibration Parameters.

Catchment: LOOKOUT CREEK 75, Area= = 63.59 km2

Period	Q-obs	Q-sim	%diff	Rainfall	PotEvap	ActEvap	Recharge	OF	IF	BF
2000	48.52	45.56	6.1	1417.1	782.3	512.2	289.1	371.3	218.9	133.0
2001	107.01	108.37	-1.3	2041.4	838.2	406.8	379.8	1106.8	252.0	301.9
2002	93.78	91.58	2.3	2096.3	957.1	458.1	406.1	918.0	236.4	314.2
2003	103.01	98.94	4	2340.6	764.9	509.3	541.6	980.6	269.8	354.9
2004	66.00	64.13	2.8	1647.2	912.1	567.9	336.6	516.0	219.3	312.9
2005	115.94	112.51	3	2359.9	906.9	530.4	455.0	1164.9	254.2	370.7
2000-2006	534.26	521.10	2.5	11902.4	5161.5	2984.6	2408.1	5057.4	1450.7	1787.6

Coefficient of determination: R2 = 0.913

Standard Error: SE = -2.52 cfs, Root Mean Squared Error: RMSE = 47.89 cfs

Table 7: Flow Calibration Metrics and Water Budget Summary for the Lookout Creek NAM Model.

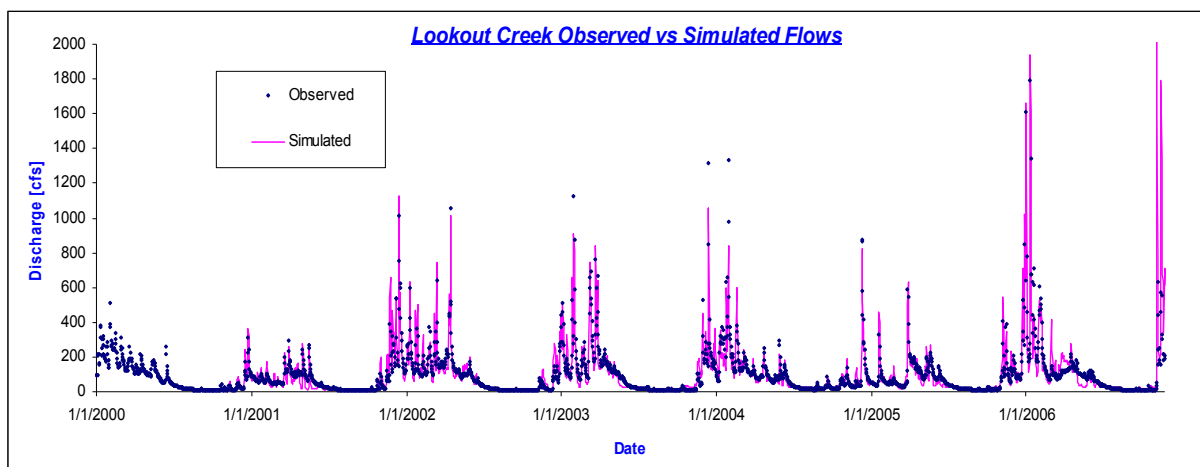


Figure 6: Lookout Creek Simulated vs. Observed Flow Comparison.

Basin / Study	ET(% of precip)	Overland Flow (% of precip)	Total Streamflow (% of precip)	Recharge (% of precip)	Baseflow + Interflow (% of tot. Q)	Overland Flow (% of tot. Q)
Lookout Creek	25.2	44.7	69.4	18.5	35.6	64.4
Waichler et al. (low end)	24.5				60.0	40.0
Waichler et al. (high end)	28.8					
Jones (2001)	44.0		56.0			
Nolin, et al. (2005)	26.0					

Table 8: Comparison of Water Budget Estimates from a Variety of Sources with the Water Budget Simulated with the Lookout Creek NAM Model.

3.2 MIKE BASIN

Once the NAM model parameters for both the lower rainfall-dominated catchments (Mohawk River parameter set) and the middle snow-dominated catchments (Lookout Creek parameter set) were determined, they were transferred to the appropriate catchment rainfall-runoff model and run to produce hourly estimated discharge for the 1/1/2000 – 10/1/2006 time period. These were then added to the MIKE BASIN model as the runoff timeseries for the model. As noted previously, runoff timeseries data for the spring-dominated upper catchments were supplied either from OSU-provided gage records or from the USGS main stem McKenzie gage below Trailbridge Reservoir. The fully-populated MRMBM model was then delivered to DHI for reach gain/loss calibration to account for main stem groundwater interaction and other sources of error.

The fully-populated MRMBM was run for the simulation period 1/1/2000 – 10/1/2006 and a comparison of the model-simulated hydrographs and the observed hydrographs at each of the main-stem McKenzie River gage locations was made. Differences between the two records result from two primary sources, a) cumulative errors from the upstream NAM models and gaged inflows representing runoff generation from the tributary catchments feeding the main-stem, and b) exchanges between the surface water and groundwater systems than occur along the main-stem valley floor which are not accounted for in the NAM models. In order to account for the surface water/groundwater exchanges along the main-stem valley floor, reach gains/losses were determined.

The process for determining the reach gains/losses was as follows. First a hydrograph separation was performed on both the simulated and observed records at the upstream-most main-stem calibration location (McKenzie River Above South Fork). The one-parameter digital filter method was used with a filter value of 0.98 for this analysis (Lyne and Hollick, 1979; Nathan and McMahon, 1990; Arnold and Allen, 1999). The baseflow residual values were then determined for each day of the simulation by subtracting the simulated baseflow record from the observed baseflow record. The computed



baseflow residuals were assumed to represent gains/losses associated with surface water/groundwater exchanges occurring in the reach upstream of the gage and downstream of the next upstream gage (Below Trailbridge in this case). An average value of the computed baseflow residuals as a percentage of the simulated flow was computed and used to fill in gaps in the reach gains/losses record for cases where baseflow residuals could not be determined directly because of missing data in the observed record. The computed reach gains/losses were then distributed along the various stream segments in the model by assuming that the exchanges were proportional to the along-channel distance over the reach between gage locations.

The above process was then repeated for the next gage downstream with the computed reach gains/losses being added to the model for the reach between the McKenzie River Near Vida and McKenzie River Above South Fork gages. The process was continued moving in the downstream direction until the farthest downstream gage (McKenzie River Near Walterville) was reached. This approach to computing the reach gains/losses was deemed the most appropriate method because it attempts to isolate the groundwater signal from the hydrographs prior to computing the gains/losses which should provide a more realistic estimate of the surface water groundwater exchanges rather than “make-up for” cumulative errors in the upstream tributary inflows. Figures 7A- 7D show the initial comparison between the simulated and observed hydrographs prior to performing the reach gain/loss analysis for each of the calibration gage locations, and Figures 8A- 8D show the comparison of the simulated and observed baseflow hydrographs determined with the hydrograph separation analysis as well as the computed baseflow residuals that were applied as reach gains/losses.

Figure 9 summarizes the average computed reach gains/losses by reach and the cumulative applied gains. Average gains were 540 cfs between the Below Trailbridge and Above South Fork gages, -215 cfs between the Above South Fork and Near Vida gages, 60 cfs between the Near Vida and Below Leaburg gages, and 70 cfs between the Below Leaburg and Near Walterville gages. The magnitudes of these gains appear to be reasonable although it is difficult to determine their accuracy without detailed modeling or field studies of surface water/groundwater interaction with which to compare them to. The relatively high values in the upstream-most reach may in part represent underestimation of springflow contributions in some of the spring-flow dominated basins that were represented with the OSU-measured spring-flow records and while the methodology employed for determining the reach gains/losses should result in limited “correction” of errors in the NAM calibration, this effect may also be present in the applied exchanges as well.

Comparison of the final hydrographs simulated with the MRMBM with the observed records indicates that the model does a very good job of predicting the main-stem discharges in terms of the magnitude and variation of baseflow and the overall shape of the hydrographs during peak flow events (Figures 10A- 10D). Magnitudes of the peaks are also captured well with a tendency to under-predict the highest peaks at the Above South Fork and Near Walterville gages and over-predict the highest peaks at the Near Vida gage. The final calibration statistics are shown in Table 9.

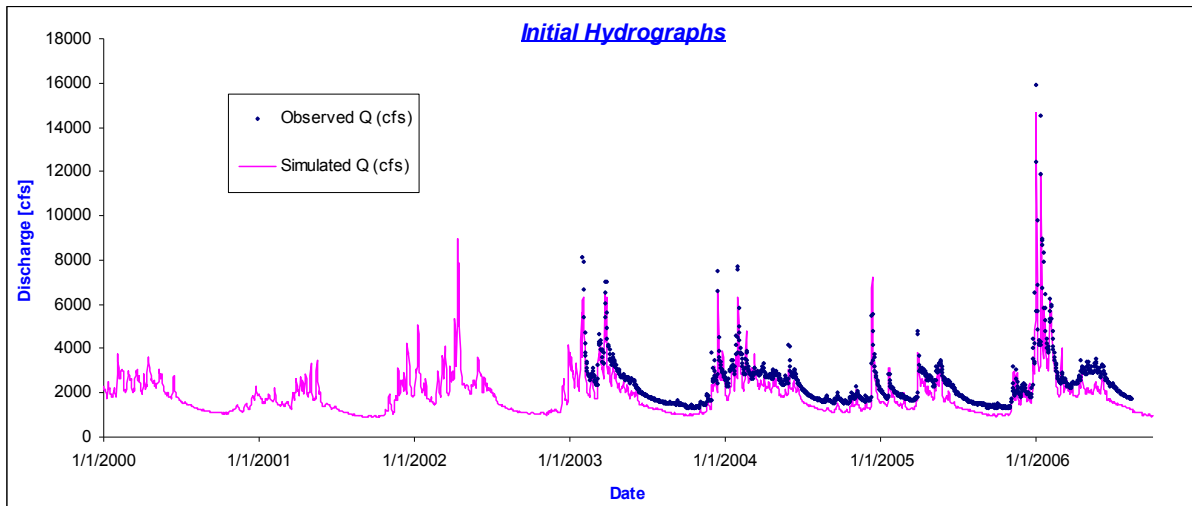


Figure 7A: Comparison of the simulated versus observed hydrographs prior to applying reach gains/losses at the McKenzie River Above South Fork gage.

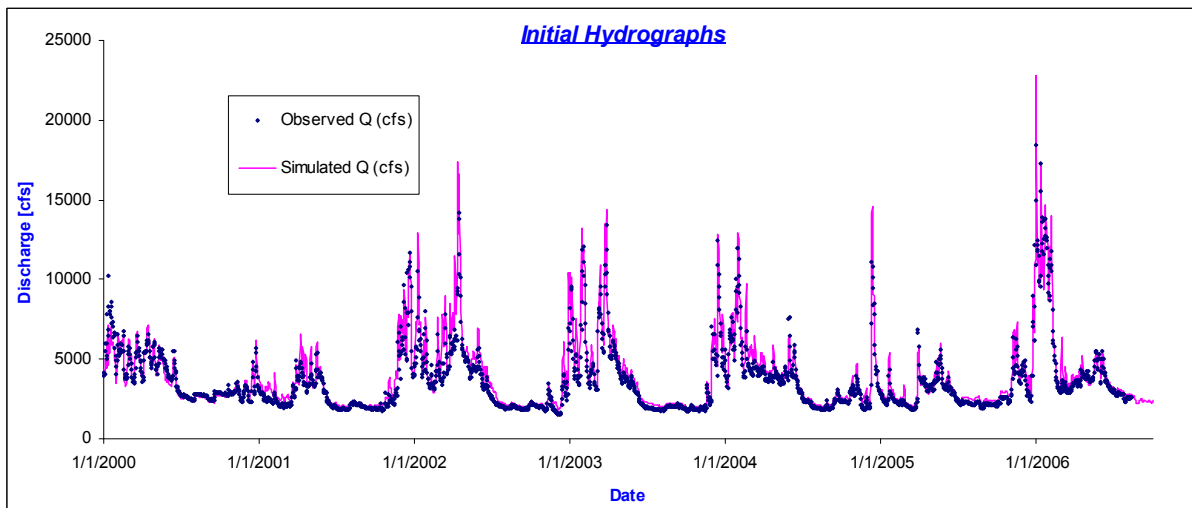


Figure 7B: Comparison of the simulated versus observed hydrographs prior to applying reach gains/losses at the McKenzie River Near Vida gage.

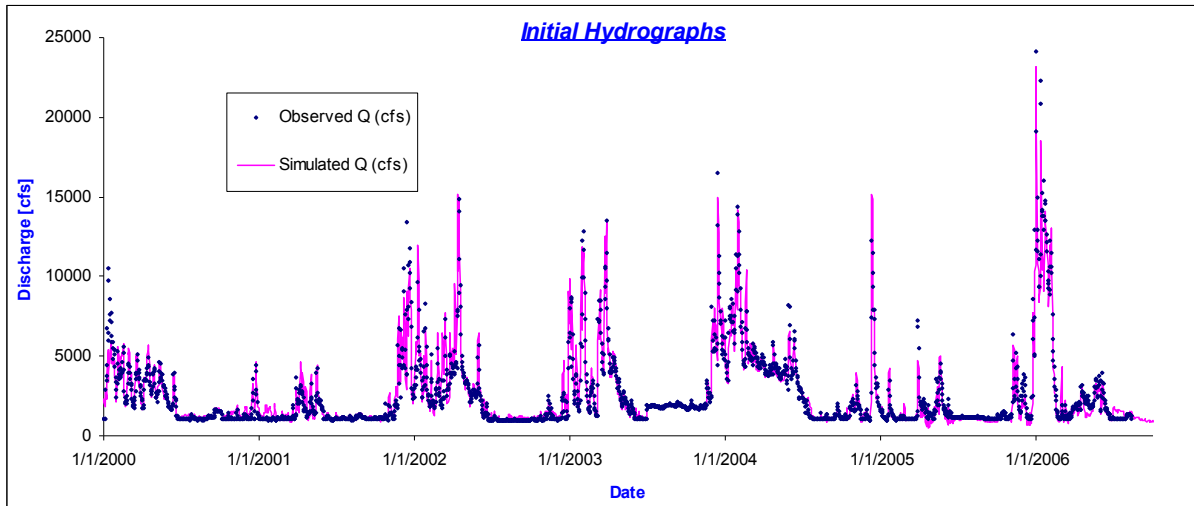


Figure 7C: Comparison of the simulated versus observed hydrographs prior to applying reach gains/losses at the McKenzie River Below Leaburg gage.

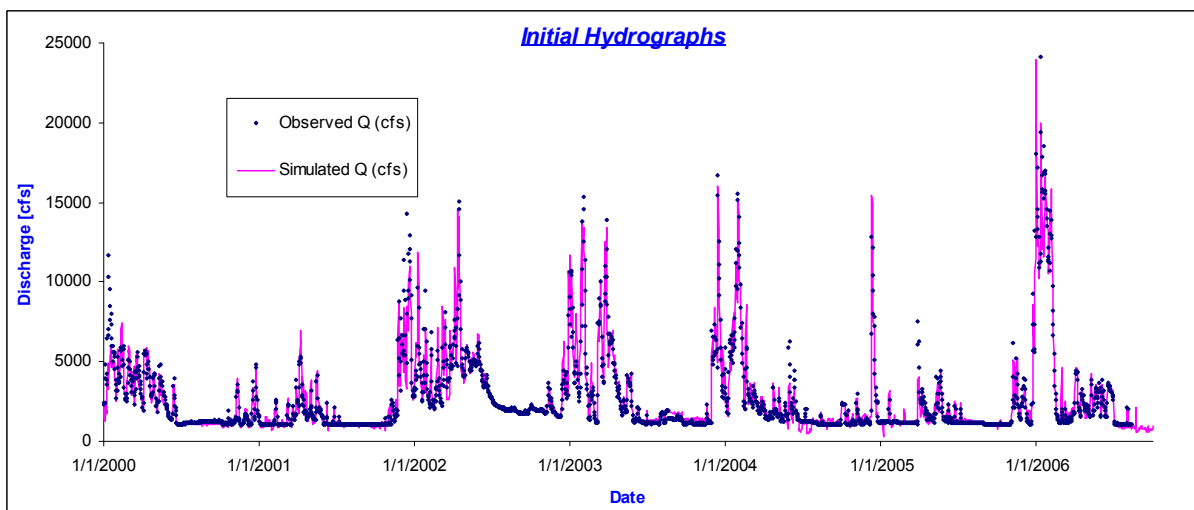


Figure 7D: Comparison of the simulated versus observed hydrographs prior to applying reach gains/losses at the McKenzie River Near Walterville gage.

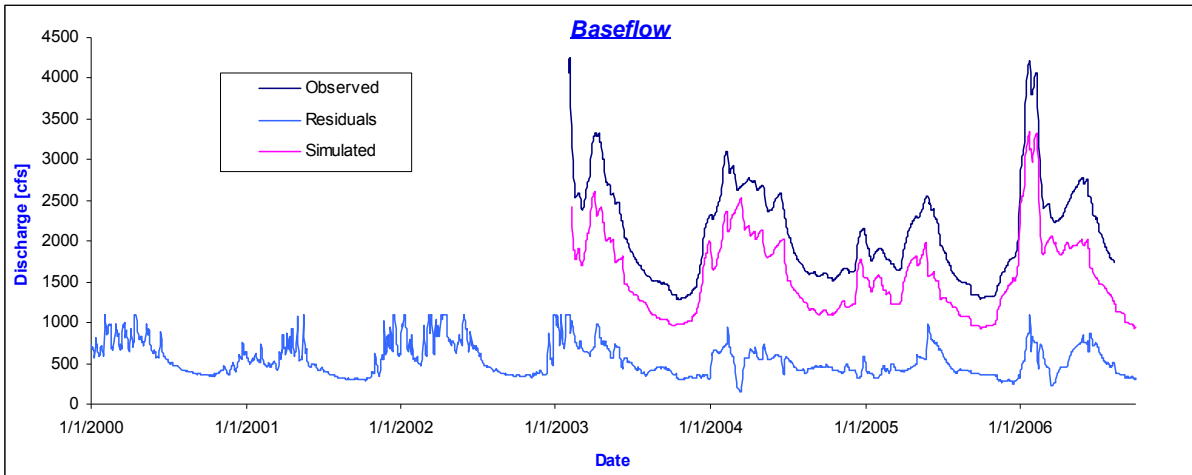


Figure 8A: Comparison of the simulated versus observed baseflow hydrographs and the reach gains/losses computed from the baseflow residuals at the McKenzie River Above South Fork gage.

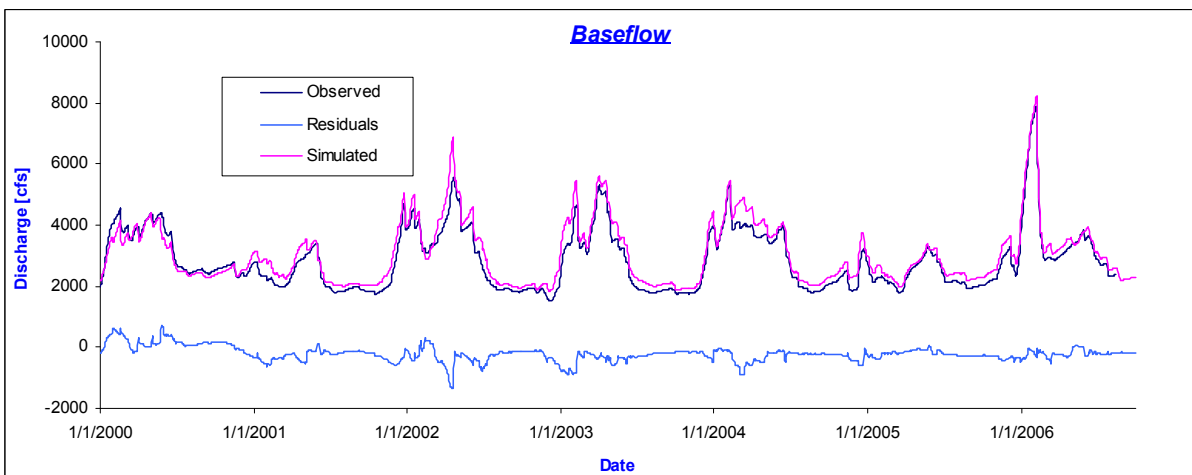


Figure 8B: Comparison of the simulated versus observed baseflow hydrographs and the reach gains/losses computed from the baseflow residuals at the McKenzie River Near Vida gage.

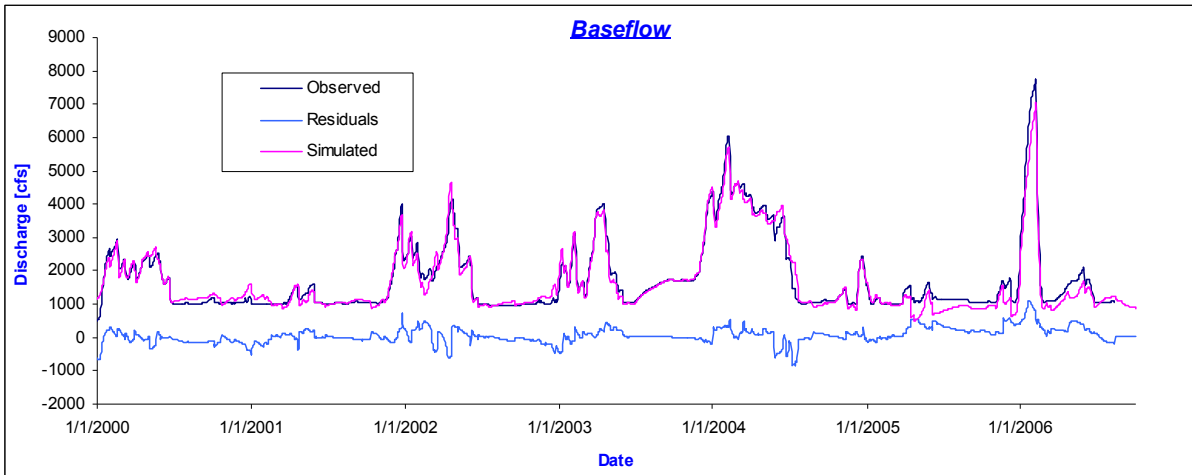


Figure 8C: Comparison of the simulated versus observed baseflow hydrographs and the reach gains/losses computed from the baseflow residuals at the McKenzie River Below Leaburg gage.

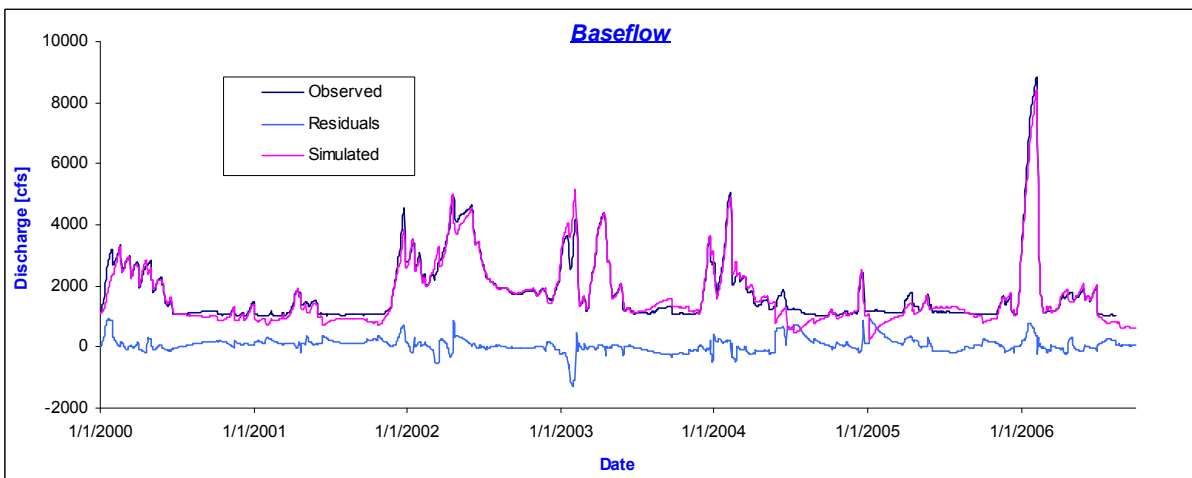


Figure 8D: Comparison of the simulated versus observed baseflow hydrographs and the reach gains/losses computed from the baseflow residuals at the McKenzie River Near Waltherville gage.

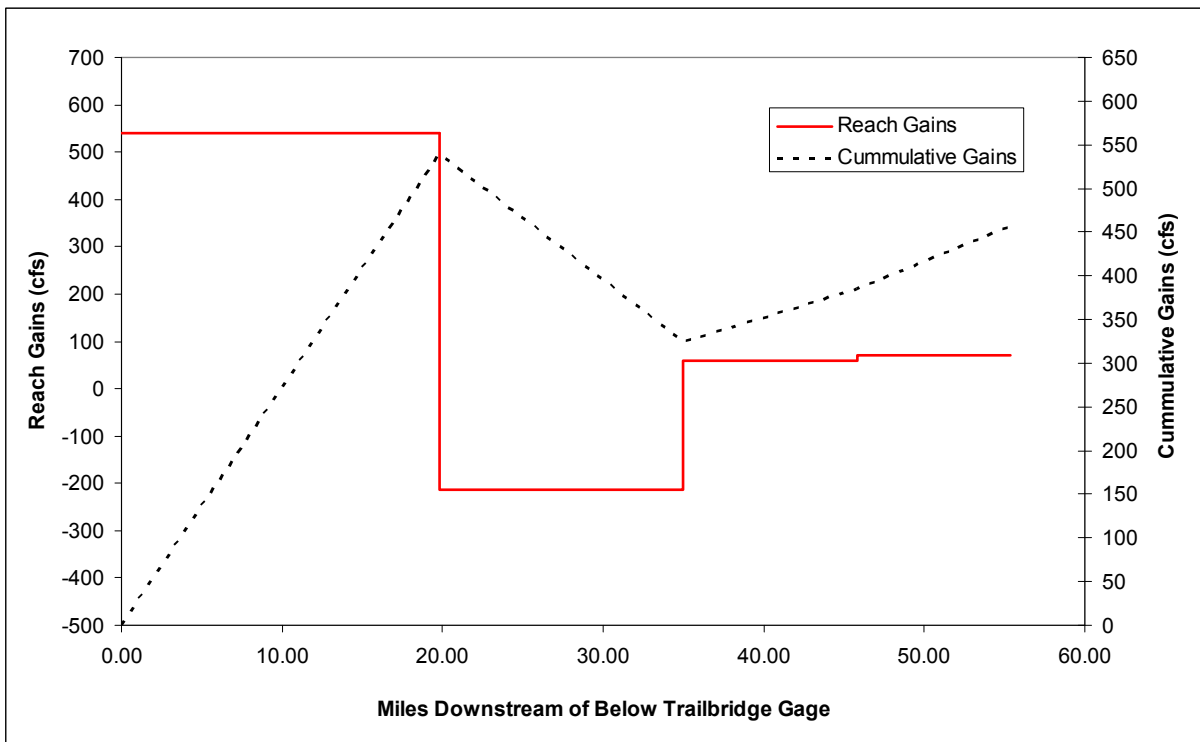


Figure 9: Average applied reach gains/losses by reach and cumulative reach gains

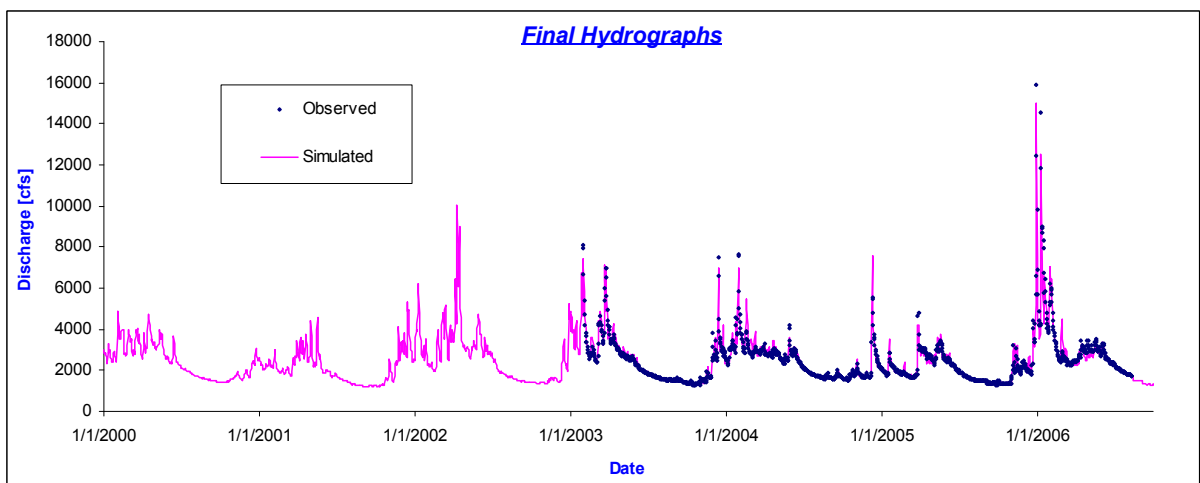


Figure 10A: Comparison of the final simulated versus observed hydrographs at the McKenzie River Above South Fork gage

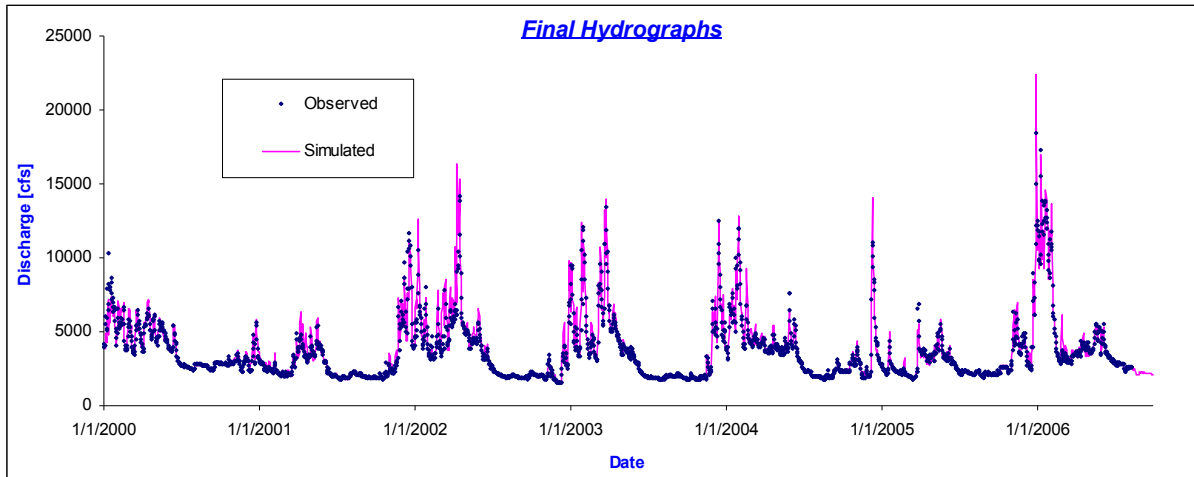


Figure 10B: Comparison of the final simulated versus observed hydrographs at the McKenzie River Near Vida gage.

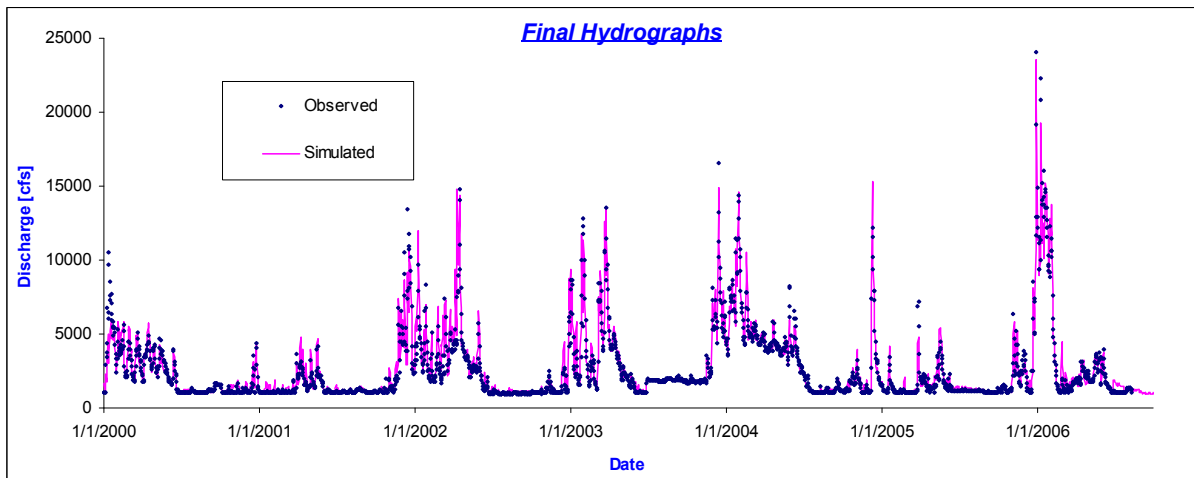


Figure 10C: Comparison of the final simulated versus observed hydrographs at the McKenzie River Below Leaburg gage.

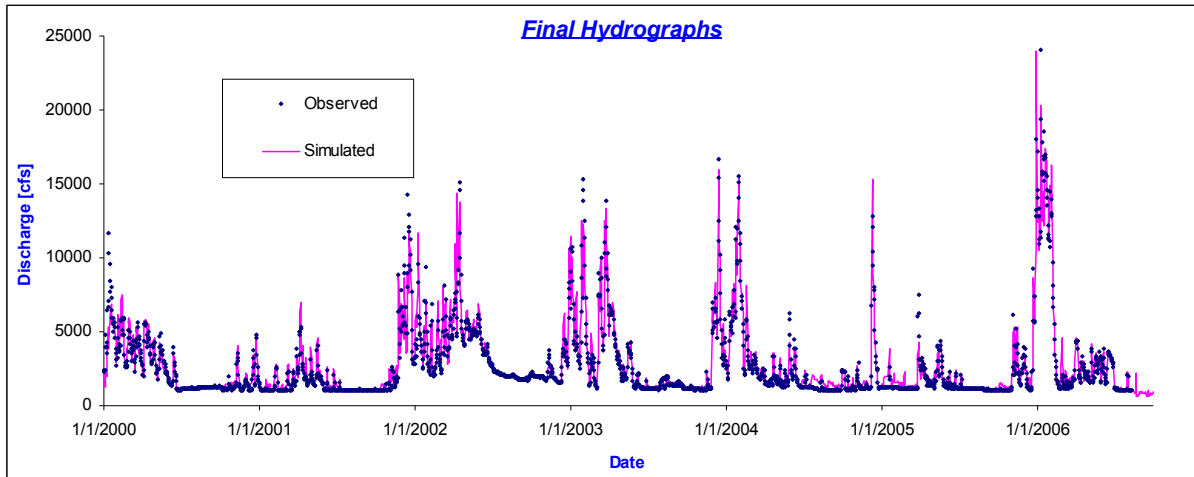


Figure 10D: Comparison of the final simulated versus observed hydrographs at the McKenzie River Near Walterville gage.

Gage Location	Mean Discharge		RMSE (cfs)	MPE (%)
	Simulated	Observed (cfs)		
Above South Fork	2441.2	2488.0	337.3	0.7%
Near Vida	3720.9	3649.5	560.8	2.5%
Below Leaburg	2665.4	2611.2	652.7	6.6%
Near Walterville	2803.3	2753.3	691.5	7.4%

Table 9: Final statistics of the MRMBM calibration, RMSE is the Root Mean Square Error and MPE is the mean error as a percentage of the observed discharge.

4 CONCLUSIONS

A GIS-based integrated water resource management and planning computer model was constructed for the McKenzie River Basin by DHI Water & Environment and the Lane Council of Governments using the model MIKE BASIN. The model also includes numerous lumped-parameter rainfall-runoff models (NAM) that simulate the generation of runoff, interflow, and baseflow from tributary catchments which then feed into the overall MIKE BASIN model. These combined models provide EWEB and others with a water resources model capable of simulating water budgets, streamflows, and snow accumulation/melt predictions along the main-stem of the McKenzie River and its major tributaries from the Below Trailbridge USGS gaging station to the confluence with the Willamette River.

One NAM model was calibrated for a higher elevation snow-dominated catchment representative of the middle 1/3 of the McKenzie basin (Lookout Creek) and a second NAM model was calibrated for a lower elevation rainfall-dominated catchment representative of the lower 1/3 of the basin. Model input parameter sets were adjusted in each case to minimize the differences between the model-simulated discharge rates and the observed gaging records. The model calibration resulted in two sets of model input parameters which were then applied to the NAM catchments representative of these two regions of the basin.

Additionally, the overall MIKE BASIN model was calibrated by computing reach gains/losses occurring between the main-stem gages through the use of a baseflow separation technique. The NAM models are capable of generating flow output results at a 15-minute or finer resolution, while the MIKE BASIN model is operated on a daily timestep. The NAM and MIKE BASIN models were calibrated from 1/1/2000 – 10/1/2006.

The model calibrated very well in terms of the magnitude and variation of baseflow and the overall shape of the hydrographs during runoff events. In general, peak discharges are also well-predicted with a tendency to under-predict the highest peak flows at the Above South Fork and Near Walterville gages and over-predict the highest peak flows at the Near Walterville gage. Mean percent error values (the difference between the simulated and observed daily discharge as a percentage of the observed flow) range from 0.7% at the Above South Fork gage to 7.4% at the Near Walterville gage with the majority of the error representing differences between the simulated and observed peak discharges during large runoff events.

The calibrated MIKE BASIN model provides a powerful means of simulating water availability under existing conditions and provides a valuable tool for running operational scenarios involving changes in water use and/or water availability. The model can be used to address various hydrologic questions posed by EWEB and its partners at the basin-scale now and into the foreseeable future as well as provide a foundation for modelling water quality constituents at the basin scale and the development of more detailed-scale water quality and hydrodynamic models during subsequent modelling phases.

4.1 Recommendations

As with any modelling effort, the accuracy and applicability of the model depends largely on the quantity and quality of the input data and the degree and accuracy of the model calibration. The availability of detailed rainfall, temperature, and streamflow information for the basin enabled construction and calibration of a robust basin-scale model.

The primary limitations of the calibrated model are due to a lack of input data for specific hydrologic processes and for specific geographic areas within the basin. The model limitations concern the current knowledge regarding reservoir operations in the basin, the high Cascades range hydrology system, surface water/groundwater interaction in the basin, the availability of data to simulate water quality during future modelling phases, and the overall predictive capabilities of the model. The following sections discuss each of these limitations in greater detail and make recommendations for how the existing model can be improved in these areas during subsequent modelling efforts.

In order to maximize the usefulness of the model, it is recommended that the model be viewed as a “living” model and that it be periodically refined as new data become available and as new questions are identified.

Reservoirs

Currently there is a lack of data describing the operational rules for Cougar and Blue River Reservoirs which prohibited their inclusion in the model. Excluding the reservoirs is a limitation of the current model because the discharge from these two reservoirs has a large influence on the timing and magnitudes of streamflows throughout the downstream reaches. The current model is limited to simulating the existing operational outflows from the reservoirs during the calibration period. Since the model calibration period consists of a 7-year time period, a wide variety of outflow conditions were simulated with the current model (as characterized by the USGS gage stations below the reservoirs).

MIKE BASIN is capable of operating the reservoirs based on the simulated reservoir inflows, reservoir water-levels, and a series of rule-curves describing the reservoir operational strategies. Some of the information required to simulate the reservoirs is already available and was initially added to the model (reservoir inflows simulated with NAM and reservoir geometry information), however the rule-curves describing the operational strategies were not available.

If the rule-curve information can be obtained, this would be the best option for incorporating the reservoirs back into the model. If however, this information can not be obtained, an alternative solution would be to “back-calculate” the rule-curves based on measured inflow, outflow, and water-level data, all of which is currently available. Additionally, if the U.S. Army Corps of Engineers is unable to provide specific rule curves for the reservoirs they may be willing to provide more general information regarding the reservoir operation guidelines that they follow from year to year which would also help to support future model development efforts.

High Cascades System

The headwaters of the McKenzie River Basin are characterized by large snow accumulations and porous volcanic materials with a high infiltration capacity. The streamflow generated from this portion of the basin includes a large groundwater contribution from numerous seeps and springs, including a smaller number of very large springs. This upper portion of the basin was not explicitly included in the calibrated model and the flow generated from this area was incorporated using timeseries of gage station flow records.

This approach is adequate for simulating existing conditions and any model scenarios involving operational changes made downstream. However, eventually it may be desirable to use the model to evaluate scenarios where the hydrologic processes in the headwaters system need to be simulated. A primary example would be investigating the impacts of various climate scenarios on the snowpack and hydrology in the high Cascades part of the basin and the associated changes to downstream reaches. In order to investigate hydrologic scenarios involving changes in the headwaters area, the calibrated model will need to be expanded to include this upper part of the basin.

Researchers at Oregon State University and the University of Santa Barbara have been conducting research on various aspects of the high Cascades system using a model called RHESSys to investigate the impacts of climate change on snow accumulation and groundwater processes in the upper McKenzie River Basin (Jefferson et al., 2006; Tague et al., 2007, 2008). One aspect of potential future model development may be to investigate if aspects of the RHESSys model can be used to enhance our understanding of the upper McKenzie basin and potentially enhance the MIKE BASIN model. Further investigation into how well the two models could be combined or support one another would be a logical next step.

Other modelling options may also be considered for the upper basin. One option is to develop a spatially-distributed integrated hydrologic model using MIKE SHE, which is capable of simulating snow accumulation, infiltration and groundwater recharge, as well as runoff and streamflow. Applying this model for the upper basin or over the entire basin may offer some advantages over the long term in terms of the range of questions that could be addressed with a model. An alternative option is to simulate the upper basin using NAM. Although the NAM model has not traditionally been used to simulate a complicated spring-flow dominated system like the high Cascades, the model does include the ability to simulate multiple groundwater reservoirs each with different time constants, and thus the model may be capable of accurately simulating the processes responsible for streamflow generation in this portion of the basin.

As with all model studies and applications the model is only as good as the data going into it. As a first step, the existing data in the upper basin should be reviewed to better understand the best way to proceed forward with a possible MIKE SHE or NAM application or whether additional data needs to be collected. If NAM is chosen, a test-case would be recommended for a smaller portion of the basin to ensure that the model is capable of representing the complex hydrology of this spring-flow dominated area.

Surface Water/Groundwater Interaction

Interaction between the surface water and groundwater systems along the main-stem valley floor was not explicitly simulated in this study but was accounted for via hydrograph separation techniques and the computation of reach gains and losses. This approach provided reasonable estimates of the groundwater exchange, but the opportunity to verify the computed exchanges was hampered by a lack of detailed data or simulations of surface water/groundwater interaction. In order to improve confidence in the applied exchanges, seepage studies may be conducted to provide information regarding the surface water/groundwater interaction; the results of which could then be compared to the applied exchanges. If seepage studies are conducted along the McKenzie River, the model developers should be involved in the design of the study to ensure that there is a clear understanding of how the results of the seepage study can be used to verify or improve the model.

An alternative approach to improving the representation of surface water/groundwater exchanges is to undertake additional modelling activities. These activities could include the addition of a groundwater component to the existing model using the groundwater module in MIKE BASIN. The advantage of this approach is that it requires relatively limited input data. The disadvantage of this approach is that the linear reservoir method used in the MIKE BASIN groundwater module does not account for losing reaches and the results of the hydrograph separation analysis performed as part of this study suggest that losing reaches do occur along the main-stem of the McKenzie River. Thus, the MIKE BASIN groundwater module may not be capable of accurately simulating the surface water/groundwater dynamics in this system.

Another alternative modelling approach is to develop a finite-difference groundwater model using MIKE SHE or a related model code. A MIKE SHE model would allow for the simulation of dynamic water-level-gradient driven exchange between the surface water and groundwater systems. Another advantage of this approach is that it may help address additional questions in the basin such as the need to gain a better understanding of the interaction between the river flow regime and the existing and proposed wells that serve as drinking water supplies in the lower basin. A MIKE SHE application in the lower basin can utilize existing efforts to model the Willamette and McKenzie River ground water area that was part of a USGS study (Conlon, et al., 2005) however, this approach requires significant input data and additional data collection may be needed in order to support such a model.

Water Quality

After the water quality constituents to be modelled are identified and the available data is reviewed as part of the next modelling phase, some modifications to the existing NAM and MIKE BASIN models may be necessary in order to facilitate the water quality modelling efforts. In particular, additional NAM models of the drainage areas adjacent to the main-stem where runoff processes were not simulated may need to be constructed in order to allow for accurate simulation of runoff-dependent loading with the Load Calculator. Additionally, it may be necessary to include a routing component and reduce the model simulation timestep employed in the MIKE BASIN model in order to accurately simulate residence times and mixing effects between reach storage and inflows. During the process of developing the water quality model for the MIKE BASIN application it will be important to make



decisions that ensure that the work supports future efforts to simulate water quality in the downstream reaches with the MIKE 11 hydrodynamic model.

Predictive Capabilities

The existing MIKE BASIN and associated NAM models provide a good basis for simulating existing conditions in the McKenzie River Basin and for setting up and running various scenarios involving changes in water-use and/or changes in water availability. Since the model was calibrated to a 7-year time period this covers a wide range of hydrologic and climate conditions which builds confidence in the model's ability to predict streamflow conditions under a variety of scenarios.

The predictive capabilities of the models are, however, limited by several factors described above. Current inclusion of the reservoir systems and the high Cascades system through the use of gaging data applied as model boundary conditions means that any scenario involving changes in reservoir operations or discharges from the upper portions of the basin will require estimates of how to apply new boundary conditions at these locations.

Given that the two reservoirs and the high Cascades system account for a large percentage of the total flow generation in the basin, predicting changes in streamflow with the existing model will be difficult without separate methods or additional model improvements to enable the simulation of changes in flow from these areas. Additionally, the reservoir outflows have an impact on the temperature regime in the main-stem river (Annear et al, 2004) and as a result one could expect the reservoirs to have an impact on some water quality constituents. In order to more accurately model the hydrodynamics, temperature, and water quality of the river system and then use the model for predictive purposes, the reservoirs will need to be included in the final model.

Lack of explicit representation of the groundwater system beneath the main-stem valley floor is also a limitation of the model's ability to predict changes in streamflow. Groundwater interaction under a given scenario can be computed using a similar method as was employed for the calibration to existing conditions, however, if major changes in groundwater recharge and aquifer storage occur under a given scenario it will be difficult to know if the computed surface water/groundwater exchanges are reasonable if these processes are not simulated.

Detailed timeseries data describing the diversion of water through the Leaburg and Walterville Canals was generated from the EWEB power generation records and the tributary inflows simulated with the NAM models. This worked well for simulation of existing conditions, however for predictive simulations additional research with EWEB personnel and some assumptions may be needed regarding how these diversions may change under a given hydrologic scenario. This can best be accomplished by determining the decision factors that account for the diversion rates such as any minimum bypass flow requirements and conveyance restrictions in the canals, as well as by gaining a greater understanding of the way that the power facilities are operated.

5 REFERENCES

- Annear, R. L., McKillip, M. L., Khan, Sher Jamal, Berger, C. J., and Wells, S. A., 2004. Willamette River Basin Temperature TMDL Model: Model Scenarios. Technical Report EWR-03-04, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.
- Arnold, J.G., and Allen, P.M., 1999. Validation of automated methods for estimating baseflow and groundwater recharge from stream flow records, *Journal of American Water Resources Association*, v. 35, pp. 411-424.
- Cooper, R. M., 2002, Determining Surface Water Availability in Oregon, Open File Report SW 02-002, Oregon Water Resources Department.
- Conlon, T. D., Wozniak, K. C., Woodcock, D., Herrera, N. B., Fisher, B. J., Morgan, D. S., Lee, K. K., and Hinkle, S. R., 2005. Ground-water Hydrology of the Willamette Basin, Oregon, Scientific Investigations Report 2005-5168, USGS and Oregon Water Resources Department.
- DHI, 2003. MIKE BASIN: Rainfall-Runoff Modeling Reference Manual, Danish Hydraulic Institute, Copenhagen, Denmark, 60 p.
- DHI, 2006. MIKE BASIN Users Manual. DHI Water and Environment, Copenhagen, Denmark.
- Lyne, W.D., and Hollick, M., 1979. Stochastic time-variable rainfall-runoff modelling. *Hydrologic and Water Resources Symposium*, Institution of Engineers Australia, Perth, pp. 89-92.
- Jefferson, A., Nolin, A., Lewis, S., Payne, M., Grant, G., and Tague, C., 2006. Climate Variability, Snowmelt Distribution, and Effects on Streamflow in a Cascades Watershed, Extended Abstracts, 63rd Eastern Snow Conference, Newark, Delaware.
- Jones, J., 2001. Modular Field Guide to the H.J. Andrews Experimental Forest.
- Nathan, R.J., and McMahon, T.A., 1990. Evaluation of automated techniques for baseflow and recession analysis, *Water Resources Research*, v. 26, pp. 1465-1473.
- Nolin, A., Jefferson, A., and Grant, G., 2005. Influence of climate change on water supply in the McKenzie River Basin: Analysis of long-term and spatial hydrological data.
- Tague, C., and Grant, G., 2004. A geologic framework for interpreting the low flow regimes of Cascades streams, Willamette River Basin, Oregon, *Water Resources Research*, v. 40, doi: 10.1029/2003WR002629.



- Tague, C., Farrell, M., Grant, G., Lewis, S., and Rey, S., 2007. Hydrogeologic controls on summer stream temperatures in the McKenzie River basin, Oregon, *Hydrological Processes*, v. 21, pp. 3288-3300.
- Tague, C., Grant, G., Farrell, M., Choate, J., and Jefferson, A., 2008. Deep groundwater mediates streamflow response to climate warming in the Oregon Cascades, *Climatic Change*, v. 86, pp. 189-210.
- Waichler, S. R., Wemple, B. C., and Wigmosta, M. S., 2005. Simulation of water balance and forest treatment effects at the H.J. Andrews Experimental Forest, *Hydrological Processes*, v. 19, pp. 3177-3199.