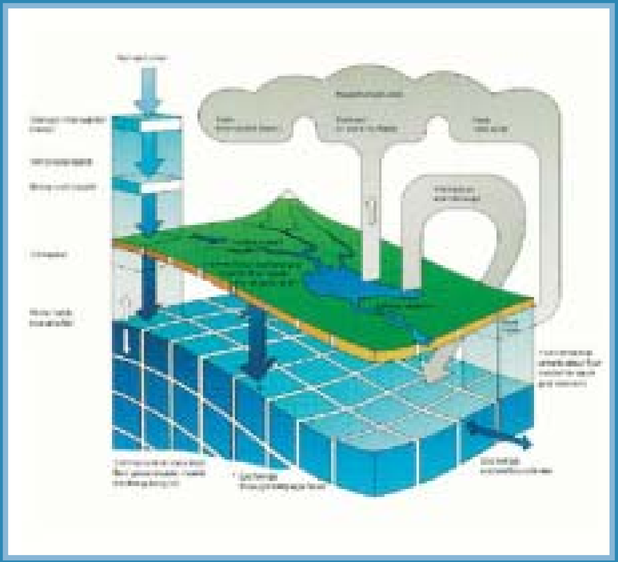
Report to the
Little and Middle Spokane Watershed
WRIA 55 and 57 Planning Unit

# Level 2 Technical Assessment: Watershed Simulation Model



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February 13, 2004

Golder Associates

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February 13, 2004 Golder ref: 013-1372.2300

Spokane County
721 N. Jefferson
Suite 303
Spokane, Washington 99260

ATTENTION: Stan Miller, Program Manager, WQMP

RE: WATERSHED SIMULATION MODEL REPORT

Dear Stan:

Enclosed are 12 copies of the Final MIKE SHE model report for the WRIA 55/57 Planning Unit. This report describes the construction and calibration of a hydrologic simulation model that integrates meteorologic, surface water and groundwater processes.

A second modeling report, which will supplement this report, will be issued in which the conversion of the model from a UNIX-compiled code to a Windows-based version will be documented. This report will also present simulations of pre-development conditions and alternative water resource management approaches.

Simulation of the WRIA 57 watershed is accurate, and was facilitated in large part by the following factors:

- The use of the variable flow boundary for the Spokane River at Post Falls that dominates the water balance;
- The hydrologic processes within the watershed domain is relatively simple and dominated by the SVRP Aquifer; and,
- There are numerous high quality calibration points available over this part of the model.

Simulation of the WRIA 55 watershed characterizes the hydrology of the basin processes but overestimates streamflows. The challenges to obtaining a better simulation of the Little Spokane watershed are:

- There are few data to confirm the distribution of actual precipitation over this portion of the model;
- The hydrology of the Little Spokane watershed is more complex and influenced by a greater number of variables (e.g., runoff and recharge related parameters), and has a greater number of subbasins of varying hydrologic character than the WRIA 57 watershed; and,
- There are few calibration points.

We appreciate the opportunity to conduct this work on your behalf.

Sincerely,

GOLDER ASSOCIATES INC.

Sara Marxen
Project Engineer

Chris V. Pitre
Senior Project Manager, Water Resources

cc: Bryony Stasney
Marcia Sands

Final Model Report Transmittal.doc

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# REPORT TO

# WRIA 55 AND 57 PLANNING UNIT

**on**

# LEVEL 2 TECHNICAL ASSESSMENT WATERSHED SIMULATION MODEL

Prepared under grant # 9800300
from the Washington Department of Ecology

Prepared for:

WRIA 55 and WRIA 57 Planning Unit
Spokane, Washington

Submitted by:

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013-1372.2300

## EXECUTIVE SUMMARY

The Planning Unit representing Watershed Resource Inventory Areas (WRIAs) 55 and 57 (Little Spokane and Middle Spokane, respectively) chose to use MIKE SHE modeling software from DHI Water and Environment as part of the technical assessment for the watershed planning process under RCW 90.82. The main goal of the modeling process is to support decision-making during development of the watershed plan. The model is intended to simulate the processes driving the hydrology of the watershed and provide a "what if" tool for stakeholders.

MIKE SHE is a deterministic, distributed and physically based modeling system. The basic MIKE SHE model includes six modular components; each describing a major flow process of the hydrologic cycle. These include interception/evapotranspiration, overland flow, channel flow, unsaturated zone flow, saturated zone flow, and snow pack. Additionally, in the Little and Middle Spokane Watersheds, simulation of lawn watering and agricultural irrigation was included. A primary benefit of the MIKE SHE modeling environment is its ability to simulate groundwater and surface water interactions.

The WRIA 55 and WRIA 57 administrative watersheds are located just west of the Washington-Idaho Stateline and encompass more than 700 square miles. The Spokane Valley includes the Spokane Valley-Rathdrum Prairie Aquifer, which is one of the most productive aquifers in the United Sates. This aquifer hydraulically links WRIA 55 and WRIA 57 and influenced the decision to combine the planning process for the two watersheds. The Spokane Valley aquifer is in direct hydraulic continuity with the Spokane River in WRIA 57 and discharges a significant amount of water into the lower Little Spokane River of WRIA 55.

The MIKE SHE model was calibrated over the hydrologic years (i.e., October 1 of the preceding year through September 30) of 1994 through 1999, which includes representative dry (1994), wet (1997) and average years (1999). Calibration data included continuous and snapshot river discharge, groundwater elevations, and snow water equivalent measurements.

Calibrations of heads in the central Spokane Valley Aquifer in WRIA 57 are shown to be accurate at both high and low water table elevations. Calibration in the Hillyard Trough area shows variable agreement between simulated and actual water levels due to the existence of a silt/clay lens in the central portion of the Hillyard Trough. This is in part due to the model's method of solving a lens setup that restricts accurate calibration to heads from wells screened above, in, and below the lens. Calibration near the model boundary indicates a need for additional data collection in this area to simulate aquifer response to the high degree of river–to-aquifer recharge and the distribution of this water in the aquifer.

Geology, hydrogeology and calibration data in the aquifers of WRIA 55 are sparser than in WRIA 57 and only general groundwater elevations are simulated in WRIA 55. Annual calibration of these points shows good over all correlation, with the sands and gravels matching measured values better than the basalt layer.

Calibration of discharge data on the Spokane River shows excellent calibration to measured data. Major losing and gaining reaches of the Spokane River are captured both in river discharge and in baseflow simulations. Calibration of the Little Spokane River data is not as good, with simulated low flows higher than actual flows on several tributaries and reaches of the Little Spokane River; particularly the early winter peak flows. Simulated peak flows match observed flows better during wet years than during dry years at all gages where peak data exists in WRIA 55 (primarily the Little Spokane River). Interaction between surface water and groundwater appears to be well simulated by the model over the full domain. Annual discharge model results for WRIA 55 indicate that either the total amount of water input to the model (primarily as precipitation) is too high or the total amount of sinks in the watershed is too low (primarily as evapotranspiration).

Sensitivity analysis shows that the model is most sensitive to precipitation and temperature inputs, boundary conditions, aquifer hydraulic conductivity, unsaturated zone hydraulic parameters and drainage parameters.

Application of the model for the planning process and future improvements to the model is recommended as part of this report. Scenarios for which the model can be used to evaluate include: the timing and spatial variations of future possible groundwater pumping; variations in river discharge through Post Falls into the model area; flow augmentation projects; aquifer storage and recovery; variations in flow through the Stateline aquifer boundary; and, variations in the location and magnitude of wastewater discharge. Potential model improvements include division of the model into sub-models for individual WRIA analysis, enhancement of precipitation data inputs and further discretization of the aquifer model layers.

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# 1.0 INTRODUCTION

This report describes the modeling process, data and results for Watershed Resource Inventory Areas (WRIAs) 55 and 57 in Eastern Washington including portions of Spokane, Pend Oreille and Stevens Counties. This modeling effort directly follows the focus outlined in the Little Spokane (WRIA 55) and Middle Spokane (WRIA 57) Watershed Planning Phase II - Level 1 Technical Assessment completed by Golder Associates, Inc. (Golder) in June, 2003.

Modeling was completed using the MIKE SHE and MIKE 11 simulation software packages developed by DHI Water and Environment (DHI). These two models run simultaneously providing a method for simulating integrated surface water-groundwater processes.

## 1.1 Objectives

Many planning and modeling objectives were identified during the initial phases of the watershed planning process during Planning Unit meetings between December 2000 and March 2001. They were initially presented in the Draft Phase II – Level 1 Technical Assessment.

Planning Objectives:

1. Determine the impact of groundwater recharge from the Spokane Valley Rathdrum Prairie (SVRP) Aquifer on flows in the Little Spokane River at and near Dartford.
2. Refine data for evaluating the effect of surface water and groundwater withdrawals on flows in the Little Spokane River.
3. Determine the effect of the interaction between the Spokane River and the SVRP Aquifer on the quantity and quality of groundwater and surface water at varying river flow conditions.
4. Refine estimates of recharge to the SVRP Aquifer from adjacent sub-basins.
5. Evaluate the effect of increased withdrawals on recharge to the Spokane and Little Spokane Rivers using a groundwater model that incorporates refined surface water / groundwater exchange information.
6. Develop a tool for evaluating water quality impacts (resulting from changes in river flow) of point source discharges on the Spokane and Little Spokane Rivers.

Modeling Objectives:

- Obtain a “wide circle of buy-in” on the decision making process through model development and use;
- Assist the Washington Department of Ecology’s (Ecology) water rights decision-making process;
- Evaluate and predict surface water/groundwater hydraulic continuity;
- Assess beneficial/detrimental impacts to downstream users due to water use or allocation changes;
- Characterize how climate, snowpack, the level of Lake Coeur d’Alene and dams affect the flow of the Spokane River;
- Estimate the impact of withdrawals from domestic wells along the Little Spokane River;
- Evaluate alternative operating and management scenarios;
- Characterize the frequency and duration of low stream flows;

- Assess mitigation measures available to water rights holders who may be affected by possible water right changes; and,
- Estimate minimum instream flows based on "natural" runoff conditions (primarily for the Spokane River, which is partially regulated by dams).

The following succinct set of task objectives have been developed to focus the modeling effort presented in this report toward the stated objectives and within the limitations of readily available data and capabilities of the software:

1. Develop an integrated surface water-groundwater modeling tool;
2. Apply water use estimates and well withdrawals developed in the Draft Phase II – Level 1 Technical Assessment to the model;
3. Apply wastewater discharge rates and distribution to the model;
4. Account for man-made structures on the Spokane River in the model;
5. Calibrate the model over a range of climatic years (dry – 1994; wet – 1997; average – 1999);
6. Develop effective databases and input/output tools to manage model runs; and,
7. Determine where additional data needs exist.

These task objectives identify key targets that will ensure a model that can assist in meeting the modeling and planning objectives. It should be noted that no water quality DHI software components have been purchased, and therefore those objectives were set aside for this effort.

## 1.2 Background

Watershed planning under RCW 90.82 is being jointly conducted in the Little and Middle Spokane River Basins. The current watershed planning effort was initiated in 1998 when funding was made available from Ecology. Spokane County is the lead agency and one of the initiating governments for this effort. Golder completed a Phase II – Level 1 Technical Assessment as part of the watershed planning process (Golder, 2003). At that time, the Planning Unit decided to proceed to Level 2 of Phase II of the watershed planning process with the development of a computer simulation model of the hydrologic watershed processes. Simulation software from DHI was chosen to model the basin due to its wide acceptance in the scientific community and it's capability to effectively simulate groundwater-surface water interactions (WRIA 55 and 57 Planning Unit Meeting Minutes, 2001).

At the writing of this report the Technical Assessment had not been finalized, but edits to that document had been determined. Most of the data and analysis compiled for the Technical Assessment was used directly in modeling the basin taking into account these edits.

The model was developed in metric units, at the request of the Planning Unit. Therefore results are presented in metric units with English units in parentheses where feasible. Conversion factors are presented in Table 1-1. Acronyms used throughout the report are listed in Table 1-2.

## 1.3 Study Area

The model domain encompasses the Little (WRIA 55) and Middle (WRIA 57) Spokane Watersheds (Figure 1.1). The WRIAs are located in Eastern Washington on the border with Idaho. They are situated on the eastern edge of the Columbia River Basalt Plateau in the foothills of the Rocky Mountain Range. The two primary drainages in these watersheds are the Little

Spokane River in WRIA 55 and the Spokane River in WRIA 57. The Spokane River flows over the Spokane Valley Rathdrum Prairie (SVRP) Aquifer. The Little Spokane River and its tributaries flow over and around several smaller aquifer systems. More complete details of WRIA 55 and 57 can be found in the Level 1 Technical Assessment (Golder, 2003).

Hydrology, climate, topography and population densities vary across the two watersheds. The natural drainage of the Little Spokane River Basin is almost entirely contained within the WRIA 55 boundary. WRIA 57 contains less than 10% of the contributing natural drainage of the Middle Spokane Basin, most of which lies in Idaho and extends east to the Idaho-Montana state border. Annual precipitation ranges from about 15 inches per year in the lower elevations of WRIA 57 to over 40 inches in the mountainous areas to the north and east. Elevations in the basin vary from approximately 500 m (NAVD 88; 1,640 ft amsl) in the southwestern portion of the basin to approximately 1,791 m (NAVD 88; 5,878 ft amsl) on the summit of Mount Spokane.

The watersheds lie at the boundary between two major physiographic provinces of North America (Fenneman, 1931). The north of WRIA 55 and the east of WRIA 57 are characterized by north-south trending mountains and valleys and are comprised of predominantly crystalline basement rocks that rise steeply from the Columbia Plateau, typical of Northern Rocky Mountains Province. The south of WRIA 55 and the west of WRIA 57 comprise landforms typical of the Columbia Plateau Province, including flat-topped basalt plateaus (Half Moon Prairie, Wild Rose Prairie, Five Mile Prairie, Greene Bluff, Orchard Bluff and Five Mile Prairie).

In both WRIA 55 and WRIA 57, there are areas of subdued topography that represent areas of basement and basalt rocks that were scoured and infilled by periglacial processes, including the Missoula Floods. The Spokane Valley represents the main Missoula Flood channel. The primary aquifers in WRIA 55 and WRIA 57 comprise these glacial unconsolidated sediments (e.g., the highly productive SVRP Aquifer). Less productive aquifers occur within the basalts (e.g., Greene Bluff Aquifer).

Natural land cover ranges from scrub brush in the lower portions of the basins to mixed coniferous and deciduous forests in the uplands. Land use is primarily urban with residential development in the Spokane Valley and around the City of Deer Park. Substantial suburban development is also occurring in the lower reaches of the Little Spokane River north of the City of Spokane. Agricultural land use is concentrated in the Dragoon Creek and Deadman Creek sub-basins of the Little Spokane watershed, and scattered in lower density throughout the rest of the lower elevations of the watersheds. Minor amounts of land are used for rangeland.

### 1.4 Authorization, Acknowledgements and Limitations

Preparation of a Watershed Plan will need a solid technical basis on which to build recommendations for future water resources management. The approach taken to prepare a computer simulation model of the hydrology of the Little and Middle Spokane Watersheds is outlined in the Draft Phase II, Level 1 Assessment – Data Compilation and preliminary Assessment (Golder, 2003; Chapter 8, and Appendix E). A model simulation tool will assist the Planning Unit toward this end.

The Spokane County Board of Commissioners is acting on behalf of the WRIA 55/57 Planning Unit in the administration of funds and contracting of services. The Board of Commissioners authorized the work presented in this report through Amendment #3 to Spokane County Contract #P2960 between Spokane County and Golder Associates, Inc. dated November 27, 2001.

Several staff contributed significantly to the preparation of this report. Stan Miller, Water Quality Section Manager for the Utilities Division of Spokane County Public Works, is the project manager on behalf of Spokane County. Reanette Boese and Bea Lackaff of Spokane County participated in the collection and compilation of input data for the model.

Chris Pitre, senior project manager, water resources, is the project manager on behalf of Golder. Sara Marxen, project water resources engineer, was the primary modeler, and was assisted by Samantha Collins. Bob Anderson of Golder provided much of the technical direction in the execution of this work. The conceptual model of the hydrology of the watershed and technical foundation of the model was in large part compiled by Bryony Stasney of Golder from numerous information sources.

This work has been completed in accordance with generally accepted professional practices at the time of preparation within the limitations of available data and budget.

## 2.0 PREVIOUS WORK

Several groundwater flow models have been constructed over the last 30 years, primarily for the SVRP aquifer. These models have been developed principally in support of groundwater supply studies and to designate groundwater quality protection areas over aquifer zones that provide water to large water supply wells (i.e., wellhead protection).

A sequential list and brief description of SVRP aquifer groundwater flow models is provided in Table 2.1. Detailed descriptions of the models are provided in Appendix D3 of the Draft Level 1 Technical Assessment (Golder, 2003).

The main objectives of these models were to characterize the SVRP Aquifer for groundwater resource studies and protection. The interaction between surface water and groundwater was not dynamically modeled, in part because surface water impacts were not the primary focus of the projects and in part because dynamic surface water-groundwater interaction algorithms were not commonly available in the modeling codes used. As a result, these models cannot accurately predict changes in the flow of the Spokane River as a result of varying groundwater withdrawals or varying groundwater recharge to the SVRP Aquifer.

## 3.0 CONCEPTUAL MODEL

Much of the conceptualization of the watershed for modeling was completed as part of the Draft Level 1 Technical Assessment and is summarized here. A full discussion of the simplifying assumptions and qualitative interpretations for each modeling component can be found in Golder (2001). Descriptions of the data used to develop this model are in Sections 4 and 5 of that report.

### 3.1 Climate

Large spatial and temporal climatic variations occur in the Little Spokane and Middle Spokane Basins. It is generally warm and dry in the summer and cool and moist in the winter. Climate varies across the basin from a subhumid mountain climate in the north with more than 1,150 mm (45 inches) of rain annually, to semiarid in the south with an annual average rainfall of less than 400 mm (16 inches). In addition, the hydrology of WRIAs 55 and 57 is significantly influenced by snowpack accumulation and spring snowmelt. Spring river discharges in WRIA 55 are fed by snowpack that falls within the basin, while in WRIA 57 snowmelt contributing to river flows generally occurs in Idaho and Montana. Snow accumulation and melt and the spatial variations of precipitation and temperature are important climatic variables.

Actual evaporation and transpiration from plants and water surfaces is estimated to range from 25.4 cm to 35.7 cm (10 inches 14 inches) across much of the basin (National Weather Service, U.S. Weather Bureau, 1962). More than 80% of this is estimated to occur from May to September. Evapotranspiration rates are driven primarily by temperature and land cover.

### 3.2 Unsaturated Zone

Infiltration rates in both WRIAs are estimated to be quite high due to the permeable nature of the soils. Therefore, the unsaturated zone is expected to impact run-off and recharge rates. Recharge is also affected by the extent of vegetative cover, available storage, temperature, and rainfall intensity.

Recharge through the unsaturated zone to the Spokane Valley Rathdrum Prairie Aquifer are expected to come from the following sources: direct precipitation and infiltration; infiltration from outdoor water use (urban and rural); drywell infiltration; septic system recharge; infiltration from streams; and, seasonal surface water runoff and infiltration from adjoining valleys. The quantity of recharge contributed by upward leakage of groundwater from the bedrock beneath the valley floor is thought to be negligible, compared to these other sources of recharge.

Recharge contributions to the Little Spokane Watershed aquifer are expected to come primarily from direct precipitation and infiltration at aquifer outcrops, stream seepage, and floodwater infiltration. It was estimated that approximately 1/5 of annual precipitation recharges the groundwater (Dames and Moore, Inc., 1995).

### 3.3 Saturated Zone

There are eight principal aquifer areas delineated in WRIAs 55 and 57 (Figure 3.1). Three of these areas contain basalt aquifers (Five Mile Prairie, Orchard Prairie and Greene Bluff). Four of these areas are unconsolidated sediment aquifers (SVRP, Little Spokane River, Peone Prairie, and the Diamond Lake). The Deer Park Basin is comprised of an upper unconsolidated sediment aquifer and a lower basalt aquifer. The Diamond Lake Aquifer area in the northeast corner of WRIA 55 may be a conduit for groundwater flow from the Pend Oreille Basin into the headwaters of the Little Spokane River. The SVRP Aquifer, which occurs within the central portion of WRIA 57 and the southern portion of WRIA 55, as well as extending into Idaho, is one of the most productive aquifers in the United States and is the primary water source for more than 400,000 people in Washington and Idaho. The SVRP aquifer acts as a conduit of groundwater flow from Idaho into Washington across the Stateline, from the Spokane River through the Hillyard Trough to the Little Spokane River and, to a lesser extent, through the Trinity Trough to lower reaches of the Spokane River.

### 3.3.1 WRIA 55

The hydrogeology of WRIA 55 is composed of two main aquifer layers: a shallow aquifer made up of unconsolidated sediments; and, a deeper aquifer system contained within the basalts, Latah sediments and crystalline basement rocks.

A distinct aquifer unit is located within the Diamond Lake area of Pend Oreille County, in the northeastern portion of WRIA 55. However, very little information is available on this aquifer. The aquifer is expected to range from a few feet thick at the aquifer margins to 100 feet thick or more in the central Diamond Lake Basin and Scotia Valley. The aquifer is bounded by crystalline basement bedrock exposures to the south, west and north. The unconsolidated deposits of the aquifer extend east toward Lake Pend Oreille. It is assumed that a hydraulic connection may exist across the northwestern boundary of this aquifer with the Pend Oreille River Watershed.

The upper unconfined sand and gravel aquifer within WRIA 55 occurs mainly adjacent to river channels, above finer grained fluvial and lake deposits. Groundwater within this upper aquifer flows rapidly along the groundwater flow gradient, has relatively high hydraulic continuity with streams, and in some places discharges as springs. Groundwater generally flows from the northeast to the southwest discharging into the Little Spokane River and Dragoon Creek.

The lower unit is primarily composed of fractured basalt, Latah sediments and crystalline basement rocks. This lower unit exists in the Deer Park Groundwater Basin, the Little Spokane River, Greene Bluff, Peone Prairie and Orchard Prairie Aquifer areas. Groundwater in the basalt layers travels along vertical and lateral fracture surfaces and locally exits the exposed face of basalt outcrops as springs. Latah sediments in Greene Bluff and Orchard Prairie are considered as part of the basalt aquifer system.

Small confined aquifers are interspersed between finer grained fluvial and lake deposits. The occurrence of these pockets is difficult to predict, but affects the overall conductivity of the unit.

A silt and clay aquitard divides the sand and gravel aquifer into two distinct units in the vicinity of the confluence of Little Deep and Deadman Creeks with the Little Spokane River. This aquitard extends into the lower reaches of the Little Spokane River and into the Hillyard Trough of WRIA 57.

Groundwater level monitoring in WRIA 55 is relatively sparse. Snapshot water levels are available in the Deer Park area for 1991 and 1992 (Emcon, 1992) and in the southern half of the WRIA 55 for 1994-1996 (Boese and Buchanan, 1996; CH2M Hill, 1998 and 2000). Continuous groundwater level monitoring data is available for 1993-1999 for 13 wells in the central and lower parts of the Little Spokane Watershed. Additional details on this data are available in Section 5 of the Draft Level 1 Technical Assessment.

### 3.3.2 WRIA 57

Within WRIA 57, the upper unconfined sand and gravel aquifer dominates the groundwater flow system. Groundwater flows across the Idaho-Washington Stateline. At the west end of the watershed, flow is directed either north through the Hillyard Trough or west through the Trinity Trough. Groundwater eventually discharges to the Spokane River, Little Spokane River and Long Lake at the western edge of the model domain.

The Central Spokane Valley Rathdrum Prairie Aquifer is over 700 ft thick within the central portion of the Hillyard Trough, and 500 feet thick within the Spokane Valley. The valley margin areas north and northeast of Pines Road Knoll have a saturated thickness between 100 and 200 feet.

The aquifer permeability decreases slightly and the groundwater flow gradient increases from east to west in a down gradient direction (west from the Stateline, north through the Hillyard Trough). The hydraulic gradient of the Spokane River is more variable as a result of bedrock and hydraulic controls such as Spokane Falls. This difference is one cause of variation in gaining and losing reaches in the Spokane River in WRIA 57.

The sand and gravel deposits of the SVRP Aquifer are underlain and laterally bounded by granite and basalt in most portions of the valley. In some areas the aquifer boundaries are also comprised of low-permeability lakebed sediments (clays) associated with the Latah Formation (CH2M Hill, 1998).

A continuous subsurface basalt ridge lies between Five Mile Prairie and downtown Spokane. The SVRP Aquifer extends around both sides of Five Mile Prairie forming the Trinity Trough south of the prairie and west of downtown, and the Hillyard Trough east of the prairie and north of downtown.

The Trinity Trough is about three kilometers wide (2 miles) and more than 100 m (~330 feet) deep, while the Hillyard Trough is about 4.5 km wide (~3 miles) and 200 m (~700 feet) deep.

Bedrock is present at shallow depths in two central locations within the SVRP Aquifer. The Greene Street Knoll is a shallow bedrock feature approximately 15 m (50 ft) below the ground surface. Pines Road Knoll is an isolated erosional remnant consisting of metamorphic basement complex rock (CH2M Hill, 1998).

A local and relatively continuous clay/silt aquitard is present in the Hillyard Trough and lower Little Spokane River area. This aquitard is estimated to be between 50 and 200 feet thick. It separates the Hillyard Trough into upper unconfined, and lower confined sand and gravel aquifers. The lower aquifer is between 50 feet and 150 feet thick. The remaining portions of the Spokane Valley aquifer contain no significant layers of low permeability materials.

Groundwater level monitoring in WRIA 57 is denser than in WRIA 55. Snapshot water levels are available for 1994-1996 and 2000 (Boese & Buchanan, 1996; CH2M Hill, 1998; CH2M Hill, 2000; and, United States Geological Survey [USGS], 2000). Continuous groundwater level monitoring data is available for 1993-2001 for 52 wells in the watershed. More information on this data is available in Section 5 of the Draft Level 1 Technical Assessment (Golder, 2003).

### 3.4 Surface Water

Seasonal flows in the Little Spokane River and the Spokane River follow that of a typical snow driven watershed. Flows are low in the summer and early fall, slightly higher in the late fall and early winter as precipitation falls as rain and snow. Peak flows are reached in the spring due to spring run-off from snowmelt, after which flows rapidly recede to summer baseflows.

The major drainage of WRIA 57 is the Spokane River. The Spokane River has no major tributaries feeding its entire length within WRIA 57. Several streams and lakes exist to the north and south but infiltrate into the ground before reaching the Spokane River. There are two reaches of the Spokane River where the main river channel briefly splits into two channels, the length is relatively short but these reaches are represented in the model as the Upriver Dam secondary channel and the Upper Falls Dam secondary channel. There is a high degree of hydraulic continuity between the Spokane River and groundwater of the SVRP Aquifer that strongly affects seasonal and annual flows. Within WRIA 57, the Spokane River has several moderately defined gaining and losing reaches. Water flowing through the Spokane River Valley flows out of the WRIA through the Spokane River, and as groundwater through the Hillyard and Trinity Troughs. Three run-of-river dams exist along the Spokane River. These dams do not have enough storage to regulate flows on the river (Golder, 2002). Hangman Creek is located within the model domain just downstream of WRIA 57, and provides year-round flow to the Spokane River.

The major drainage in WRIA 55 is the Little Spokane River. The headwaters of the Little Spokane River are split approximately evenly between the West Branch of the Little Spokane River and the mainstem. The mainstem appears to receive baseflow from the Pend Oreille River system in the form of inter-basin groundwater flow. The West Branch has several large shallow lakes in its headwaters (i.e., Eloika, Sacheen and Diamond Lakes). The upper reaches of the Little Spokane River are relatively undeveloped.

Flow in the upper and middle reaches of the Little Spokane River increases primarily through the contribution of tributaries such as Deadman and Dragoon Creeks. In the lower reaches, flow increases significantly as a result of groundwater discharge from the SRVP Aquifer extending from WRIA 57 through the Hillyard Trough. The river is dominantly gaining throughout its length. The Little Spokane River has few artificial controls on its flow and the hydrograph shows sharp responses to seasonal effects such as snow melt.

A well-developed river network feeds the Little Spokane River. The following rivers are considered primary tributaries of the Little Spokane River, and were considered necessary to include in the model in order accurately simulate run-off from the surrounding watersheds and interactions of tributaries with local aquifers:

- Little Spokane River
- West Branch Little Spokane River
- Dragoon Creek
- Deadman Creek
- Little Deep Creek
- Dartford Creek

### 3.5 Groundwater-Surface Water Interaction

Groundwater-surface water interaction occurs in both WRIA 55 and WRIA 57 and is a significant factor influencing surface water flows. In WRIA 57, the Spokane River and the SVRP Aquifer interact almost continuously along the full length of the river and alternates between gaining and losing reaches. Reaches where groundwater discharges to rivers are termed gaining reaches, and reaches where the river recharges groundwater are termed losing reaches. These gaining and losing reaches occur because of the relative elevation differences between groundwater and surface water. The thickness and permeability of the finer grained sediments that line the riverbed controls the rates at which these interactions occur.

In WRIA 55, rivers in the watershed are primarily gaining reaches. On the lower reaches of the Little Spokane River, below Dartford, groundwater discharge increases significantly as groundwater flowing from the SVRP Aquifer through the Hillyard Trough discharges to the Little Spokane River. Groundwater discharges year-round as springs and baseflow to the lower Little Spokane River.

### 3.6 Overland Flow

Overland flow, commonly called run-off occurs when water moves over the surface of the ground until it either infiltrates or flows into temporary or permanent surface water bodies (lakes and rivers). Overland flow generally occurs following storm or snowmelt events. Run-off rates and volumes are controlled by the type of ground surface (e.g., soil), ground cover (e.g., vegetation), and the slope of the ground. Run-off in urban areas is increased due to greater impervious area (e.g., pavement). In the urbanized areas of WRIA 55 and 57 (in and around the Cities of Spokane and Deer Park), run-off is routed to either sewers or drywells. Storm water from some sewered areas in Spokane urban area is discharged outside of WRIA 57, downstream of the Spokane River at Spokane USGS streamflow gage. Drywells exist in the non-sewered and some sewered urbanized areas around Spokane and in Deer Park. Run-off to drywells is estimated to recharge between 83% and 87% of total precipitation that falls within the capture zone of the wells directly to groundwater. Drywells are estimated to increase recharge to the aquifer and decrease evapotranspiration.

### 3.7 Water Use and Discharge

Water in WRIA 55 and 57 is used primarily for domestic, commercial/industrial and agricultural use with domestic use comprising the largest portion. Domestic water is supplied either by municipal purveyors, private systems, or exempt wells. The water use cycle of municipalities and commercial/industrial users can be represented by withdrawal and discharge rates and locations, with a portion of the withdrawal being lost to consumptive use. Total water use by exempt well users was estimated in the Technical Assessment to be approximately 9,600 AF/yr (6,300 AF/yr in WRIA 55 and 3,300 AF/yr in WRIA 57). It is assumed that the majority of exempt well water users also use septic systems on the same property for water disposal, with withdrawals and recharge of water occurring in the same location. Therefore, water used by exempt well users can be represented as a consumptive use only, rather than a distinct withdrawal and discharge sequence.

The primary consumptive use in both WRIAs is lawn watering. There are approximately 15,257 acres of residential lawns watered in WRIA 55 and WRIA 57. Water used by domestic households (both exempt and municipally served) for watering these lands represents the only major consumptive use of water in the basin by residential users. Additional consumptive use is incurred by agricultural irrigation. There are approximately 3,600 acres of irrigated agricultural land within the basin.

Wastewater discharge includes domestic, commercial and industrial discharges. Domestic and commercial discharge within the City of Spokane, sewered portions of north Spokane, and the Spokane Valley are routed to dedicated or combined sewers (storm water and wastewater) and discharged outside the WRIA, downstream of the Spokane River near the Spokane USGS gage. Some industrial wastewater is discharged to surface water and some to ground surface locations around the basin. There are five industrial wastewater dischargers in WRIA 57 and six in WRIA 55.

## 4.0 DATA SOURCES

This section outlines the sources of data used in modeling the Little and Middle Spokane Basins. Much of this data was obtained for the Technical Assessment and additional information can be found in that report.

### 4.1 Topography

Public domain USGS Digital Elevation Models (DEMs) were obtained through the University of Washington Geospatial Data Archive. These ten-meter DEM grids were developed using 40-foot or finer contour interval lines on 7.5' topographic quadrangle maps.

### 4.2 Meteorological Data

Daily precipitation and temperature data and the monthly spatial distribution of these variables were obtained for the Technical Assessment. Daily data originated from NOAA/NWS-COOP and SNOTEL. Stations included are listed in Table 4.1. Spatially distributed monthly precipitation was obtained from the Climate Source, Inc. This data is the results of the model titled, The Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Daley and others, 1994).

Mean annual actual evapotranspiration contours were obtained from the U.S. Weather Bureau (now the National Weather Service; U.S Weather Bureau, 1962). These estimates were created using Thornthwaite’s procedures under two soil moisture conditions – 2 inches and 6 inches of water – supplying a range of possible actual evapotranspiration rates. Estimated actual evapotranspiration estimates were specified at Spokane, Deer Park and Newport.

Monthly potential evapotranspiration ($P_{ET}$) estimates were calculated using the Blaney Criddle FAO (Doorenboos and Pruitt, 1977) method. PRISM monthly gridded daily temperature estimates provided spatial distribution of temperature for the calculation.

### 4.3 Land Cover

USGS National Land Cover Database (NLCD) provided land cover information for the domain. This is a 30-meter resolution land-cover classification based on an unsupervised clustering algorithm run on 30 m Landsat thematic mapper (TM) data. The resulting spectral clusters were resolved into one of 21 thematic mapper classes using logical modeling and ancillary data sources as required (e.g., census, slope/aspect/elevation, etc.). The resulting data is checked for accuracy using probability sampling and spot checks against NAPP Aerial Photographs. Source data for the coverage is predominantly Landsat TM data for the years near 1992.

### 4.4 Overland Flow Roughness Coefficients

Strickler’s roughness values for land classifications in the watershed were assigned based on data in the Spokane County, Washington Guidelines for Stormwater Management (October, 2000 Public Review Draft), shown in Table 4.2. Manning’s n values supplied in the Guidelines can be converted to Strickler’s roughness through the following equation.

Strickler’s roughness = 1/Mannings n (DHI, 2001)

## 4.5 Vegetation Characteristics

Vegetation growth and consumptive use characteristics were obtained from the following sources:

- Worldwide Historical Estimates of Leaf Area Index, 1932-2000 (Scurlock and others, 2001).
- Evaluating Evapotranspiration for Grasslands on the Arid Lands Ecology Reserve, Benton County, and Turnbull National Wildlife Refuge, Spokane County, Washington, May 1990 to September 1991. (Tomlinson, 1995);
- Above and Below Ground: A comparative study of the root and shoot growth of pasture legumes (Campbell and others).
- Leaf Area Index of an old-Growth Douglas-fir Forest Estimated from direct structural measurements in the canopy. (Thomas and Winner, 2000).
- Forest Ecosystems Concepts and Management (Waring and Schlesinger, 1985).
- Irrigation Scheduling (Trimmer and Stasney, 1994).
- Forest Stand Dynamics (Oliver and Larson, 1990).
- Evapotranspiration and Irrigation Water Requirements (Jensen and others, 1990).

## 4.6 Irrigation

Average Annual lawn watering rates in urban areas were calculated as 50% of total per capita water use rate provided by the Planning Unit of 320 gallons per day (gpd). This average rate was sub-divided into a monthly hydrograph using the monthly demand distribution in the Technical Assessment (Golder, 2003). The daily timing of lawn watering was developed based on conversations with Stan Miller of Spokane County.

Agricultural irrigation demands were calculated in the Technical Assessment (Golder, 2003). The timing of agricultural irrigation was estimated based on conversations with Stan Miller of Spokane County and experience in similar basins.

The spatial distribution of irrigated lands, including residential lawns, agriculture and ground surface wastewater discharge areas, were obtained from the following four land GIS coverages.

- Agricultural Irrigated Acreage. Generated by Spokane County from field surveys with notes for the Irrigated Land Survey for Spokane County and aerial photos from 1995 as a reference.
- Urban Irrigated Areas by parcel. Generated by Spokane County from parcel data.
- NLCD Land Cover created by the USGS (used for areas outside of the WRIAs).
- Wastewater ground surface discharge locations obtained from Spokane County.

Residential Irrigation water is provided by either municipal water systems or exempt wells. Irrigation sources were determined using water district boundaries obtained from Spokane County for the Technical Assessment (Golder, 2003). Water district purveyors are assumed to serve residential irrigated areas within their boundaries, while exempt wells are assumed to serve irrigated areas outside of water district boundaries.

Total irrigation is then calculated as:

Total Irrigation = Irrigation Demands * Irrigated Areas.

Where Irrigation Demands and Irrigated Areas both have many data sources and therefore must be averaged across the basin based on available data.

## 4.7 Rivers and Lakes

Geographic Information System (GIS) coverages of streams in the basin were obtained from both the Washington Department of Transportation (WSDOT) and Ecology for the Technical Assessment (Golder, 2003).

A total of 63 field measured river cross sections were supplied by several sources including Spokane County, Spokane County Conservation District, USGS and Ecology. Cross section data included in the model has been collected at various times over the past 30 years.

Lake bathymetries were obtained from Wolcott (1973).

## 4.8 Dams

Spokane County, the City of Spokane and Avista Utilities provided Dam operational and physical information.

## 4.9 Wastewater Discharge

Wastewater discharge data was compiled by Spokane County for the Technical Assessment (Golder 2001). It consists of monthly discharge rates and the location and type of discharge.

## 4.10 Unsaturated Zone

The spatial, vertical extent, and hydrologic groupings of soil types in the basin were obtained from Spokane County GIS and the Natural Resource Conservation Service (NRCS; formerly the Soil Conservation Service [SCS]) of the United States Department of Agriculture (USDA) for the Technical Assessment (Golder, 2003). Soils coverage from Spokane County is a digitization of original county soil survey maps (USDA SCS, 1968; USDA 1978; USDA SCS, 1980). Soil coverage for Stevens County, Washington and Kootenai County, Idaho were obtained from the NRCS SSURGO database.

Soil hydraulic properties related to hydrologic soil groups were obtained from the Soil Survey Manual (Soil Survey Division Staff. 1993), SEEPW Software package (Version 5), and the paper titled “Estimating Generalized Soil-Water Characteristics From Texture” (Saxton and others, 1986).

The following GIS coverages and documentation sources were used to estimate drywell recharge through the unsaturated zone.

- GIS coverages of sewered areas and the urban growth area were supplied by Spokane County for the Technical Assessment (Golder, 2003).
- GIS coverages of drywell locations were obtained from Spokane County. This coverage included the majority of drywells on public rights of way.

- Methods for estimating drywell locations on private and city land, based on impervious area, were provided in a memo from Spokane County (received 7/25/02). This memo can be found in Appendix A.

## 4.11 Geology

The majority of the geologic data used in the model was obtained for the Technical Assessment and is presented in more detail in that report (Golder, 2003). Data sources include the following.

- Cross-sections of the Spokane Valley were obtained from both the Washington State Department of Natural Resources (Derkey, 2000) and seismic investigations completed by CH2M Hill (2000).
- Cross-sections for the Little Spokane River Valley and Deer Park were obtained from Boese and Buchanan (1996) and EMCON (Deer Park only; 1992).
- Additional geologic cross sections of various areas within the model domain were obtained from the DNR (In Press, 2002).
- The horizontal extent of the Tertiary and Quaternary units against the surficial exposure of crystalline basement rock was obtained from a surficial geology map created by the DNR (In Press).

## 4.12 Hydrogeology

A number of previous modeling efforts in the Spokane Valley were used in the estimation of hydrogeologic parameters for the SVRP Aquifer. These reports are summarized in the Technical Assessment (Golder, 2003).

- Bolke and Vaccaro, 1981.
- Buchanan and Olness, 1993.
- Buchanan, 1999.
- CH2M Hill, 1999.

For northern Spokane County (e.g., the Deer Park area), estimates of lateral hydraulic conductivity were compiled by Boese and Buchanan (1996).

## 4.13 Abstraction Wells

Municipal and industrial abstraction well locations and monthly withdrawal rates were provided by Spokane County for the Technical Assessment (Golder, 2003).

## 4.14 Groundwater Surface Water Interaction

Leakage coefficients and the magnitudes of gaining and losing reaches were reported in the Technical Assessment (Golder, 2003). Reports providing estimates of leakance values for the Spokane River include:

- Bolke and Vaccaro, 1981; and,
- CH2M Hill, 1998.

Many aquifer interactions studies have been completed in which the magnitude of gaining and loosing reaches of the Spokane River have been estimated through measurements and modeling.

Each report presented slight variations on the magnitude and location of gaining and losing reaches of the Spokane River. The following reports were reviewed in Appendix D of the Technical Assessment (Golder, 2003):

- McDonald and Broom, 1951;
- Broom, 1951;
- Drost and Seitz, 1978;
- Bolke and Vaccaro, 1981;
- Miller and others, 1996;
- CH2M Hill, 1998;
- CH2M Hill, 2000;
- Gearhart and Buchanan, 2000; and,
- USGS (ongoing).

The topography of the land surface and the elevation of the riverbed affect the resulting aquifer interactions. The elevation profile of the Spokane River was defined through 48 cross sections. The elevation of the Little Spokane River was defined through 10 measured cross sections. The remaining tributaries of the Little Spokane River had two or fewer measured cross sections. Topography of the land surface was supplied through the USGS DEM (Section 4.1) that was dissolved to the 400 m model grid size.

## 5.0 DESCRIPTION OF MIKE MODEL

The MIKE Suite of software used for modeling the hydrologic system of WRIA 55 and WRIA 57 includes two distinct packages: MIKE 11 Hydrodynamic (MIKE 11 HD) and MIKE SHE Water Movement (MIKE SHE WM) both developed by the DHI. These two models can be integrated to effectively model surface water and ground water interactions.

### 5.1 MIKE 11

MIKE 11 HD is a software package developed to simulate flows in estuaries, rivers, irrigation systems, channels and other water bodies. MIKE 11 HD utilizes the 1-Dimensional Saint Venant equations, which are vertically integrated equations for the conservation of continuity and momentum. The version of MIKE 11 used was 2001b, build 4.302. MIKE 11 is a Microsoft Windows based software code and can run on Windows 95, 98, NT, 2000 or XP.

### 5.2 MIKE SHE

The MIKE SHE WM software package was developed to simulate the interrelationships of hydrologic process including the saturated and unsaturated zone, overland flow, evaporation, evapotranspiration and snow melt (Danish Hydraulic Institute, 2000; Table 5.1).

The model used to simulate the hydrologic processes in the WRIAs 55 and 57 presented in this report uses MIKE SHE WM Version 5.44, released October 2001. This version of MIKE SHE was originally developed for UNIX and exported to Windows and therefore requires Xwindows in order to run (this is bundled with the software). MIKE SHE can run on Windows 95, 98, NT, 2000 or XP.

Additional modules purchased or provided by DHI for modeling include:

- MIKE SHE IR – This module provides a water accounting module that provides for irrigation demands, sources and application methods.
- MIKE SHE GIS Converter – this module provides a method to transfer geographical data to and from Arc View version 3.1.
- MIKE SHE Pre and Post Processing (PP) – this module provides a method to retrieve results from model runs in both graphical and tabular forms.

A windows version of MIKE SHE was released in November 2002.

# 6.0 MODEL SETUP

This section describes the data preparation and model setup.

## 6.1 Model Domain/Grid

The model domain is shown in Figure 6.1. The domain encompasses all of WRIA 55 and WRIA 57, except for small portions of WRIA 57 that drain to Idaho. These areas were discussed the Technical Assessment and consist of a small area to the north (Blanchard Creek WAU) and another area to the south of WRIA 57 (southern half of Liberty Creek WAU), both adjacent to the Stateline. (Watershed Administrative Units [WAUs] are subbasins defined by the Washington Department of Fish and Wildlife.) Contributions of water from these areas to flows in the Spokane River are accounted for in the surface water and groundwater boundary conditions of the model near the Washington-Idaho Stateline.

Two additional areas were included in the model domain that are outside the WRIA boundaries; the area between the Stateline and Post Falls in Idaho that overlays the SVRP Aquifer, and the portion of WRIA 54 that contains the reach of the Spokane River between the Spokane River at Spokane USGS gage and river mile 44.8 of Long Lake on the Spokane River. This was done for one of two reasons:

1. Data at the WRIA boundary was not sufficient to model the actual flow across the boundary or a natural divide exists elsewhere.
2. The boundary is some distance from areas of interest to ensure that the model can simulate that area.

MIKE SHE solves simulations using the finite difference method over a uniform grid that includes the model domain. This grid extends from just west of the WRIA boundary into Idaho. Cells outside of the model domain have an "ignore" value that indicates the model should currently not run simulations in those cells. The grid used for MIKE SHE has the following coordinates (State plane NAD83).

- x-lower left = 735177.6 m (2412000.0 ft)
- y-lower left = 67056.0 m (220000.0 ft)
- x-upper right = 822681.9 m (2699087.5 ft)
- y-upper right = 142059.7 m (466075.0 ft)
- Cell Size 400.0 m (1312.4 ft)

The grid is shown in Figure 6.1. There are a total of 17,709 cells in the model domain: 10,950 cells in WRIA 55, and 3,458 in WRIA 57. The Spokane model was completed in metric units; unit conversions can be found in Table 1.1. The horizontal datum is Washington State Plane NAD83 (m); the vertical datum is NAVD 88 (m).

## 6.2 Channel Flow

MIKE11 HD requires data on surface water channels including elevation, length, blocking structures, cross sections, roughness, and leakage coefficients. Only the primary river and/or lake in each Watershed Administrative Unit (WAU) were modeled (Table 6.1, Figure 6.1). MIKE11 HD channel notation dictates that river lengths and locations are identified by chainages. Chainages are equivalent to river miles, except that chainages are measured from the headwaters to the mouth, with the headwaters being chainage 0.0 m, and the mouth being set to the total length of the river in meters (the reverse of river miles). In situations where the headwaters are not modeled (such as on the Spokane River) the upstream and downstream boundaries are still notated as the distance from the headwaters – not chainage 0.0 m. The chainage at the upstream extent of the Spokane River within the model domain was assigned a value of 18,428.4 m.

The river network of the model was digitized based on data contained in WSDOT and Ecology GIS coverages. Digitization of rivers provides the general horizontal location of the river over the DEM. Cross sections provide elevation and channel shape. Table 6.1 also summarizes the number of measured and created cross sections for each modeled river. Appendix A lists all cross sections obtained for this project.

Measured cross sections were received in various formats. Cross section elevations and locations need to match the model 400m square DEM as closely as possible to prevent “floating” or “submerged” rivers. Several steps had to be taken to prepare this data for the model.

- River miles were added, changed, or verified with USGS river miles (where possible), and converted to metric.
- Cross section elevations that were supplied as a relative elevation had to be referenced to the USGS DEM.
- Cross section elevations that were supplied as referenced elevations were checked against the USGS DEM and, where necessary, converted to NAVD 88 (m).

Where sufficient cross section data was not available, ground surface elevations were extracted from the USGS 10 m DEM and a default trapezoidal channel was inserted to represent the river channel.

Channel roughness values were not explicitly provided for most of the rivers in the watershed, though channel descriptions of substrate and geomorphologic data was provided for the Spokane River (Box and Wallis, 2002). An average range of Manning’s roughness values was used depending on the population density, slope and land cover in the river basin. These values range from 0.045 to 0.090. Reported Manning’s roughness values range from 0.011 for a sandy plane bed type to 0.1 for streams with a high boulder density and low flow depths (Maidment, 1993).

Leakage between the river and the aquifer is controlled by the permeability of the riverbed and the hydraulic conductivity of the saturated zone. The exchange flow is described by a Darcy approximation as a function of the head gradient and the riverbed conductance (calculated assuming flow resistance in the river lining and the saturated zone). Where bedrock is known to line the riverbed, leakage is set to 1.0 E-10 $s^{-1}$. Leakage estimates for the Spokane River and portions of the Little Spokane River were developed in previous modeling efforts (Table 6.2). These estimates were used for initial leakage values where possible. Leakage coefficients used in final calibrated model runs are shown on Table 6.3.

The Spokane River within the model domain has 7 main structures in and off channel. The MIKE 11 structures module was not purchased for this project because the operations of the hydroelectric projects are expected to have little impact on the overall hydrology of the Spokane River due to their operation as run-of-river projects. Therefore a weir, designed to contain water behind the structure at recorded normal elevations, represents each structure. Table 6.4 shows information on structures provided by Spokane County, Avista Utilities and the City of Spokane. Structures on the Spokane River included in modeling are:

- The Upriver Diversion Dam at chainage 0.0 of the Upriver Side Channel,
- The Upriver Powerhouse at chainage 51.2 km of the Spokane River,

- The Upper Falls Control Works at chainage 0.0 of the Upper Falls Side Channel,
- The Upper Falls Powerhouse at chainage 60.1 km of the Spokane River, and
- The Monroe Street Dam at chainage 60.5 km of the Spokane River,
- The Nine Mile Dam at chainage 86.0 km of the Spokane River.

## 6.3 Meteorological Data

Precipitation and temperature data were input to the model as daily, 4 km gridded data. A method outlined in Bauer and Vaccaro (1987) was used to calculate daily, distributed data across the watershed. In this method, point daily measurements are weighted by the inverse square of the distance between the gage and the cell centroid, and corrected by the ratio of the mean monthly PRISM precipitation to the mean monthly measured precipitation at the gage. Monthly and annual maps of PRISM distributed data were presented in the Technical Assessment (Golder, 2003); Figure 6.2 displays the locations of daily, meteorological gages. A 4 km grid for meteorological input was chosen because a 400 m grid would be too computationally intensive (DHI, professional communication, 2002). Use of 4 km gridded data for precipitation and temperature is still numerically intensive and required a recompiled version of the MIKE SHE WM executable software.

Two parameters control simulation of snowmelt: the degree-day snow melts factor, and the threshold at which snowmelt occurs. These parameters are required to be uniform across the watershed. The degree-day snowmelt factor was set to 2.0 mm snow/day/°C, and the snowmelt threshold was set to 1.0°C.

## 6.4 Overland Flow

The overland flow module of MIKE SHE requires topography and a spatial map of roughness coefficients (Strickler’s roughness coefficients).

USGS DEM provided a topographic coverage of the watershed. Each map was converted from NGVD29 (m) datum to NAVD88 (m) datum using Corpscon Version 5.11. The DEM grid cell size was then increased to a 400 m cell size for model input using the MIKE SHE Converter extension for ArcView. Additional edits were made to the DEM to represent the depth of lakebeds (the DEM represents the water surface, not the lake bottom).

The USGS National Land Cover Data (NLCD) GIS grid coverage provided a distribution of 21 classes of land cover for the Spokane Watershed. Each class was assigned an initial value for Strickler’s roughness coefficient ($m^{1/3}/s$) for overland flow. The assigned Strickler’s roughness values were decreased to 60% of the original values during calibration based on conversations with DHI regarding recommended ranges of roughness coefficients. The 30 m NLCD grid was converted to a 400 m grid by aerially averaging roughness coefficients. Land cover classes were assigned roughness coefficients and total acreage within the model domain (Table 6.5, Figure 6.3).

## 6.5 Unsaturated Zone

Unsaturated zone data setup includes the depth, distribution and hydrologic characteristics of soils within the model domain. In addition, drywell effects are handled within the unsaturated zone computational component.

Soils within the model domain were grouped into four types based on NRCS hydrologic soil groups for the Technical Assessment (Table 6.6, Figure 6.4). Each NRCS soil group represents the saturated hydraulic conductivity of the entire soil column.

Soil depth in the NRCS SSURGO soils database for the watershed ranges from 20 inches to 60 inches. A uniform soil depth of 1.5 m (60 inches) was chosen for the entire domain. Because MIKE SHE dynamically changes the boundary between the unsaturated zone and the saturated zone, the definition of the unsaturated zone must extend to the deepest depth the aquifer water table might reach. Therefore, aquifer materials (which are already defined for the saturated zone) are specified from below the initial 1.5 m of soil to the water table. During simulation the model calculates movement in the unsaturated zone using user-defined vertical layers of the total soil depth vertical discretization ranges from 0.1 m, at the surface, to 1.5 m at the base of the soil profile.

Soil hydrologic characteristics required by MIKE include vertical saturated hydraulic conductivity and moisture retention curves with at least three data points, including water content and pressure head at saturation, field capacity, and wilting point. Ranges for vertical saturated hydraulic conductivity for each hydrologic group were obtained from the Natural Resource Conservations Service. (1996), Vertical saturated hydraulic conductivity of aquifer materials was based on an average of vertical conductivities used for that layer in the saturated zone.

Generalized moisture retention curves are not available from the NRCS for each hydrologic soil group. Therefore a database of moisture retention curves available in the SEEP/W software package was used (Geo-Slope, 2001). SEEP/W uses a standard set of sediment types (e.g., coarse sand, silt, silty clay) and assigns a standard hydraulic conductivity value and soil moisture retention curve for each type. Each hydrologic soil group in the model area was associated with a hydraulic conductivity value for the generic soil groups in SEEP/W (Figure 6.5).

MIKE SHE generates the specific yield of the saturated zone of layer 1 based on the deficit between the moisture content at effective saturation and the moisture content at field capacity of the material in which the water table resides at the start of the run. Both of these are specified as part of the moisture retention curve in the unsaturated zone.

Drywell simulation was determined to be most accurately represented by the unsaturated zone module. The MIKE SHE model does not have an explicit method for simulating drywell recharge, therefore it was determined that a function of the unsaturated zone, called a “bypass”, provided the best representation of drywell infiltration. The bypass function works by recharging a specified percentage of groundwater directly to the saturated zone when the water content in the unsaturated zone is greater than a minimum value. When the water content in a cell falls below the minimum water content, the recharge volume is linearly decreased until the water content falls below a stop value, after which water no longer bypasses the unsaturated zone.

The number of drywells in a grid cell was estimated through the following steps (see Appendix A for memo detailing calculations).

- A percent impervious area was assigned to land use codes defined for counties within the model domain.
- It is assumed that every 15,000 square feet of impervious area in a cell drains to one drywell, and that drywells only exist outside of sewered areas within the urbanized area.

- The final drywell estimate is compared to a drywell GIS coverage provided by Spokane County for all public rights-of-way. The estimated number of drywells should be equal to or slightly greater than the number provided in the Spokane drywell coverage.
- Drywells are then grouped based on the total number of drywells in a cell and assigned a percent recharge value based on the number of drywells in that group.

The following list displays the drywell groups and the assigned percent increase in recharge over natural levels in a cell.

- 0 – 9 drywells, 4.2% increase in recharge
- 9 – 20 drywells, 6.7 % increase in recharge
- 20 – 33 drywells, 12.3 % increase in recharge
- 33 – 58 drywells, 21.2 % increase in recharge
- 58 – 87 drywells, 40.5% increase in recharge

The distribution of these drywell groups is shown on Figure 6.4 on top of the hydrologic soil groups.

## 6.6 Saturated Zone

Saturated zone input includes the spatial and vertical extent of geologic layers, hydrogeologic parameters, initial conditions and boundary conditions for each layer. This section first describes how the modeled geologic layers were determined and created and then describes the components that make up each layer. More detailed information on the geology and aquifers within WRIA 55 and WRIA 57 can be found in the Technical Assessment (Golder, 2003).

### 6.6.1 Geologic Layers (Stratigraphy)

Geology in the model domain is composed of 2 aquifer layers, a low conductivity geologic lens in the Hillyard Trough and Lower Spokane area, and an impermeable basal boundary.

#### *6.6.1.1 Quaternary Glaciofluvial Sediments – Layer 1*

Layer 1 was defined by the extent of glaciofluvial sands and gravels within the model domain. The bulk of groundwater within the model area occurs within the coarse-grained glaciofluvial sediments deposited in ancestral river valleys of what are now the Spokane River and Little Spokane River Valleys, as well as in the Diamond Lake Basin. These sediments are generally highly permeable, being composed of coarse sand and gravel, and exhibit little anisotropy. Because of these characteristics, the glaciofluvial sediments are defined as a separate model layer from the Tertiary units. The extents and elevation of the bottom of Layer 1 is shown in Figure 6.6.

#### *6.6.1.2 Low- Conductivity Lens*

In the vicinity of the Hillyard Trough and the junction of Deadman Creek with the Little Spokane River, a lens of low-permeability glaciolacustrine clay exists that divides the unconsolidated glaciofluvial aquifer into confined and unconfined components. Because the hydraulic characteristics of this lens differ significantly from the surrounding glaciofluvial sediments and may greatly affect groundwater flow within the glaciofluvial layer, this lens is defined separately in the model. However, due to the limited spatial extent of the unit, it is entered into MIKE SHE as a geologic lens within Layer 1, rather than a complete layer. The location of the Low K lens is shown on Figure 6.6.

#### *6.6.1.3 Tertiary Basalt/Latah Formations – Layer 2*

Layer 2 was defined by the extent of the basalt and Latah Formation within the model domain. The basalt and the coarser layers of the Latah Formation can be significant groundwater sources in the North Spokane County area; therefore the Tertiary units are defined as a single model layer separate from the crystalline basement and overlying Quaternary sediments. Though the hydraulic characteristics of the basalt and Latah Formation can differ significantly, the considerable interbedding of the two units prevent separation into two layers. These differences in hydraulic characteristics range from the anisotropic, highly permeable fractured zones within the basalt, to homogeneous clay-rich or gravel-rich layers within the Latah. However, the significant vertical stratification within the Latah Formation as a whole between clay and coarse sand/gravel may create similar bulk hydraulic properties as the basalt, which is characterized by layers of high hydraulic conductivity in the fractured zones alternating with layers of very low conductivity in the massive, mid-flow zones. Thus, lumping of the two geologic formations into one model layer is considered justified, particularly at the scale of the watershed model. The extents and elevation of the bottom of Layer 2 is shown in Figure 6.7.

#### *6.6.1.4 Impermeable Basal Boundary*

The basal impermeable boundary of the model was defined by the upper surface of the crystalline basement rock. This unit is defined as impermeable because it has low hydraulic conductivity, except for the fractured top zone, and is not considered a significant source of water in the context of this model. The majority of groundwater within the model area occurs within the units overlying the crystalline basement rock, notably in the Tertiary basalt and Latah Formation, and the Quaternary glaciofluvial units.

### 6.6.2 Stratigraphic Complexities

Previous groundwater models of the Spokane area have not encompassed the entire watershed. Because of this, definition and digitization of the horizontal and vertical extent of the geology was conducted to generate model input. Previous investigations in the region (e.g., Boese and Buchanan, 1996; Derkey and Hamilton, 2000; EMCON, 1992; CH2M Hill, 1999) have resulted in detailed characterization of the geology, notably depth to the crystalline basement, and thickness and aerial extent of the Tertiary and Quaternary units. Numerous geologic cross-sections were generated for each of these investigations. These cross-sections, in conjunction with geologic maps of the region, were used to characterize the geologic representation in the model and create aquifer layer contours (Appendix B).

Definition of the geology was accomplished in a series of steps. Each cross-section was plotted on a geologic base map of the model domain (Figure 4.12 in Golder, 2003). At horizontal controls along each cross-section, depth below ground surface to the bottom of each geologic layer was determined and plotted. A separate map was created for each layer. These points were then contoured by hand using the geologic base map to aid in determining actual horizontal extent. The map was especially useful for delineating the lateral extent of the Tertiary and unconsolidated deposits by the presence of crystalline basement at the surface.

Due to varying geologic definition by different investigators and a lack of available data in certain areas of the watershed, independent interpretation of the geology in some areas was required to define the layers for the model. Such areas are identified below:

- The lens and layers of unconsolidated sediments within the Hillyard Trough were redefined. In Boese and Buchanan (1996), the glaciolacustrine lens in the Hillyard trough was not differentiated from the fine-grained Latah sediments. This caused difficulty for interpretation of the Latah sediments overlying the basalt. All unconsolidated units other than the coarse sand/gravel were lumped into one unit, "Undifferentiated Clay, Sand, and Landslide Deposits". Thus, only clay *within* the coarse gravel was chosen to represent the lens. All other clay was included with the upper Latah Formation (Layer 2).
- Loess and Latah sediments within T26N, R44E, the southwest quarter of T27N, R44E, and the eastern third of T26N, R43E were redefined. In the DNR cross-sections, loess and Latah sediments appear to be misinterpreted as Quaternary clays. When contouring, identification of these units as Quaternary did not make sense. Consultation of the geologic map showed these units mapped as Tertiary and loess.
- In the Diamond Lake area, no previous studies have characterized the depth to bedrock. In order to contour the Quaternary unit in this area, the surficial geologic map was used in conjunction with well log data. No well logs were available for Diamond Lake, but total depths of wells were available. Though they are a rough estimate, total well depths were used as an estimate of the depth to bedrock. Therefore the thickness of the unconsolidated sediments used in the model represents a minimum actual thickness. In areas with multiple well logs, the deepest well log was used. These depths were then contoured using the crystalline basement exposure as the bounding lateral extent.
- Original contouring of flood gravels did not extend beneath Newman and Hauser Lakes. Originally, this was because flood gravels did not appear on the surficial geology map (lacustrine and alluvial deposits are mapped) and none of the cross-sections used for contouring extend into these areas. However, these lakes are thought to be in hydraulic connection with the SVRP Aquifer (based on modeling conducted by Buchanan), so the layer was extended beneath the two lakes. Though flood gravels are not present at the surface, it is likely to be present in some thickness beneath the lacustrine deposits based on the truncation of the unit against the lacustrine unit. This was assumed when mapping the layer beneath the two lakes. In the northern portions of the lakes, bedrock is mapped to the lakeshore, so it was assumed that flood gravels extended only partially beneath the lakes, though still enough to maintain hydraulic continuity with the aquifer. Even though flood gravels may not extend beneath the lakes, the lacustrine and alluvial sediments are permeable enough to transmit water to the aquifer, allowing them to be included with flood gravels in the Layer 1 sediments.

The contours of the geologic layers and lens were digitized and converted into a GIS shapefile. The contour shapefiles were converted to MIKE's *.dig format as digitized lines; the *.dig files were then imported into and converted by the MIKE SHE package T2INTP. T2INTP utilizes a bilinear interpolation with up to four point values surrounding each output point. The interpolation method did not completely extend between contours in areas where there was little change in elevation (therefore having contour lines spaced further apart). Therefore, once the grid was created, manual interpolation was used to fill in areas where T2INTP did not create grid outputs.

### 6.6.3 Hydraulic Aquifer Properties

Each geologic layer requires spatial definitions for horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield (unconfined conditions) or specific storage (confined conditions). Figure 6.8 displays the hydrologic properties used for each geologic layer and lens (Appendix B).

#### *6.6.3.1 Spokane Valley Rathdrum Prairie Aquifer*

The spatial distribution and conductivity values estimated by Buchanan (1999) and CH2M Hill (2000) were used to develop initial conductivity values for this modeling effort. These values were further refined during this modeling efforts calibration.

Characterization of the vertical anisotropy in the sand/gravel aquifer has not been conducted. Previous investigations have assumed various values for vertical hydraulic conductivity. CH2M Hill (1999) used a ratio of 10:1 between horizontal and vertical conductivity because their modeling was focused on wellhead capture zones and needed to be conservative. Bolke and Vaccaro (1981) used a ratio of 3:1, based on the absence of significant stratification in the sand/gravel unit. Because this study is focused more on large-scale water movement rather than smaller-scale wellhead protection, the ratio of 3:1 use by Bolke and Vaccaro (1981) is used in this modeling effort for horizontal to vertical hydraulic conductivity.

Initial values for specific yield were also obtained from Bolke and Vaccaro (1981). These estimates were initially based upon comparison of lithologic information with tables relating specific yield to grain size. These values were further refined during calibration of their model. These final values were used for this project and compiled into a distribution map for import into the model and calibration of the aquifer parameters specified in the unsaturated zone (see Section 6.5).

#### *6.6.3.2 Little Spokane Watershed Aquifers*

Estimates of horizontal hydraulic conductivity, compiled by Boese and Buchanan (1996), are provided for the Tertiary basalts (Wanapum and Grande Ronde) and for various areas of the sand/gravel aquifer in the Little Spokane Watershed. Based on previous investigations (e.g., Boese and Buchanan, 1996; EMCON, 1992), the Grande Ronde basalt is the prevalent basalt comprising the Tertiary aquifer in Northern Spokane County. The Wanapum basalt is mainly found capping mesas such as Orchard Bluff. Because the Grand Ronde Basalt is the dominant lithology in the Tertiary stratigraphy, hydraulic properties of the Grand Ronde Basalt were used to represent Tertiary unit (Layer 2). Estimates of lateral hydraulic conductivity for the Grande Ronde basalt range from 0.0015 m/day to 768.7 m/day (0.005 ft/day to 2,522 ft/day). Estimates for vertical hydraulic conductivity of the basalt flows range from 0.00015 m/day to 1.07 m/day (0.0005 ft/day to 3.5 ft/day; Whiteman and others, 1994 in: Boese and Buchanan, 1996).

For this study, an initial value of 0.015 m/day (0.05 ft/day) was used for horizontal hydraulic conductivity (lower range of the Grande Ronde estimates). However, as calibration proceeded, this value was increased to 4.84 m/day (15.9 ft/day).

A 10:1 ratio of horizontal to vertical hydraulic conductivity was assumed, also based on the values given in the lower ranges of the horizontal and vertical conductivity estimates, resulting in a vertical hydraulic conductivity of 0.484 m/day (1.59 ft/day) used in the model.

Values for specific yield or storativity for northern Spokane County were obtained from Boese and Buchanan (1996). A summary of values for the different geologic units at different areas is presented in that report. These values were included in a map that was imported into the model.

### 6.6.4 Saturated Zone Drainage

MIKE SHE contains a drain module for routing water out of the shallow depths of the ground. This module can be used to simulate flow from perennial streams, streams not modeled in Mike

11 HD and interflow. Interflow constitutes an important contribution to the river runoff in the Little Spokane Watershed. . The drainage module requires definition of a spatial area where drainage is simulated, drain level (elevation or depth below surface), and a detention time constant. Drainage then occurs when the saturated zone water table rises above the drain level. Drainage outflow from an individual cell is calculated using the following equation:

$$\text{Drainage Outflow } (m^3/s) = \text{Detention Time Constant} * (\text{Saturated Zone Head} - \text{Drain Level}) * \text{Cell Area}$$

Drains were primarily implemented outside of the Layer 1 aquifer area in WRIA 55 (Figure 6.6 for Layer 1 extent). A uniform time constant of $1 \times 10^{-7}\ s^{-1}$ was specified as the drainage constant for the entire drained area. Drainage levels range from 1 m to 2 m below the ground surface. No previous data or studies were available to determine drainage parameters.

## 6.7 Evapotranspiration

Evapotranspiration includes evaporation from soil, snow, water and plant surfaces and transpiration from plants. Evapotranspiration is calculated by the model using spatial and time varying potential evapotranspiration (PET) along with the relative evapotranspiration potential of vegetative cover, unsaturated zone characteristics, water surfaces, snow coverage and saturated zone characteristics.

PET is by far the most influential parameter of the evapotranspiration component. Monthly PET estimates were calculated using the Blaney Criddle FAO (Doorenboos and Pruitt, 1977) method. This method was chosen based on the availability of crop coefficients, which is also required by the model. PRISM monthly gridded daily temperature estimates provided spatial distribution of temperature for the calculation. PET data is input on a 4km square grid resolution.

Distributed land coverage of vegetation was created using NLCD and Spokane County data. Because there is a wide range of vegetation found in the Little and Middle Spokane and little specific data on vegetation characteristics, vegetation groups were created to reflect available data and model demands (Table 6.7, Figure 6.3).

Vegetation characteristics were pulled from several studies and reference manuals (see Section 4.5; Table 6.8).

## 6.8 Irrigation

The rates used are as follows (Golder, 2003).

- Lawn watering: 3.69 ft/yr. Lawn watering was assumed to occur for two hours a day, every other day, during April through October. This results in a total annual volume of 56,300 AF/yr of irrigation over 15,260 irrigated acres.
- Agricultural irrigation, WRIA 55: 1.64 ft/yr; WRIA 57: 1.58 ft/yr. Agricultural irrigation was assumed to occur for 24 hours a day for a full week, every other week of the irrigation months. No irrigation occurs during November to March. This results in 5,880 AF/yr of irrigation over 3,360 acres. These irrigation rates may be lower than actual use due to over irrigation of cropland, distribution losses, and other factors

Coverages of irrigated agricultural and residential lawns were provided by Spokane County. Additionally, areas where wastewater is discharged to the surface, such as a golf course are included as irrigated areas. These areas were merged into an irrigated area coverage. The residential lawn coverage was generated from parcel data. Parcels with Property Code 11 or 12 (single and multi-unit housing) and having an improvement of $20,000+ were selected for areas with potential urban irrigation. Urban irrigated areas were assigned using the following algorithm:

Property Class 11

| | |
|---|---|
| For parcel area <5,500 $ft^2$ | Irr_area = ([parcel area] – 3,000) * 100% |
| For parcel area 5,500 – 10,999 $ft^2$ | Irr_area = ([parcel area] – 3,000) * 90% |
| For parcel area 11,000 – 16,499 $ft^2$ | Irr_area = ([parcel area] – 3,000) * 80% |
| For parcel area >=16,500 $ft^2$ | Irr_area = 10,800 $ft^2$ |

Property Class 12

| | |
|---|---|
| For parcel area <5,500 $ft^2$ | Irr_area = ([parcel area] – 3,000) * 80% |
| For parcels area 5,500 – 11,000 $ft^2$ | Irr_area = ([parcel area] – 3,000) * 60% |
| For parcels area >11,000 $ft^2$ | Irr_area = 4,800 $ft^2$ |

Irrigated areas are displayed on Figure 6.3. However, it should be noted that a cell is either irrigated or not irrigated in the model. Therefore the distribution of irrigated areas is more dispersed than what is used in the model. However, irrigation rates for each cell are scaled to result in the correct total volume of irrigation.

The source of irrigation water was assumed to be a municipal purveyor well if it is within current water district boundaries and from shallow well within the same cell if it is outside of water district boundaries.

## 6.9 Groundwater Withdrawals

Purveyor, industrial/commercial and residential exempt wells groundwater withdrawals occur within the watershed. Withdrawals were divided into purveyor/industrial/commercial, and exempt.

Abstraction rates for the purveyor/industrial/commercial group were supplied by Spokane County. A total of 277 wells were identified. Of those wells, 49 were not modeled because the well was outside of the modeled aquifer boundaries. This is only 0.38% of the total abstraction volume. An additional 37 wells were not modeled because abstraction rates were not specified. In total, 191 wells were modeled accounting for a total annual withdrawal of 52,663 million gallons per year (Figure 6.9). A list of all abstraction wells provided by Spokane County can be found in Appendix B.

Abstraction rates for the exempt well group are modeled at consumptive use rates only, accounting for lawn watering or agricultural irrigation. Modeled abstraction rate equals consumptive use estimates. Because the locations and depths of exempt wells are unknown, it is assumed that where an irrigated area (such as a lawn) exists, one or more exempt wells to irrigate that lawn also exist. These exempt wells are modeled as "shallow wells". This causes the model to extract groundwater from the same cell from which water demand (irrigation) occurs (see Section 3.7). The discussion of irrigation demands can be found in Section 6.8.

## 6.10 Boundary Conditions

Boundary conditions are assigned to portions of the model where hydrologic conditions are known or cannot be calculated independently by the model. The Spokane model was assigned surface water flow and water level boundaries and groundwater head and impermeable boundaries.

### 6.10.1 Surface Water

Two external boundary conditions exist in the surface water domain of the model

- The Spokane River enters the model domain at the USGS Post Falls gage (USGS Stn # 12419000). This gage provides continuous daily discharge measurements from which a time varying flow boundary is assigned.
- The western boundary of the model domain occurs at chainage 107.5 km of the Spokane River in Long Lake. A constant water elevation of 469 m NAVD 88 was assigned to this boundary. In reality, the water surface elevation of Long Lake typically varies by approximately 0.91 m (3 ft) throughout the year and sometimes can vary as much as 10 ft but the distance of this boundary from the WRIA boundary indicated that a constant water surface elevation boundary would suffice.

Internal surface water boundary conditions include Hangman Creek inflows to the Spokane River and several wastewater discharge locations. Hangman Creek intersects the Spokane River at chainage 63.2 km. USGS gage Hangman Creek (Stn # 12424000) provided discharge data for this boundary. Table 6.9 details the location, type and monthly discharge rate of each wastewater discharge boundary condition.

### 6.10.2 Groundwater

Impermeable boundaries were assigned to all but two areas of Layer 1.

1. The eastern edge of the model domain where the SVRP flows towards the Stateline; and,
2. The northeastern point of WRIA 55 near Newport where there is estimated to exist a hydraulic connection with Pend Oreille Watershed (WRIA 62).

Figure 6.9 shows the location of permeable and impermeable boundaries and the location of wells used to define permeable boundaries.

Two boundary conditions were evaluated at the SVRP eastern boundary. It was initially assigned a normal gradient (flux) condition (Neumann’s condition). A gradient boundary was chosen because only sparse data is available around the boundary and it was assumed that the gradient across the boundary remains constant even when the head is changing (CH2M Hill, 1994). Gradient values were calculated using single water level measurements (only one measurement was available) taken on Oct 30, 1996 from the following monitoring wells:

1. East Greenacres ID #3C (1528R03), east of Stateline
2. Greenacres Plant Food Center #1 (1531Q01), west of Stateline
3. Wolkenhauer (1521M01), Northernmost on the SVRP Model Boundary
4. East Greenacres ID #1C (1528N03), Midpoint

5. Don Beck #1 (1528E01), Southernmost on the SVRP Model Boundary

Wells 1 through 3 were used to calculate the east to west gradient, while wells 4 through 6 where used to calculate the north to south gradient. The following gradients were obtained:

- E-W gradient = 0.0065; and,
- N-S gradient = 0.0039.

Time varying head condition was also implemented. Four wells along the boundary with single water level measurements were used to create the boundary, these are:

- Schneidmiller (1533E01), measured 10/30/1996;
- East Greenacres ID #1C (1528N03), measured 10/30/1996;
- Wolkenhauer (1521M01), measured 10/30/1996; and,
- Unnamed, USGS (50N05W04CACC02), measured 3/1/2000.

An additional well in the area (50N05W01DABC01), and two wells closer to the Stateline (Idaho Rd. wells) with more than 1 measurement indicated that well water levels varied by approximately 2 meters seasonally. A time varying head boundary was created for the boundary wells by extrapolating an approximately 2 m fluctuation observed at the Idaho Rd. wells and at USGS well # 50N05W01DABC02. Table 6.10 shows measured and extrapolated head level measurements used for definition of the time-varying boundary. The time varying head boundary condition was ultimately chosen as the most accurate representation of the eastern saturated zone model boundary.

The Newport boundary was assigned a constant head boundary based on four well water levels in the area. Well water levels were obtained during well drilling activities.

- DL 1 – 664 m
- DL 2 – 653 m
- DL 3 – 674 m
- DL 4 – 681 m

## 7.0 EXECUTION PROCESS

A MIKE SHE simulation is controlled by several simulation control parameters including the simulation period, the simulation time step, iteration stop criteria, data storage selection and storage time step. These parameters can impact the simulation run time, water balance error and size of the stored results file.

Three series of time steps are specified for a model run. The first controls the time step of the overland flow, snowmelt, unsaturated zone and evapotranspiration modules (dtMax UZ/OC). The second specifies the time step for the saturated zone (dtMax SZ). The third specifies the time step for the MIKE 11 channel flow module (dtMIKE11). The following time step values were used.

dtMax UZ/OC = 3 hours

dtMax SZ = 9 hours

dtMIKE 11 = 40 seconds.

With the above values, a single model run of one year runs in about 6 hours (Intel Pentium III, 1.2 GHz, 768 MB RAM). Additional tuning of the model could likely further decrease run times.

The time steps above act as an optimal step to use during simulation, but actual time steps will generally vary during a model run depending on simulation control parameters (MaxP and MaxUZWB). MaxP indicates the maximum rate of precipitation that can occur before the time step is reduced. MaxUZWB indicates the maximum water balance error that can occur during one iteration of the unsaturated zone before the time step is reduced.

Iteration stop criteria control when each component’s iteration scheme will be stopped during simulation. The following list identifies the type of iteration stop criteria for each component.

- Saturated zone - mass balance and head criteria when less than maximum allowed number of iterations.
- Unsaturated zone – mass balance error in one soil column, maximum water balance error in one node when less than maximum allowed number of iterations.
- Overland flow – mass balance error or when less than maximum allowed number of iterations.

The storage time step and type of data stored primarily impacts hard disk space. For example, a model run for a single year with results stored on a weekly basis for all components takes almost two gigabytes of disk space.

The MIKE SHE solution sequence is carried out in the following fashion (Figure 7.1):

- MIKE SHE is initialized, reading input data for each component;
- The unsaturated zone component is called, which calls the evapotranspiration and snow melt components;
- The river aquifer exchange component is called next; and,
- The saturated zone component is called next if it is the correct time step; and,
- The overland component is called.

It is recommended that MIKE SHE be run with a saturated zone time step that is 2 to 3 times that of the unsaturated and overland components. Therefore the saturated zone is only called every 2 to 3 times that the other components are called.

During the solution sequence a large number of state and flow variables are set and used by the other components to represent the entire hydrologic cycle. Table 7.1 shows variables set in one component and transferred to another component.

## 8.0 CALIBRATION

Model Calibration is the process of matching model results to field observations. The calibration process is primarily aimed at obtaining and/or adjusting a set of model parameters in order to provide a satisfactory agreement between model results and field observations. Determining what is "satisfactory" is affected by the overall size of the model, the data available for calibration and the objectives of the modeling process.

The overall size of the model affects the degree to which agreement can be expected. At one extreme, calibration of small, well defined areas may require agreement of mean water levels to be within inches of measured values, and daily or hourly variations to be accurate. For large scale simulations data density may be low and only the overall response can be represented. The Spokane Watershed Model falls towards the large end of the modeling scale, with a modeled area of approximately 2,800 square kilometers (~1,094 square miles) and a grid size of 400 $m^2$ (1,312.4 $ft^2$). This grid size prevents the model from accurately representing individual points such as drywells or impervious areas, but still allows it to represent the overall effect of these processes.

The density of calibration data directly affects the accuracy of the simulation. For example, calibration data is sparse in much of the Little Spokane Watershed, with only three surface water gages in the mid and lower reaches of the Little Spokane River, and sparsely collected groundwater level data from the last 10 years. On the other hand calibration data in the Middle Spokane Watershed is relatively abundant. Groundwater levels are available throughout the Spokane Valley, and continuous discharge data is available at four points along the Spokane River. With this in mind, it is expected that calibration of the Middle Spokane Watershed would provide better agreement between measured and modeled data than that of the Little Spokane Watershed. In short, good calibration to abundant data leads to greater confidence in the model for simulating current and future conditions.

A continuous simulation was run for water years 1994–1999 based on weekly calibration of the model for the years 1994, 1997 and 1999. These three years were presented in the Technical Assessment as representative of the dry, wet and average hydrologic conditions respectively. Calibration data included groundwater levels and measured river discharge collected during each year.

### 8.1 Calibration Data

This section describes data used in model calibration. Calibration is conducted to observed groundwater levels, river discharges and snow pack accumulation.

#### 8.1.1 Groundwater Levels

Water level data used for calibration was obtained from a number of sources including: Spokane County; EMCON (1992); Boese and Buchanan (1996); CH2M Hill (1998); USGS (2000: http://montana.usgs.gov/nrok/nrokpage.htm). Data from Spokane County is generally long-term monitoring data while data from previous reports is limited to "snapshot" water level measurements.

Wells used for calibration were chosen according to their placement within the aquifer, data availability, and data quality. Where wells with an extended period of record were not available (e.g., wells in Diamond Lake or Layer 2) snapshot data were used as an estimate of the water level in the well.

Figure 8.1 displays the location of calibration wells and river discharge points available for 1994, 1997 and 1999. Table 8.1 summarizes wells used in calibration.

### 8.1.2 River Discharge

River discharge calibration points are shown in Figure 8.1 and in Table 8.2.

Calibration of river discharge in the Middle Spokane Watershed (WRIA 57) was aimed at matching weekly discharges at

- The USGS Spokane River at Spokane gage (USGS stn 12422500);
- The Spokane River below Greene St gage (SCC gage at location of former USGS stn 12422000); and,
- The Spokane River above Liberty Bridge near Otis Orchard gage (USGS stn 12419500).

The Otis Orchard gage measures a losing reach of the river between the Stateline and Flora Rd. The Greene Street gage measures river flows below a gaining reach of the river generally thought to occur between Flora Road and Greene St. (MACINNIS AND OTHERS, 2000). The Spokane River at Spokane gage measures a losing reach of the river that is reported to begin at Greene St and extend to the confluence with Hangman Creek (Latah Creek) (MACINNIS AND OTHERS, 2000).

Calibration of river discharge in the Little Spokane Watershed was aimed at matching weekly discharges at three primary continuous gaging stations:

- The Little Spokane River at Chattaroy Rd. gage (SCC 8327Q);
- The Little Spokane River at Dartford gage (USGS stn 12431000); and,
- The Little Spokane River near Dartford gage (USGS stn 12431500).

The Chattaroy gage measures river inflows from the West Branch Little Spokane River and the Upper Little Spokane River. The USGS gage at Dartford is generally thought to represent Little Spokane River flow before any inflows from the SVRP Aquifer occur and after river inflows from Deadman Creek and Dragoon Creek. However, there may be some influence of discharge from the SVRP Aquifer. The USGS gage near Dartford measures flows that occur between the SVRP Aquifer and the Little Spokane River before discharging into the Spokane River.

Additional snapshot gage data is available for several additional locations in the Little Spokane Watershed (Table 8.2). Snapshot calibration data is available for every modeled tributary except Dartford Creek and Little Deep Creek.

### 8.1.3 Snow Pack

Snowpack accumulation and melt was calibrated against data from Quartz Peak for 1994, 1997 and 1999 where snow water equivalent is measured. Spokane International Airport is located just outside the model domain but considered representative of the southwest corner of the model domain. Measurements for Spokane International Airport for 1997 and 1999 appeared to be unreliable due to a large number of “no report” values for the snow depth and snow water equivalent measurements, and no snow pack accumulation was recorded for 1994. Therefore only calibration results for Quartz Peak are presented. Spokane International Airport simulated results were checked for 1994 to verify little to no accumulation of snow.

## 8.2 Calibration Parameters

MIKE SHE model parameters were discussed in Section 6. Estimation of these values to best represent actual distributions is obtained by calibrating them to obtain a best fit between model results and measured data. While the primary goal is to match measured data, it is not the intention to manufacture parameters for processes for which there is little data. If variation of parameters within a logical range (consistent with available measurement and best professional judgment) does not yield an appropriate response, this likely indicates an area where additional data collection is needed to modify model parameters.

Parameters that were adjusted in the calibration process include:

- Vertical and horizontal hydraulic conductivity of the aquifer layers;
- Unsaturated zone saturated hydraulic conductivity;
- Unsaturated zone moisture retention and hydraulic conductivity curves;
- River bed lining leakage coefficients;
- Snow melt degree-day coefficient and melting point temperature;
- Overland run-off parameters; and,
- Drainage time constants.

The hydrology of the Spokane Watershed is strongly influenced by the SVRP Aquifer, and calibration was primarily accomplished through modification of the aquifer properties (i.e., vertical and horizontal saturated zone hydraulic conductivity, specific yield, unsaturated zone parameters and river bed leakage coefficients). The influences on the hydrology of the Little Spokane Watershed are much more disperse, and as a result, each of the parameters in the above bullet list had to be carefully examined for its effect on results of the simulated hydrology.

## 8.3 Calibration Targets

Calibration targets are goals which indicate how calibration should proceed and when calibration is completed. Calibration targets of the groundwater component of the Spokane model are to first simulate annual and seasonal variations, and then match weekly average groundwater potential heads within the calibration period.

Calibration objectives of the surface water components are similar; to first simulate total annual discharge, then match seasonal and annual response to climate and snow pack, and finally to match peak and low flow levels and timing on a weekly basis. Calibration objectives of snow pack and melt were to match peak snow pack and, rate of melt.

## 8.4 Calibration Results

A wide range of outputs can be generated from the model. In addition to objective statistically based criteria, the model is also evaluated in terms of its overall capability to represent common hydrologic processes of the basin.

It is important to understand the non-uniqueness of the final set of parameters obtained from the calibration process. The number of parameters, and their possible combinations, is extremely high. Field data are used to limit the range of model parameters and thereby reduce the number of parameter combinations. However, even by imposing restrictions supported by field data, several sets of parameters may yield an acceptable calibration. Consequently, the parameter combination used for calibration should be seen as one likely alternative, and that other combinations may provide similar results.

This section provides the results of annual and weekly calibration, including a brief discussion of measured versus modeled groundwater elevations, surface water discharge, and snow pack accumulation and melt. A thorough discussion of results, presentation of additional non-calibration results, and model sensitivity is included in Section 9 (Model Interpretation).

### 8.4.1 Annual Calibration

Figure 8.2 shows a correlation plot between average annual simulated and measured head at wells with snapshot and long term gaging records for water year 1997. Correlation is good with an r-squared value of 0.95. The majority of outliers are found in the Layer 2 aquifer (basalt and Latah) of WRIA 55, or in the areas surrounding the Little Spokane River between Dragoon and Deadman Creek where the clay aquitard likely has effects that the model is not capturing. Annual results are not presented for additional calibration years because the snapshot measurements are only available for a single date.

Calibration of average annual river discharges is displayed in Table 8.3 and Figure 8.3 for the Spokane River at Spokane, the Little Spokane River at Dartford, and the Little Spokane River near Dartford. Annual discharge for the Spokane River shows good correlation (r squared = 0.995) with the percent error from measured discharge between 0.5% and 4.5%. Annual discharge for the Little Spokane River is displayed for both the “near” Dartford and the “at” Dartford gages. Although the model shows reasonable correlation of simulated flows to actual flows at the “at” Dartford gage (r squared = 0.845), simulated flows tend to be higher than actual (9% to 66% higher). The near Dartford USGS gage is closest to the river mouth but does not have data for 1993 – 1996. The percent error from measured discharge ranges from 9% to 98%. The overestimation of streamflow in the Little Spokane River indicates that there is either a sink of water in the system that the data and model are not properly representing (possibly evapotranspiration), or that water inputs (primarily precipitation) are too high.

### 8.4.2 Weekly Groundwater Calibration

The seasonal and weekly variation in modeled groundwater elevations correlates well with measured levels in most of the water level calibration points (Figures 8.4 through 8.7, with additional calibration plots shown in Appendix C). Figure 8.4 provides examples of this in weekly calibration plots for the City – Felts Field (5312C01) and Vera #3 (5422R01) well. These plots show a well-matched response between measured and modeled well water levels and are representative of calibration points in the central Spokane Valley.

There are some calibration points in which the elevations are in agreement for portions of the simulation but the magnitude of variation is greater or less than measured values (e.g., Figure 8.5 City – Trinity [5307M01], and City – Franklin Park [6331J01]). The locations of these wells are in areas where more complex flow patterns are occurring in the saturated zone. Flow is effectively splitting and a portion is flowing through the Trinity Trough and the rest is flowing into the Hillyard Trough. In addition, the Hillyard Trough is reported as being divided into two levels by a clay aquitard (CH2M Hill, 2000). Additional field data and model refinements would be necessary to achieve a more consistent match.

Calibration near the eastern boundary at the WA/ID Stateline shows simulated water levels that are higher than measured levels and greater water level variations throughout the year (Figure 8.6). Simulated groundwater heads are between 2 and 5 meters higher than measured values throughout the year. The seasonal and weekly variation in modeled heads mimics measured heads but the magnitude of variation of measured groundwater elevations is 2 to 3 meters while modeled variations are approximately 4 meters.

Two calibration points were used in the northern Hillyard Trough area of WRIA 55 (Dakota and Whitworth Wells; Figure 8.7). Both of these wells extend only into the upper sands and gravels of the Trough. Wells below the clay lens were not used for calibration because the model cannot extract data specifically for locations above or below the lens. Results show that the modeled water levels of the Whitworth Well are within one meter of observed water levels, while the Dakota Well shows poor calibration with water levels almost 10 m higher than measured water levels (~10% of total saturated thickness). The seasonal variation in head at the Dakota Well correlates well with the measured values, with the groundwater head increasing slightly during the winter months (0.5 to 1.0 m) and decreasing during the summer months. Only one well, with sparse data in the calibration period, is available in the Deer Park area (Deer Park well #9233G01; figure shown in Appendix C). This well shows that modeled groundwater levels are lower than measured groundwater levels by 2 to 5 m (12 to 30% of the saturated sand and gravel aquifer thickness). This well is located very close to the boundary of the modeled aquifer and water levels might be affected by this relative location.

### 8.4.3 Weekly Surface Water Calibration

Surface water discharge calibration points in the Middle Spokane Watershed show good agreement with measured flows (Figures 8.8 through 8.10). Flows decrease from Post Falls to Liberty Bridge, increase from Liberty Bridge to Greene Street (relative to flow levels at Post Falls) and then decrease from Greene Street to the Spokane gage. Simulated flows at the Greene Street gage are slightly low relative to measured flows, and better agreement is achieved in drier years (e.g., 1994).

Modeled stream flows in the Little Spokane Watershed do not correlate with measured values as well as modeled flow in the Middle Spokane Watershed (Figure 8.11 through 8.13; additional plots in Appendix C). However, simulated values capture the form and magnitude of the Little Spokane River hydrograph. Summer flows are low, winter flows gradually increase as the occurrence of storms increase, and peak flows occur in the mid-spring and quickly recede to baseflow levels by summer.

Simulated baseflows in the Little Spokane River system are generally in good agreement with measured flows, with agreement being better during wetter years (1997, 1999) than during dryer years (1994). However, several recurring discrepancies are visible in all the calibration hydrographs for the Little Spokane River:

- Early winter modeled flows are too high and “peaky”, but peaks occur at the correct time in response to storm events.
- Some peaks are not simulated or are too high.

### 8.4.4 Weekly Snow Water Equivalent Calibration

The correlation between measured and simulated snow water content at Quartz Peak is good, with simulated peak snow water content matching measured values for most years (Figure 8.14). The rate of snowmelt also shows good agreement. Snow water equivalent simulations in cells near the Spokane International Airport (#457938) show less than 1 inch of accumulation throughout the year of 1994, which is consistent with recorded measurements at the gage.

# 9.0 MODEL INTERPRETATION

Based on calibration results reviewed in Chapter 8 and presented in Appendix C, the model is representing the majority of the system well (both Little and Middle Spokane watersheds) given the data available and the conceptual understanding of the system. This chapter presents additional results that are not part of the calibration process, a discussion of these results, and how the model can currently be applied for the planning process and improved in the future.

There are a multitude of results that can be generated from the MIKE SHE model, from water stored in the vegetation canopy to aquifer boundary inflows. In this section results that are of interest to the Planning Unit are highlighted.

Also presented are a water balance of each WRIA, aquifer flow hydrographs of areas of interest, surface water-groundwater exchange rates, and the results from each primary component of the watershed. In addition, values from previous modeling efforts are compared with results from this model and model sensitivity is discussed.

## 9.1 Water Balance

The MIKE SHE system allows the user to generate a water balance for the entire model domain, a specified sub-area within the model domain, or even a specified component of the model such as the saturated zone (aquifer). Water Balance values are expressed in millimeters (mm) of accumulated water to allow comparison of the relative magnitude of the components of the water balance within each WRIA. Where comparisons between sub-basins are desired, values are expressed in cubic meters ($m^3$). Basin volume calculations multiply the volume of accumulated water (converted from millimeters to meters) by the area of the individual WRIA portions of the model domain. Therefore, to convert values from mm to $m^3$the following conversions can be used.

WRIA 55: volume in $m^3$ = mm * 1,752,000 $m^3$/mm

WRIA 57: volume in $m^3$ = mm * 553,280 $m^3$/mm

To convert volumes calculated in cubic meters to acre-feet (AF):$m^3$ * 0.000811 AF/$m^3$

### 9.1.1 Annual Water Balance

The WRIA 57 water balance shows results for water year 1999 (October 1, 1998 – September 30 1999; Figure 9.1). The following basic relationships are observed:

- Evapotranspiration is approximately 74% of precipitation.
- Well abstraction (including purveyor well total abstraction and exempt well consumptive use) is 13% greater than mean annual groundwater recharge (excluding stream/aquifer interaction) and 28% of total aquifer inflow across the boundary.
- Irrigation water for crops and lawn watering supplied by purveyor wells comprises 12% of total annual well abstraction.
- Irrigation water for crops and lawn watering supplied by exempt or unmetered wells is approximately 1/12 the irrigation water supplied by purveyor wells.

The WRIA 55 water balance also shows results for water year 1999, and the following basic relationships are observed (Figure 9.2):

- Evapotranspiration is approximately 64% of total precipitation.

- There is very little recharge to the aquifer from the river.
- Baseflows and drain flow from the sands and gravels, and basalt aquifers are approximately 73% of total river outflow, and includes groundwater discharge from the SVRP Aquifer.
- Water used for agricultural irrigation and lawn watering is approximately equally supplied by purveyor and exempt wells.
- A significant amount of exchange occurs between the sands and gravels, and basalt aquifers, but the net exchange shows a loss from the sands and gravels to the basalts.
- Layer 2 (basalt aquifer) provides less than 5% of total baseflow to the river.

### 9.1.2 Weekly Water Balance

Tables 9.1 (WRIA 55) and 9.2 (WRIA 57) present a more traditional representation of a water balance for each WRIA. The water balance is formulated as a series of inputs and outputs to the entire watershed. With this water balance, internal processes such as run-off or baseflow are not specified. Water balance components are displayed in millimeters for each week; the conversion from millimeters to volume ($m^3$) described previously is still applicable.

The following components are included in the weekly water balance:

**Inputs** (always negative):

- Precipitation: Total precipitation (rain and snow) input to the system.
- Irrigation: Irrigation from municipal wells - does not include exempt well volumes.
- Groundwater Inflow: Inflow to the aquifer from outside of the WRIA.
- River Inflow: Inflow to the river from outside the WRIA.
- Overland Inflows: Inflow to the ground surface from outside the WRIA.

**Outputs** (always positive):

- Evapotranspiration: The combined effect of evapotranspiration from water stored in the canopy, ponded water, water stored in the soil and vegetation transpiration from the unsaturated and saturated zone and evaporation from snow.
- Abstraction: Abstraction from wells.
- Groundwater Outflow: Outflow from the aquifer to aquifer areas outside of the WRIA.
- Overland Outflows: Outflow from the ground surface inside the WRIA to the ground surface outside the WRIA.
- River Outflow: River outflow from the WRIA.

**Changes in storage** (negative indicates loss of stored water, positive indicates an increase in stored water):

- Subsurface Storage Change: Changes in water stored in the unsaturated and saturated zones (aquifer and soils layers).
- Canopy Storage Change: Change in storage in the vegetation canopy

- Snow Storage Change: Change of water stored as snow (same as snow water equivalent).
- Overland Storage Change: Change of water stored on the surface of the ground (not in MIKE 11 rivers).

The WRIA 57 water balance shows that (Table 9.1):

- River inflow and outflow across the WRIA boundary (due primarily to flows across the WA/ID Stateline and out of WRIA) are, by far, the largest components of the water balance.
- Groundwater flow out of the WRIA is relatively constant year round, but does show a response to peak winter and spring flows.
- Snow storage is a small component of total storage.
- Of the total outflows, well abstraction is a larger component of the total water balance than in WRIA 55, particularly in the summer when well abstraction is approximately half as large as total outflows from the WRIA.

The WRIA 55 water balance shows that (Table 9.2):

- Subsurface inflows are relatively constant throughout the year, with a slight increase in the late spring and early summer.
- Evapotranspiration is greatest between March and September, and is greater than stream flow during much of this timeframe.
- The amount of water exiting the watershed as groundwater is small and relatively constant year round.

More detailed water balance results for each model year run for WRIA 55 & 57 are provided in Appendix D. Water balance results in the appendix present weekly outputs for all major components of the MIKE SHE model including such items as baseflow and run-off.

Aquifer storage comprises by far the largest component of WRIA 57 storage components, with 2 to 6 times more storage annually available in the aquifer than in any other component (Figure 9.3). Unsaturated zone storage and snow storage share approximately equal portions of storage. They peak between December and February and decrease to initial levels by July (snow) and September (unsaturated zone). The saturated zone rises, starting in October, to it's peak between March and June and rapidly decreases to initial levels by early September. Snow and saturated zone storage show variation from year to year while the unsaturated zone storage remains relatively constant. (The unsaturated zone includes any water stored above the water table.)

As in WRIA 57, water stored in the saturated zone of WRIA 55 is greater than that stored in other components (Figure 9.4). Snow and unsaturated zone storage are close in magnitude in WRIA 55. Peak storage for the unsaturated zone occurs between January and March while peak snow storage generally occurs in late February. Saturated zone storage peaks in mid-March throughout the model run. Canopy storage is a small component of total storage. Saturated zone and snow storage show inter-annual variations while unsaturated zone storage remains relatively constant.

The total volume of water stored in the saturated zone in WRIA 55 is greater than that in WRIA 57. Additionally, peak levels of water stored as snow in WRIA 55 are double that in WRIA 57.

### 9.2 Aquifer Flow

Groundwater elevation contours (head) are useful for indicating the general direction and gradient of flow in an aquifer. Layer 1 depicts the following general flow in WRIA 57 (Figure 9.5):

- Head in the sand and gravel SVRP Aquifer are highest on the eastern-most boundary and decrease in a relatively steady gradient from east to west, through the Central Spokane Valley.
- Towards the western boundary of the aquifer, flow splits as water flows north through the Hillyard Trough and west through the Trinity Trough.
- A steep gradient exists in the Trinity Trough and in the northern end of the Hillyard Trough near the Little Spokane River.

The sand and gravel aquifer in WRIA 55 have a more convoluted flow path due to the more variable nature of the thickness of Layer 1 and topographic influences (Figure 9.5):

- In the Diamond Lake Area, groundwater flow drains toward the West Branch Little Spokane River and Diamond Lake or towards the headwaters of the Little Spokane River.
- In the Deer Park Aquifer flow generally occurs in a northwest to southeast direction towards Dragoon Creek, with additional flows entering the creek from the southwest. Towards the central portion of the watershed (what is commonly called the Little Spokane River Aquifer) groundwater flow patterns become more convoluted due to basalt outcrops. In general, water flows towards the Little Spokane River with head levels continuously decreasing in a southerly direction.
- In the Peone Prairie aquifer, groundwater flows from east to west toward Deadman Creek where aquifer water discharges to the river.

In the Layer 2 basalt aquifer of WRIA 55, the following observations on groundwater flow are made (Figure 9.6):

- In the Deer Park Aquifer, groundwater flows in a southeast direction.
- In the Orchard Prairie, groundwater flows in a northeast direction.
- In the Greene Bluff area, groundwater flows from east to west with a portion of the flow heading towards Deadman Creek and another portion flowing towards Little Deep Creek.

Quantification of groundwater flow rates through the aquifer at several locations - the Stateline, and the Hillyard and Trinity Troughs - was identified as one objective of this modeling process. The flow across the Diamond Lake WRIA 55 boundary is also identified as an area of interest. The MIKE SHE model does not provide a direct method for determining flow through a cross section. It is possible, however, to extract a water balance for a subset of cells that cross an area of the aquifer, such as the Hillyard Trough (Figure 9.7). Average annual flows for each cross section are:

- Hillyard Trough – 7.9 cms (281.7 cfs)
- Trinity Trough – 5.9 cms (210.1 cfs)
- Stateline Boundary – 15.6 cms (551.8 cfs)
- Diamond Lake, model boundary – 0.7 cms (28.1 cfs)

From Post Falls to just downstream of the Stateline (Otis Orchards) a significant amount of river water recharges the aquifer (between 1 cms and 40 cms). This recharge peaks when flows in the

Spokane River are highest such as the during the spring and early summer. During this peak flow period groundwater elevations in the area around the Stateline are close to or higher than groundwater elevations defined at the model boundary causing the model to predict that flows, stagnate or even reverse directions (i.e., flow eastward) and flow out of the model boundary. There are insufficient data to determine whether this is actually occurring, and further analysis is warranted. Based on the available data and measured parameters, this response cannot be ruled out. Groundwater flow across Stateline shows a wide variation due to hydrologic complexities that cannot be represented given available data.

Groundwater flows across the Hillyard and Trinity Troughs show seasonal variability (Hillyard more so than Trinity), reaching a peak between March and June (Figure 9.8). Groundwater flow across the Diamond Lake-Pend Oreille model boundary is low and constant year round.

### 9.3 Surface Water-Groundwater Exchange

In WRIA 57 there is a high degree of hydraulic continuity between the Spokane Valley Rathdrum Prairie Aquifer and the Spokane River. Flows along the river increase and decrease (i.e., gaining and losing reaches) alternately along the river due to groundwater-surface water interaction. Model results indicate there is a net loss of flows from the river to the aquifer. In WRIA 55 the degree of hydraulic continuity is not as high, and the main interest is characterizing the degree to which stream baseflows are sustained by the discharge of groundwater. Figure 9.9 presents mean annual river aquifer exchange for the entire model domain. Negative numbers (green shading) indicate a loss from the river to the aquifer, while positive numbers (red shading) indicate a gaining reach of the river.

Figure 9.10 shows the interaction between the Spokane River and the SVRP Aquifer. The graph shows the simulated maximum and minimum baseflows that occur in the Spokane River over the modeled period (i.e., WY 1994 to 1999), along with a representative intermediate condition (i.e., October 25, 1995). Negative values indicate that the river is losing water to the aquifer, while positive values indicate that the river is gaining water from the aquifer. Gaining and losing reaches can be defined from this figure, and are described in Table 9.3. It should be noted that the estimation of gaining and losing reaches by the model is most accurate where river cross sections have been defined. Otherwise gains and losses are determined by linear interpolation between cross sections.

The Little Spokane River and its tributaries are primarily gaining rivers. Water in every modeled river of WRIA 55 is generated from four modeled components: baseflow from the aquifer; overland runoff from storm events; drain flow; and, waste water discharge. Aquifer contributions are of particular interest in the lower end of the Little Spokane River where the SVRP Aquifer discharges groundwater to the river. Primary groundwater contributions to baseflow occur on the following reaches of the Little Spokane River (Figure 9.9):

- Near the river source in the Diamond Lake Aquifer area;
- Between the Chain Lakes and the confluence with the West Branch Little Spokane River; and,
- Just upstream of Dragoon Creek to the mouth.

At Dartford Creek the SVRP Aquifer provides a large influx of water in the form of baseflow and overland flow. Figure 9.12 presents an example of the individual contributions of baseflow, drain flow and overland flow to total discharge along the length of the Little Spokane River at a single time step in a model run. The large increases in discharge are primarily due to inflows from tributary creeks (such as Deadman Creek). Large changes in elevation of both the ground surface and the aquifer in the Dartford area cause some of the aquifer water to be discharged to the surface as springs and therefore is represented by the overland flow component of the model. Average simulated annual influx to the river in between Dartford Creek and the confluence of the Little Spokane River with the Spokane River is 7.9 cms (279 cfs).

## 9.4 Component Results

A multitude of results can be created from the MIKE SHE modeling package. Several additional results are included in Appendix D and are briefly described here. Each graphic presents a spatial distribution of mean or peak annual results from water year 1999. Unless otherwise noted, negative values indicate a downward movement of water (e.g., from the unsaturated zone to the saturated zone) while positive movement indicates an upward movement or accumulation of water.

1. <u>Peak Annual Snow Storage</u>: Peak snow pack ranges from 0 to over 900 mm (35.4 inches) across the watershed with large snow packs occurring on the central eastern side of the domain in the vicinity of Mount Spokane, and in the northwestern part of the model domain.
2. <u>Mean Annual Evapotranspiration</u>: Evapotranspiration within the domain ranges from 0.02 to 0.2 mm/hr. The largest rates of evapotranspiration can be found in open water bodies (rivers and lakes) followed by forested areas. Average annual evapotranspiration for the entire domain is 0.06 mm/hr (~19.5 inches a year).
3. <u>Mean Annual Depth of Overland Water</u>: Overland water depth is greatest along modeled (MIKE 11 defined) and non-modeled river channels and in lakes. There are a few areas where overland depth is greater than would be expected (see areas in WRIA 54). This is an artifact of the model calculation and the DEM creation at a 400 m grid cell size resolution.
4. <u>Mean Annual Saturated Zone Recharge and Bypass</u>: Recharge by drywells (bypass) ranges from 0.0007 to 0.04 mm/hr within cells where drywells exist. The average annual recharge by drywells is 0.006 mm/hr. Natural recharge ranges from –2.4 to 0.7 mm/hr, with an average of –0.03 mm/hr. Discharge (positive recharge) is focused in areas where water bodies are in contact with the saturated zone or in areas where aquifer water is discharged to the surface (e.g., springs).
5. <u>Mean Annual Irrigation</u>: Irrigation rates (including agricultural irrigation and lawn watering, by purveyor and exempt well supplies) range from 0.001 mm/hr to 0.11 mm/hr with an average of 0.02 mm/hr.

## 9.5 Comparison to Previous Work

Several models have been created to simulate the Spokane Valley Rathdrum Prairie Aquifer. Some results that have been presented include estimation of the volume of water that crosses the Stateline in the aquifer (Table 9.4), gaining and losing reaches of the Spokane River (Table 9.5), and flows through the Hillyard Trough to the Little Spokane River (Table 9.6). See Section 10 for further discussion of the model boundary and Stateline for the MIKE SHE model.

## 9.6 Sensitivity Analysis

There are two forms of sensitivity analysis that can be completed. The first identifies model parameters, usually during calibration, that are determined to have a significant effect on model results. The second, sometimes referred to as scenario analysis, is an explicit sensitivity analysis of the model to variations in human controlled parameters (e.g., flow abstraction well withdrawals), climate variability, or other parameters. This second type of analysis is discussed in Section 10.1.

In this section sensitivity analysis was completed to evaluate model parameters and model inputs which are of primary importance to the model results. If the model results are particularly sensitive to a specific parameter or input type, the model results should, be interpreted with the uncertainty associated with that particular parameter. Through this process, the model (and therefore the watershed) can become better understood. The following parameters appear to have significant effect on model response and are discussed in this section:

- Boundary conditions;
- Unsaturated zone hydrologic parameters;
- Drainage;
- Irrigation;
- Precipitation; and,
- Temperature.

There are any number of parameter variations that will evoke a change in model response. To perform sensitivity analysis to a parameter, the single parameter must be changed from a baseline setting (usually a calibrated state) to an alternate setting, the model is then run, generally for a year, and results evaluated for the overall effect of that change. Therefore sensitivity analysis is a time consuming process. The paragraphs below describe the response of the model to the above-mentioned parameters. Some of these parameter variations were not run as explicit sensitivity analysis and only the general system response is described.

### 9.6.1 Boundary Conditions

Flow into the aquifer across the model boundary near Post Falls is dependant on the type of boundary, the geologic representation, and the aquifer hydraulic conductivity and at the boundary.

Flow across the model boundary is simulated using a time varying head (groundwater elevation) boundary condition. Groundwater elevations are specified at three-month intervals based on single water level measurements at 4 wells, and the variation of measured water levels at additional wells in the vicinity of the boundary (see Section 6 and Table 6.10 for details).

The geologic cross section at the model boundary was created by extending contours from data supplied at the Stateline (Derkey, 2000) out to Post Falls. Geologic cross sections in the area of the model boundary (Post Falls) have not been completed and borehole logs do not extend to the crystalline basement. Changes to the geologic boundaries of the aquifer in this area were not modeled but it can be inferred that changes to the depth, or extent of the aquifer in this area would produce variations in the total flow crossing the boundary and therefore the response of the system downstream to surface water and aquifer interactions. Therefore the total area of saturated zone flow across the boundary is uncertain and would have impacts on model results.

Data used for calibration near the model boundary consists of groundwater elevations collected by Spokane County between May 1999 and September 1999 for the Idaho Road Pipeline well (#6525R01). River discharge data was used from the Spokane River above the Liberty Bridge near Otis Orchards gage (stn 12419500) from 1994 through 1999.

Five hydraulic conductivity measurements are reported in the area between Post Falls and the Stateline (a distance of approximately 5,000 m apart [~3 miles]). Measured values range from 0.007 m/s (well # 6631M06) to 0.04 m/s (Drost and Seitz, 1978). Calibrated conductivity measurements between the boundary and the Stateline range from 0.09 m/s to 0.2 m/s. At the boundary conductivity values are set to 0.09 m/s.

Model results show that lower model conductivities (< 0.01 m/s) result in:

- Groundwater elevations near the Stateline vary from 602 m to 616 m, while measured elevations range from 604 m to 606 m (well#6525R01 and #6631M01).
- Conversely, calibration points towards the central Spokane Valley then show good correlation with measured values, and surface water-groundwater interactions are within previously estimated ranges.
- River flows in the Spokane River at the Above Liberty Bridge near Otis Orchard gage show good agreement in this scenario while simulated river discharge in the Spokane River at Spokane gage is lower than measured river discharge by as much as 19 cms (700 cfs) during the summer months.
- Groundwater mounding that occurs in the Stateline area that cause groundwater to flow east out of the model boundary during high river flow periods (April-May).

Increases in conductivity (> 0.08 m/s) result in:

- Groundwater elevations ranging from 606 m to 611 m at the Stateline. This provides a better range of groundwater elevations but with the total elevation still being too high.
- Calibration of groundwater elevation in the central Spokane Valley is good.
- Low flows at the Spokane River at Spokane gage show much better correlation with flow differences of less than 5 cms (170 cfs).
- The gradient of flow between the Stateline and Post Falls is lower than single point measurements in previous studies. Groundwater flow generally does not flow in an easterly direction out of the model domain except during peak flows.

Changes to the model boundary condition from specified head to constant gradient results in:

- Groundwater elevations ranging from 608 m to 619 m at the Stateline; a wider range of flows.
- More annual variations in SVRP Aquifer head elevations because the boundary elevation can change freely.
- Groundwater flow never occurs in an easterly direction because the gradient boundary prevents this from occurring.

A time-varying head boundary was chosen for final results because the total annual head change at the model boundary and Stateline for a time varying head was smaller than that of a constant gradient boundary for aquifer properties within an acceptable range of measured values, and dry season (August-October) head levels are lower with a time varying head level. Therefore, the simulated total flow across the model and Stateline boundary is expected to more accurately predict reality.

### 9.6.2 Unsaturated Zone

The unsaturated (vadose) zone includes anything above the water table; therefore it includes soils and aquifer materials. The unsaturated zone controls recharge to the aquifer through vertical saturated and unsaturated hydraulic conductivities, and the moisture retention curve (Figure 6.5).

Hydraulic conductivity was chosen from a range of conductivities provided by the NRCS (Soil Survey Division Staff, 1993), and moisture retention curves from a database of generalized retention curves provided in the SEEP/W software manual (Geo-Slope, 2001).

A change to the soil hydrologic parameters has an effect on the total recharge to the aquifer. For example in WRIA 57 changing soils from their original configuration to uniform soils characteristics equal to type "D" soils (this constitutes a change in conductivity from 8.0 x $10^{-5}$ m/s to 8.4 x $10^{-9}$ m/s) results in an average weekly decrease in recharge of 3.4 x $10^{-6}$ $m^3$ (2,700 AF). This effect is most pronounced during wetter months.

### 9.6.3 Drainage

Drain flow is controlled by the drain depth below ground surface and the drainage time constant (Section 6.6). Drainage primarily affects discharge to the tributaries of the Little Spokane River from the upper part of the saturated zone. Drainage parameters were derived through conversations with DHI and model calibration. Changes to the depth of the drain primarily affect baseflow to the river during summer months by accelerating groundwater drainage year-round and thereby lowering summer baseflow. Changes to the drainage time constant affect the timing and peak response of the river to precipitation events. An increase in the time constant, from 1 x $10^{-7}$ $s^{-1}$ to 1 x $10^{-5}$ $s^{-1}$, increases peak river discharge in response to precipitation events. Figure 9.11 displays discharge results with this variation in drainage time constant along with measured discharge levels at the USGS Dartford gage (stn 12431000). Higher drainage time constants result in higher peak discharge, and a steeper recession limb of the hydrograph (the period where flows decrease directly after a storm event) in which streamflows fall to lower levels than that seen with a lower drainage time constant.

### 9.6.4 Precipitation/Temperature

Sensitivity analysis was not completed on precipitation and temperature but these parameters are addressed here because they are important inputs to the model and have significant uncertainty associated with them.

Precipitation is the primary hydrologic input to the model, this parameter is particularly important in the Little Spokane Watershed where river flows are primarily generated from water derived from precipitation inputs. A change in the temporal or spatial distribution of precipitation would affect the entire watershed. The most notable impacts could include changes in peak flows, snow pack, baseflows and aquifer recharge.

Temperature, evapotranspiration and snow pack are closely linked in the model. Temperature inputs impact calculations of potential evapotranspiration, and snow accumulation and melt. Of these model components, evapotranspiration is by far the largest net loss from both watersheds. Additionally, snow accumulation is directly computed from temperature inputs. Therefore changes in the temperature distribution or timing would directly impact the timing and peak of the river discharge hydrograph.

Meteorological (precipitation and temperature) coverage of the Middle Spokane Watershed is good with gages at the east, west and northern edges of the aquifer, additionally precipitation and temperature vary little from gage to gage, in part because of the relatively constant elevation across this portion of the model domain. There is much less meteorological data in the Little Spokane Watershed – stations are only located at the southern and western edge of the watershed. Correlations between precipitation at the discontinued Deer Park weather station (in central WRIA 55) and other gaging stations were poor. Therefore there may be some orographic effects that are not represented by precipitation inputs to the model.

# 10.0 MODEL APPLICATION

The Spokane MIKE SHE model provides a detailed and comprehensive physical model of the Little and Middle Spokane Watersheds. More than 100 different spatial and temporal parameters can be extracted from model results. The model is currently capable of simulation and reporting for the time period of WY 1994 to 1999, on a 400-meter square resolution, the following items:

- Quantities and locations of surface water - groundwater interactions;
- Aquifer water levels;
- Aquifer flow at spatially and temporally distributed locations;
- Rainfall and run-off;
- Infiltration and recharge;
- Drywells;
- Irrigation;
- Evaporation and transpiration from plants;
- Well Abstraction;
- Snow pack and melt;
- Aquifer storage;
- River discharge on a daily basis;
- Baseflow overland flow and interflow contributions to rivers; and,
- Depth of overland water.

To gain the most benefit from the existing model and to use it to move into Phase III of Watershed Planning, requires a focused approach. It is recommended this model be used for two primary purposes:

1. To better understand the watershed as it currently functions and the main drivers of the system; and,
2. To develop watershed scale management scenarios over which the response of the model can be examined.

## 10.1 Scenario Development

In discussions with the planning unit several scenarios were developed over which the model can be run. These include:

- Remove all extraction wells and irrigation inputs to simulate the “natural” condition of the watershed (the “what was” scenario”).
- Increasing well withdrawals to determine impacts to river discharge and aquifer water levels (e.g., increase pumping by a percentage or to the water rights limits).
- Decrease well withdrawals to determine impacts to river discharge and aquifer water levels (e.g., shut off all abstraction, decrease by a percentage).
- Change the spatial distribution of well withdrawals to predict impacts to river discharge and aquifer water levels (e.g., more pumping further from the river).

- Flow augmentation to the Spokane River via aquifer storage and recovery (ASR). This involves injecting water into the aquifer at one location and simulating the affects on river discharge and aquifer levels over time. One suggested location to test this is east of Harvard Road and north of Kaiser from the river during peak flows.
- Increase Spokane River discharge through Post Falls in the summer months (e.g., July through September). Assess its effect by examining the Spokane River at Spokane USGS gage.

- Simulate varying wastewater discharge locations and volumes and assess their impacts on river flow.
- Varying flows at the Stateline and quantifying the impacts of this on the interactions of the Spokane River with the SVRP aquifer.

# 11.0 DISCUSSION AND CONCLUSION

The Spokane MIKE SHE model is designed to simulate all the major hydrologic processes of WRIA 55 and 57, as outlined in the conceptual model, and is intended for use in planning and management of watershed hydrologic resources. This section summarizes some limitations of the MIKE SHE model, outlines potential model improvements (including data collection and model set-up), and presents the conclusion.

## 11.1 Model Improvements

During the development of the MIKE SHE model, available field data and studies have been utilized; most of which was summarized in the Technical Assessment. A number of general assumptions and approximations are necessary in any model application due to conceptualization, limitations in available data and distribution of model parameters. Several suggestions for additional data and model set-up improvements are discussed below.

### 11.1.1 Precipitation/Temperature

Precipitation and temperature data for the western half of WRIA 55 would improve, snowmelt, discharge and evapotranspiration simulations in this watershed. Efforts to correlate historical Deer Park 2 E weather data with currently recording precipitation stations were not successful and indicate that orographic effects in this region may play a role in variations in the total precipitation and temperature variations in this area. Model results indicate that the there is a discrepancy in either the total source of water (precipitation) in WRIA 55 or in the total sink in this watershed.

### 11.1.2 Surface Water Components

River flow data for secondary channels in WRIA 55 is lacking. Discharge measurements for each major tributary of the Little Spokane River would improve calibration in these areas.

There are few measured channel cross sections for secondary channels in WRIA. Additional cross sectional measurements would improve surface water aquifer interaction estimates in these reaches. The necessary density of the cross sections is dependent on the stream gradient. For this stage of modeling a cross section approximately every five kilometers of stream would be beneficial with higher cross section density in areas where large changes in gradient, or specific interactions exist. It is beneficial for model development if channel cross sections extend beyond bank-full levels.

To better relate irrigation to actual physical parameters (such as rainfall), irrigation water demand could be defined as a prescribed crop water requirement rather than a prescribed demand. (Prescribed demand indicates that a time series of water applications is specified for each defined crop and the model will apply this amount of water as long as it is available. Prescribed crop water requirement indicates that the amount of water a specific crop needs is specified and the model applies this water if the requirement is not being met by rainfall. One other difference is that prescribed demand allows specification of variable timing of water application where as prescribed requirement will apply the same rate constantly for each time step.) This will eliminate the problem where irrigation shut-off or turn-on is missed due to time step discrepancies between the model and the irrigation input file.

The MIKE 11 river model can be improved to decrease the time step. The first step in this effort should be to improve the detail around the dams on the Spokane River where large changes in gradient require the time step to remain small.

### 11.1.3 Subsurface Components

Estimates of hydrogeologic parameters and calibration points in the upper sand and gravel, and basalt aquifers of WRIA 55 are limited. Additional measurements would improve calibration. DHI recommends observations for 2-5 locations within each sub-basin. Groundwater elevations should be collected for a minimum of 6 months, or covering both a wet and dry period at a minimum of monthly intervals.

The groundwater aquifer calculation layers could be further subdivided into additional geologic layers. This was not done in the model developed in this report because of MIKE SHE limitations in the total number of computational cells, DHI recommendations, and to prevent long computation times. Therefore, this change would also require separation of the model into sub-models. If this option is pursued, it is recommended that two additional layers be added: a water table aquifer that simulates aquifer layers within the range of the water table; and, a clay lens layer. The water table aquifer is recommended due to the model's use of unsaturated zone data to calculate specific yield for Layer 1 rather than the specific yield specified in the saturated zone. Creation of a water table aquifer will allow the specific yield of the aquifer to be more easily spatially varied. An additional layer representing the clay lens in the vicinity of the Hillyard Trough and the lower reaches of the Little Spokane River would improve estimates of head in the upper and lower sands and gravels in this area, as well as provide a method for extracting data above and below the lens.

Additional data on the geology (namely the depth to crystalline basement around Post Falls) and the hydrogeology of the Stateline and Post Falls area will improve estimates and understanding of flow in this region.

Additional geologic data collection for areas outside of the defined aquifer boundaries (Figure 1.1) will ensure that abstraction, subsurface storage, and the timing of water movement from these regions is more accurately represented.

### 11.1.4 Sub-Models

The model can be run as a sub-model in areas where additional detail is needed, for example in the Trinity Trough, or for future analysis on each WRIA. The current cell size of 400 m was selected based on several factors:

- The cell size needed to capture flow through aquifer areas of interest. For example flows through the Trinity Trough required a cell size equivalent to or less than 400 m (~ ¼ mile).
- Limitations in the total number of cells recommended by DHI. DHI recommended 10,000 cells or less for acceptable computation times. The model developed has 17,709 cells
- Limitations in the total number of cells allowed in a single MIKE SHE model.

For more flexibility in future planning analysis it might be beneficial to separate the model into two distinct sub-models. This will provide benefits through decreased run times, smaller result files (extracting the results for interpretation and presentation will take less time), and the potential for increased detail in the aquifer layers (see the discussion above on aquifer layers).

## 11.2 MIKE SHE Model Limitations

During the modeling process the following model limitations were recognized that either prevented modeling the system as planned or required variation of parameters outside of normal limits:

1. While the MIKE SHE model is designed to simulate all the physical processes that occur within a watershed, it is not designed to specifically model urbanized areas. These components can still be included but required some innovative use of model components. For example, there are not specific components for simulating
    - Drywell infiltration;
    - Run-off and infiltration changes due to partially paved (impervious cells); or,
    - Routing of specified well abstractions to irrigation demand areas.
2. Though the MIKE SHE model software has an extensive evapotranspiration module it is highly dependant on PET inputs calculated by the user. Therefore, it is difficult to manipulate evapotranspiration simulations without significant external calculation time.
3. The lens option of the MIKE SHE Model for the saturated zone is not calculated as a separate unit. The hydraulic properties of the lens and surrounding aquifer are averaged. This prevents variation of parameters and retrieval of results for the aquifer areas above and below the lens.
4. The MIKE SHE model has some known instability problems in the Overland Flow component (DHI Communication, 2002). These problems are particularly apparent on the Lower Little Spokane River, and near Sullivan Road on the Spokane River. The instability presents itself as variations in river flows (usually of 1 to 5 cms) due to overland run-off.
5. Both physical and computational limits exist in the MIKE SHE model. The total number of cells, and therefore, the grid cell size must be moderated to prevent run times from being too long. This prevents the level of detail the model can represent. This limitation could be lowered by separation of the model into sub-models.

## 11.3 Conclusion

A highly advanced and comprehensive integrated hydrologic model has been developed for the Spokane Watershed. The model includes: subsurface flows in terms of groundwater and unsaturated flow; surface water in terms of overland and river flow; and, a fully dynamic coupling between the components of the model. Additionally, a distributed irrigation module is applied linking irrigated land and irrigation sources. Meteorological data, topographical data, soil physical data, land cover data, vegetation data, hydrogeologic data, canal and hydraulic structure data, and irrigation permit data have been used to build the model.

The well-developed conceptual hydrology of the basin allowed the successful development of a simulation model of flows in the watershed. The fully dynamic model includes:

- Spatially and temporally distributed meteorological coverages;
- Evapotranspiration based on 12 characteristic vegetation cover classes;

- Overland flow based on topography and local surface roughness estimates;
- Seven modeled rivers plus structures to simulate the four dams within the model domain, two secondary diversion channels, as well as wastewater discharge;
- An unsaturated zone with five characteristic soil columns;
- A 2-layer geologic model with an encompassed clay lens and impermeable lower boundary;
- Extraction wells including purveyors and exempt wells;
- Irrigation of agriculture, lawns and waste water discharge to the ground surface using distributed water sources; and,
- Dry well simulation through the bypass module of the model.

The model has been calibrated against available surface water discharges and groundwater heads. Calibration of heads in the central Spokane Valley Aquifer have been shown to be accurate at both high and low water table elevations. Due to the existence of a silt/clay lens in the central portion of the Hillyard Trough and the model's method of solving a lens setup, heads cannot be calibrated to above and below the lens. This may reduce the accuracy of simulated water levels in the Hillyard Trough. Calibration near the model boundary indicates a need for additional data collection in this area to capture the high degree of river–to-aquifer recharge and the distribution of this water in the aquifer. Geology, hydrogeology and calibration data in the aquifers of WRIA 55 is more sparse than that available in WRIA 57. Because of this, only general groundwater elevations can be simulated in WRIA 55. Annual calibration of these points shows over all good correlation, with the simulation matching water levels in the sand and gravel aquifer better than the basalt layer.

Calibration of discharge data on the Spokane River shows excellent calibration to measured data. Major losing and gaining reaches of the Spokane River are captured both in river discharge and in baseflow simulations. In WRIA 55, calibration data is less well matched. Simulated low flows are higher than measured flows in Dragoon Creek, Deadman Creek, and the upper Little Spokane River at the USGS Dartford gage, but match well on the West Branch Little Spokane River, the SCC Chattaroy gage and the USGS near Dartford gage. Simulated peak flows match better during wet years than during dry years at all gages where peak data exists (primarily the Little Spokane River). Simulated surface water-aquifer interaction appears to represent the system well, aquifer discharge into the Little Spokane River as baseflow below Dartford matches discharges indicated by measurements in this reach.

# BIBLIOGRAPHY

# TABLES

# FIGURES