THE LEMHI RIVER MIKE BASIN MODEL: A TOOL FOR EVALUATING STREAM FLOWS, DIVERSION OPERATIONS AND SURFACE WATER-GROUND WATER RELATIONSHIPS IN THE LEMHI RIVER BASIN, IDAHO

Prepared for the

Bureau of Reclamation
and
Idaho Governor's Office of Species Conservation
through
Idaho Department of Water Resources

by

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SEPTEMBER, 2006

To: Bill Graham, Idaho Department of Water Resources

From: Rose Wallick and Carter Borden

Date: September 14, 2006

Subject: Extension of the Lemhi River MIKE BASIN Model (LRMBM) to include the tributaries of the lower Lemhi River Basin and the upper Lemhi River Basin

Dear Mr. Graham:

Enclosed are two reports describing an initiative by the Idaho Department of Water Resources (IDWR) to develop a surface water budget model for the entire Lemhi Basin from its headwaters above Leadore, Idaho to its confluence with the Salmon River near Salmon Idaho. The first report summarizes the process of adding 14 tributary watersheds to the previously developed Lemhi River MIKE BASIN Model (LRMBM) (DHI, 2003) which extends from McFarland Campground to the Lemhi's confluence with the Salmon River. The second report describes the process by which the model was further extended to include the mainstem Lemhi River and 12 tributaries upstream of McFarland Campground.

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

- A brief description of the numerical model used for the demonstration
- Summaries of data and assumptions that went into the model setup
- Limitations to the modeling effort
- Results from the modeling effort
- Data gaps to be filled
- Recommended studies to further refine the model.

As these two reports were written to independently present the further developments of the LRMBM, in some sections the text is redundant from the original report, *Evaluation of Diversion Operation Plans to Meet Negotiated Flow Targets for Salmon and Steelhead in the Lemhi River Basin Using the MIKE BASIN Model* (DHI, 2003), and with each other.

ACKNOWLEDGEMENTS

The refinement and further development of the Lemhi River MIKE BASIN Model involved technical expertise and data to set up the model. These were provided by many individuals and agencies. Significant recognition should be given to Rick Sager, the Lemhi River watermaster, for his knowledge of the system and patience in creating the model. Mr. Sager is the expert on the Lemhi River system and without his assistance the model could not have been constructed to its current level of success. Other water masters and land owners that provided local expertise include Dean Shiner, Jerry Eastman, Steve Crofoot ,Pat McConnaghy, Jim Skinner, John Tracy, Verdell Olson, Lamar Cockrell, Bob Loucks, John Amonson, Rick Snyder, Thomas Udy, and Dan Smith were great sources of local knowledge about the system. Matt Hightree and Sharon Merit, Idaho Department of Fish and Game, provided the daily stage records to develop the daily diversion rates for each diversion. The Model Watershed provided a space for conducting the public meetings.

The Idaho Department of Water Resources (IDWR) was extremely instrumental in providing and formatting data, and providing technical expertise. Of particular note is Nick Scheidt, Technical Hydrologists, and Morgan Case, Staff Biologist, who provided technical support and organized meeting and data collection efforts. Michael Ciscell, Adjudication Bureau, converted water right documentation into irrigated land maps associated with each diversion. Bill Graham, Bureau Chiefs of Technical Services, Water Planning, and Adjudication, provided support and guidance on the development of the model. Bill Kramber provided guidance on ET rates and the SEBAL analysis. Roxanne Brown provided guidance on ditch loss calculations. Bob Foster, IDWR Salmon Regional Office, helped gather data and other relevant information on the Lemhi River Basin.

ADDITION OF LOWER TRIBUTARY WATERSHEDS TO THE LEMHI RIVER MIKE BASIN MODEL

1 INTRODUCTION

This memorandum describes the initiative by the Idaho Department of Water Resources (IDWR) to develop a surface water budget model for major tributaries in the lower Lemhi River Basin, Idaho. A MIKE BASIN model for the mainstem Lemhi River downstream of McFarland Campground was previously developed by DHI personnel in 2003 for the purpose of quantifying and collectively representing sources and uses of stream flow throughout the entire mainstem of the Lemhi River system from McFarland Campground to the Salmon River (DHI, 2003). The original Lemhi River MIKE BASIN Model (LRMBM) has been expanded to include the mainstem to Leadore, Idaho and 28 tributaries watersheds (Figure 1). This report documents the process by which 14 of the lower tributary watersheds were added to the existing Lemhi River MIKE BASIN Model (LRMBM).

Model construction occurred from October 2005 to June 2006. During this period, IDWR and DHI, Inc. personnel worked to build the river network for each tributary, compile and populate the model with existing data, and identify data gaps. The model consists of a defined network for each tributary basin, data files ready for population with data, and customized supporting spreadsheet files for processing and loading data and aiding in the calibration of the model. The result is an updated and calibrated LRMBM for the mainstem Lemhi River and a ‘skeleton model’ for the tributaries. A calibrated model for the tributaries was not possible at the conclusion of this phase due to insufficient stream flow and diversion data throughout the basin. The ‘skeleton model’ of the tributaries does support knowledge of the movement of flow and data fulfilled and gaps. Once the tributary inflow and diversion data have been collected and the tributaries have been calibrated, the model described herein will be able to evaluate mainstem and tributary diversion operations throughout the lower Lemhi River Basin.

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

- A brief description of the numerical model used for the demonstration
- Summaries of data and assumptions that went into the model setup
- Limitations to the modeling effort
- Data gaps to be filled
- Recommended studies to further refine the model.

As this report supplies a summary of the activities for adding the tributaries to the LRMBM, much of the background material for the modeling effort can be found in the attached document *Evaluation of Diversion Operation Plans to Meet Negotiated Flow Targets for Salmon and Steelhead in the Lemhi River Basin Using the MIKE BASIN Model* (DHI, 2003).

2 BACKGROUND

The State of Idaho, local landowners and irrigators, NOAA Fisheries, the U.S. Fish and Wildlife Service, and a number of other local, State, and Federal agencies developed a Conservation Agreement to outline measures for landowners and water users in the Lemhi area that would conserve and restore fish species listed under the Endangered Species Act. Some of these measures focus on improving stream flow during the spring runoff period.

During average and wet runoff years, the mainstem of the Lemhi River generally provides enough water for year-round upstream and downstream migration of salmon and steelhead. However, in dry years, there is not always enough instream flow during the spring runoff and during the irrigation season in a short reach of the river at the L-6 Diversion. Furthermore, the lower reaches of many of the tributaries run dry, or nearly dry, for much of the summer in low flow years due to a combination of upstream diversions and minimal inflows from headwater areas (Idaho Department of Fish and Game, in preparation). Without sufficient tributary flows, migrating salmon, steelhead and bull trout are unable to reach spawning habitat along the upper reaches of tributaries. In cases where spawning has successfully occurred along tributaries, low flows may block salmon, steelhead trout and bull trout fry from accessing rearing habitat in the Lemhi River (Idaho Department of Fish and Game, in preparation).

Water management along the mainstem Lemhi River and its tributaries is complex because the Lemhi River Basin is a semi-arid environment and there is a limited supply of water to satisfy irrigation and environmental needs. Furthermore, the Lemhi River irrigation system is composed of a network of ditches and diversions which often intersect tributaries, tributary diversions or other Lemhi River diversions.

The ground water – surface water interplay and the temporal nature of irrigation demands also lend complexity to the Lemhi River system. During high flows in the spring runoff period, irrigators along the main Lemhi and tributary streams open their diversions to fill their canals and soak their fields (Rick Sager, John Tracy and Steve Crofoot, personal communication 2005). Irrigation water causes ground-water levels to rise seasonally (Donato, 1998). It is widely believed that this shallow ground water storage is slowly released back to the Lemhi River which sustains stream flows later in the irrigation season (Rick Sager, personal communication 2005). This scenario is also evident on some tributary streams where flood irrigation of upper fields in the early season is thought to benefit lower fields (near the valley floor) as water percolates downslope through the shallow subsurface (John Tracy, personal communication, 2005, Steve Crofoot, personal communication 2005).

In order to better understand and manage water resources within the Lemhi River Basin, IDWR is developing and using new technologies such as Geographic Information System (GIS) and watershed modeling tools. IDWR is using GIS to assist with prioritizing watersheds while MIKE BASIN is being used to understand water allocation in river basins. MIKE BASIN is a surface water budget tool which IDWR will use to:

- Evaluate watershed priorities
- Move forward with existing water transaction proposals
- Develop new water transactions with special focus on Basin 74.

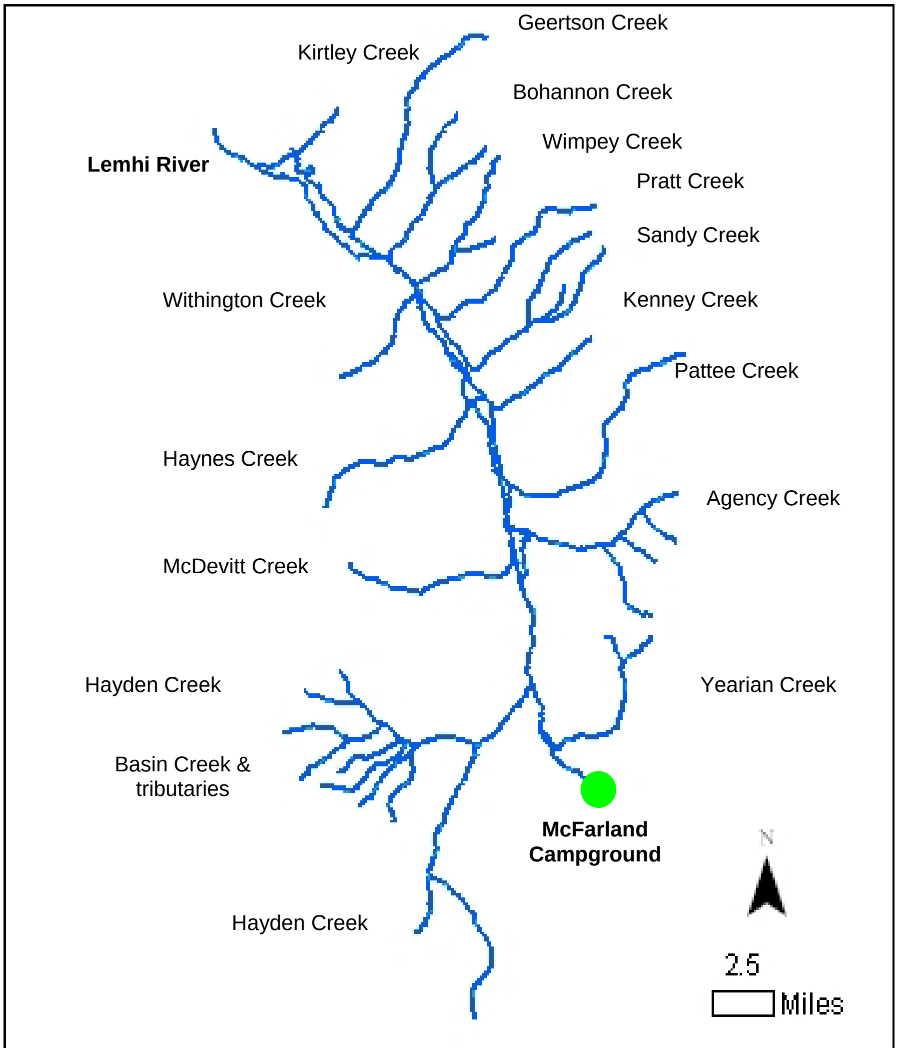

Figure 1. Lemhi River Basin #74. The study reach extends from McFarland Campground to the confluence of the Lemhi and Salmon Rivers upstream from Salmon, Idaho. Included in the study area are 14 tributary basins including: Yearian, Hayden, McDevitt, Agency, Pattee, Kenney, Sandy, Pratt, Wimpey, Bohannon, Geertson, Kirtley, Haynes and Withington Creeks. The green dot signifies the upstream end of the model area of the LRMBM considered in this document.

3 MODEL USED: MIKE BASIN

MIKE BASIN is an integrated water resource management and planning computer model that integrates GIS with water resource modeling (DHI 2006). This gives managers and stakeholders a framework within which they can address multisectoral allocation and environmental issues in a river basin. In general terms, MIKE BASIN is a mathematical representation of the river basin, including the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing as well as potential major water use schemes and their various demands for water.

MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. Branches represent individual stream sections while the nodes represent confluences, diversions, locations where certain water activities may occur (municipal, industrial, reservoir, and hydropower water uses), or important locations where model results are required. The river system is represented in the model by a digitized river network that can be generated directly on the computer screen in ArcMap 9.1 (a GIS software package). All information regarding the configuration of the flow simulation network, location of water users, reservoirs and intakes, and outlets of return flow are also defined by on-screen editing.

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

In MIKE BASIN, reservoirs and lakes can be modeled using three methods: standard reservoir, allocation pool reservoir, and lake. For the reservoirs, the performance of specified operating policies using associated operating rule curves can be simulated. Rule curves define the desired storage volumes, water levels, and releases at any time as a function of existing water level, the time of the year, demand for water and possibly expected inflows. For periods of drought, release from reservoirs can be reduced a certain factor for each of several critical (also termed reduction) water levels. The lake method has no operation rules, but a water level-dependent outflow. All methods take into account evaporation, direct precipitation, and leakage losses.

The standard reservoir and allocation pool reservoir methods differ in the accounting of the water available to downstream users. The standard reservoir method, all water users draw water from the same storage volume and operation rules regulate the water user's extraction from the storage pool. The allocation pool reservoir is similar in that water is drawn from a storage volume and operation rules regulate the water user's extraction from the storage pool. However, the allocation pool method subdivides the storage by user's storage right. An accounting procedure keeps track of the actual water storage in one pool for downstream minimum flow releases and in the individual pools allocated for water supply.

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

- A time series or monthly summary in graphic or tabular form.
- A map of visualized groups of results for the entire or any specified part of the model network in the ArcMap Graphical User Interface (GUI). Map views can be stepped through time to generate animation files. The GUI can help create graduated color result presentations for many combinations of results. Several result groups can be animated simultaneously (e.g. flow in the mainstem of the stream and extractions by users).

Animations can be saved as a Windows movie (*.avi file) and imported into PowerPoint presentations.
- Model results stored in a database that can be queried using Microsoft Access. The user can create programs in Microsoft Access to automatically generate reports to display results.

MIKE BASIN has additional capabilities, including the ability to simulate municipal, industrial, reservoir, and hydropower user; and simulate transport and degradation of substances affecting water quality in rivers and reservoirs. Water quality substances that MIKE BASIN simulates include ammonia/ammonium, nitrate, oxygen, total phosphorus, and organic matter. Organic matter is represented in terms of biological oxygen demand and chemical oxygen demand. A complete description of the capabilities of MIKE BASIN is at http://www.dhisoftware.com/.

4 LEMHI RIVER MIKE BASIN MODELING METHODS

Adding tributaries to the original LRMBM involved expanding the river network, diversions, and water users for the tributary basins; compiling, formatting, and inputting the available data for the tributaries; and developing customized Microsoft Excel spreadsheets. In this text, the updated 2006 LRMBM is referred to as the LRMBM and the original model will be specifically noted with referenced. The model network has the following criteria:

- LRMBM encompasses the Lemhi River upstream downstream from McFarland Campground as well as 14 tributary basins including Yearian, Hayden, McDevitt, Agency, Pattee, Kenney, Sandy, Pratt, Wimpey, Bohannon, Geertson, Kirtley, Haynes and Withington Creeks (Figures 3 - 14).
- The original LRMBM network has been kept largely intact, with only minor modifications to account for several major ditches including the Sandy Slough and the L-9 Ditch (Figure 15).
- Model simulations are run on a daily time step from 240 offtake nodes along the Lemhi River and its tributaries and 244 irrigation nodes (representing the irrigated area associated with the offtake nodes).
- Multiple irrigation nodes are used in diversions along the mainstem Lemhi River where water is applied in several distinct locations and the water allocation to those separate fields has been determined.
- Return locations for each irrigation node represent the downstream location where the majority of the return fraction is believed to have returned to the Lemhi River or its tributaries.
- Catchment nodes at upstream end of the Lemhi River and its tributaries represent direct flow input into the model (Figure 2, Table 2)
- Reach loss time series are attached to the arcs upstream of the 5 stream gage sites along the mainstem Lemhi and 3 locations along tributaries to represent points where reach gains/losses are incorporated (Table 3).
- A Microsoft Excel spreadsheet calculator was used to determine the return fraction parameter for each irrigation node.

The following section describes the construction methods, data availability, and assumptions associated with adding tributaries to the Lemhi River MIKE BASIN Model.

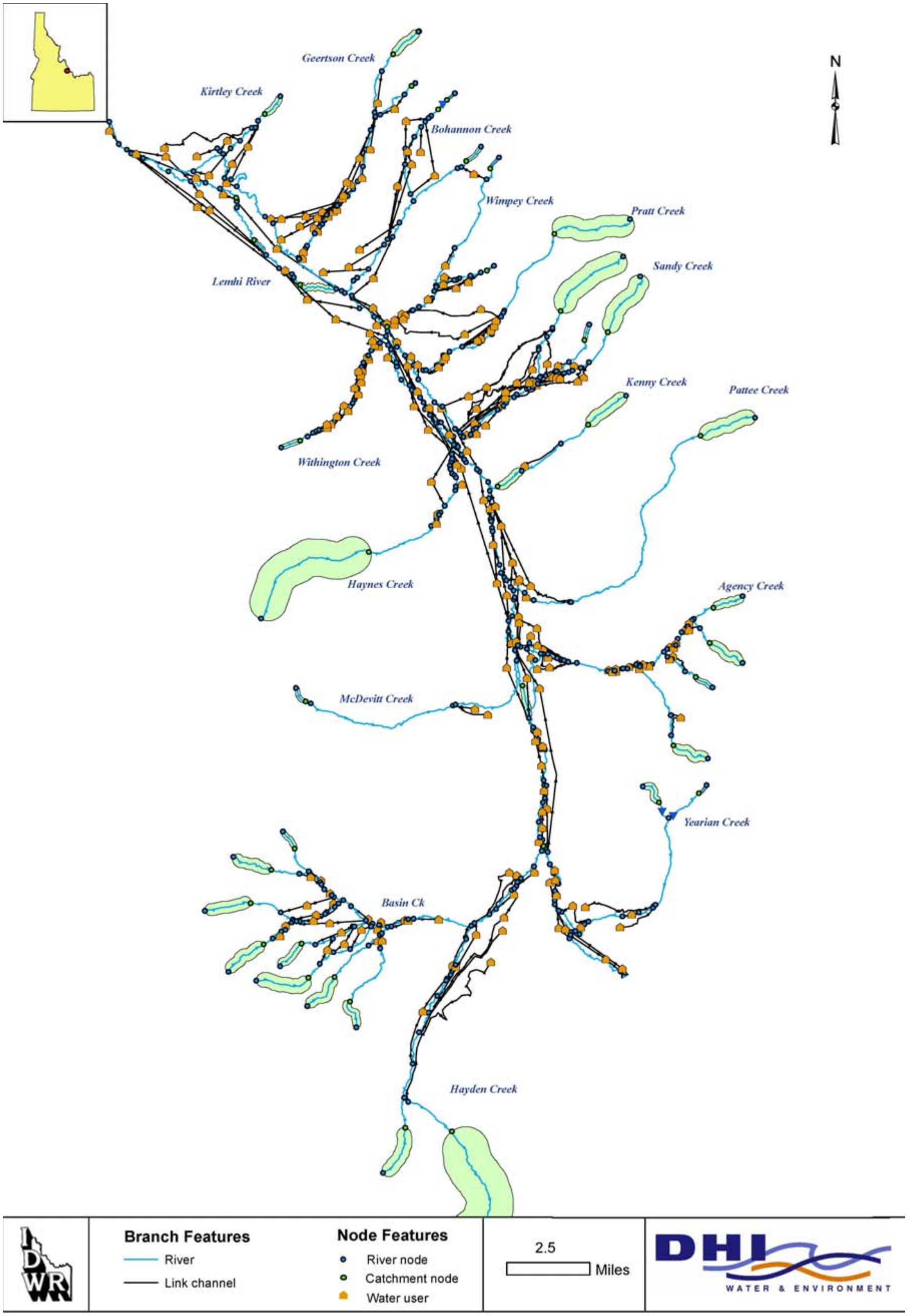

Figure 2. Overview map of the lower LRMBM

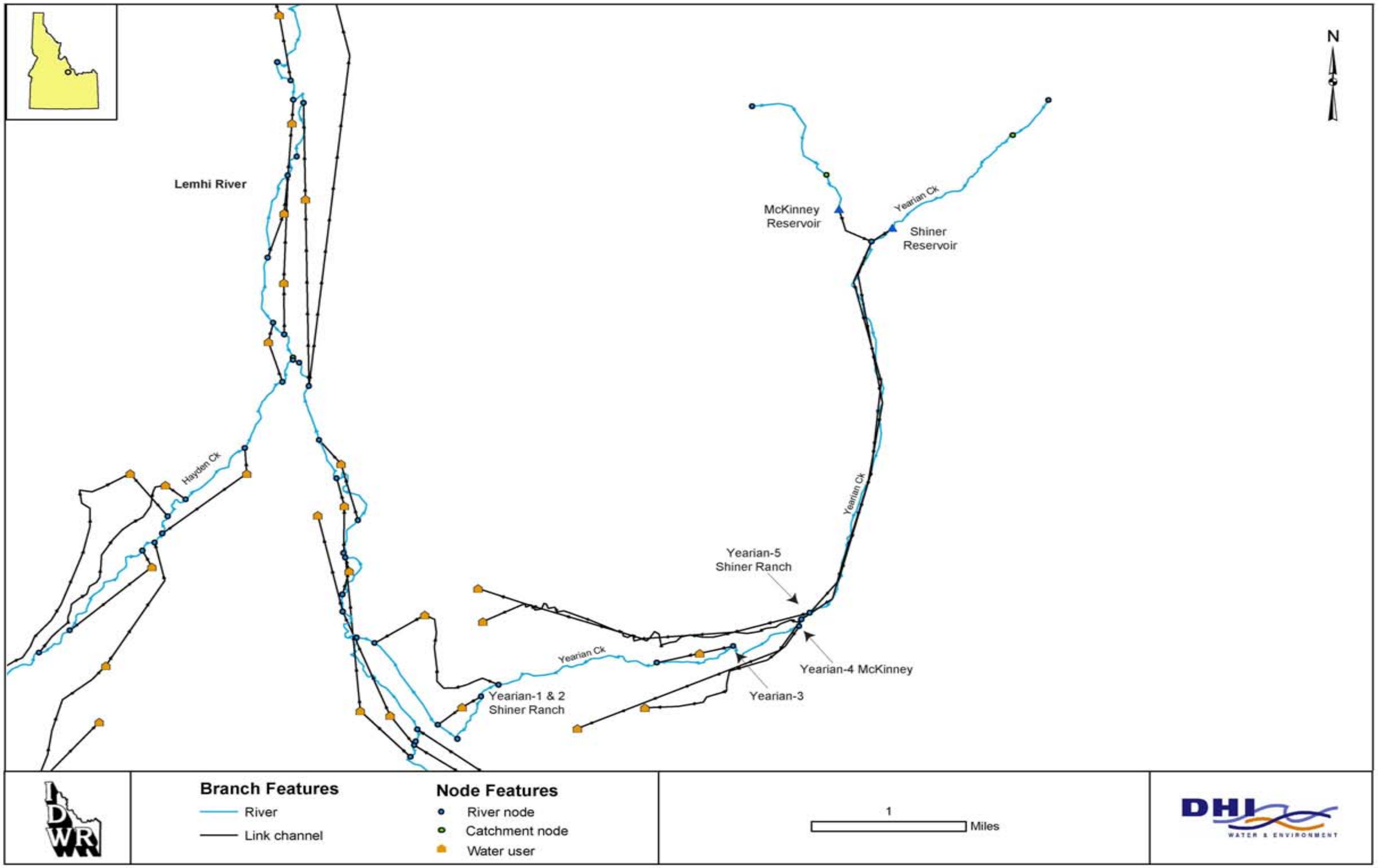

Figure 3. Map of Yearian Creek in the lower LRMBM

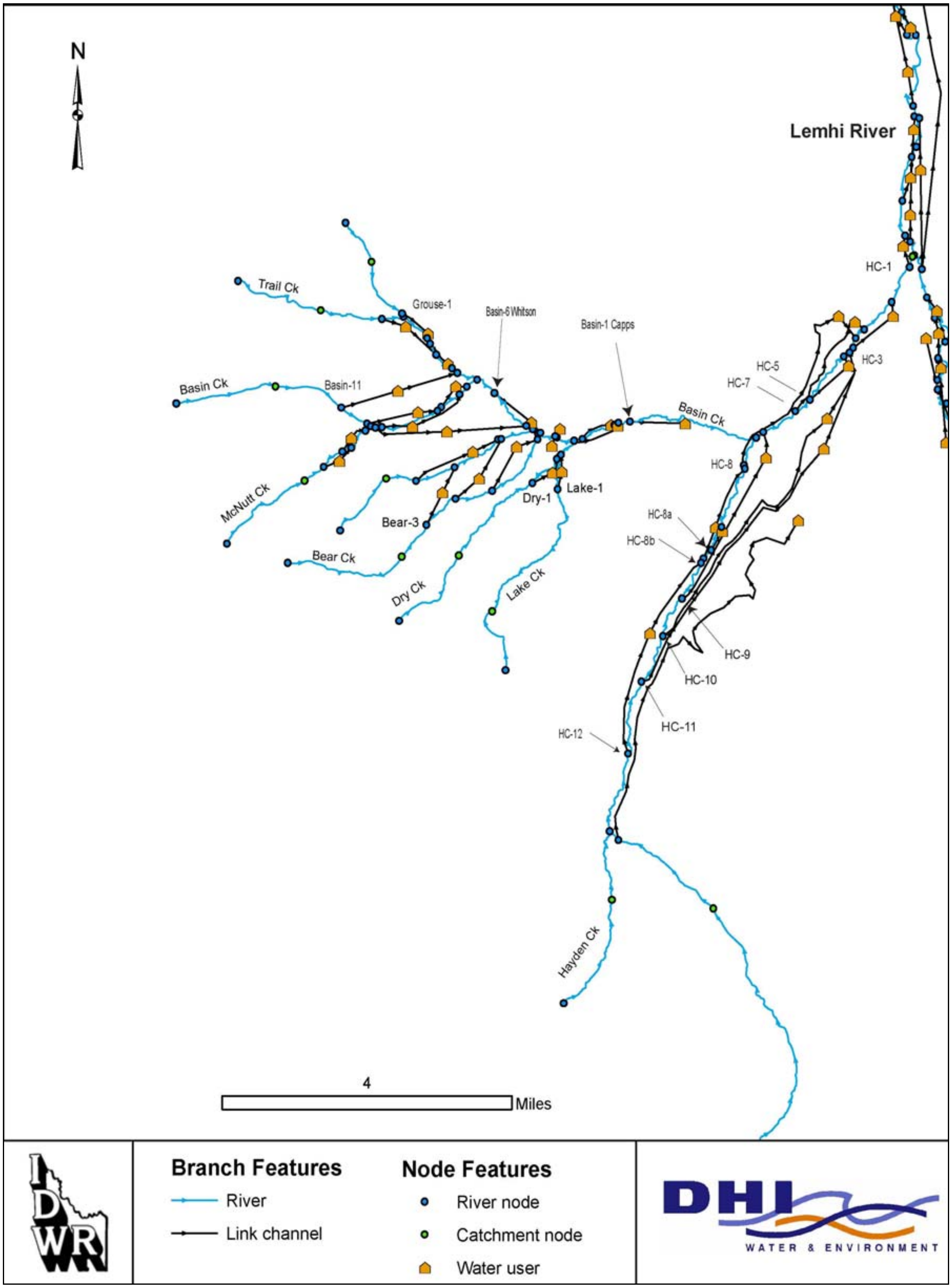

Figure 4. Map of Hayden and Basin Creeks in the lower LRMBM

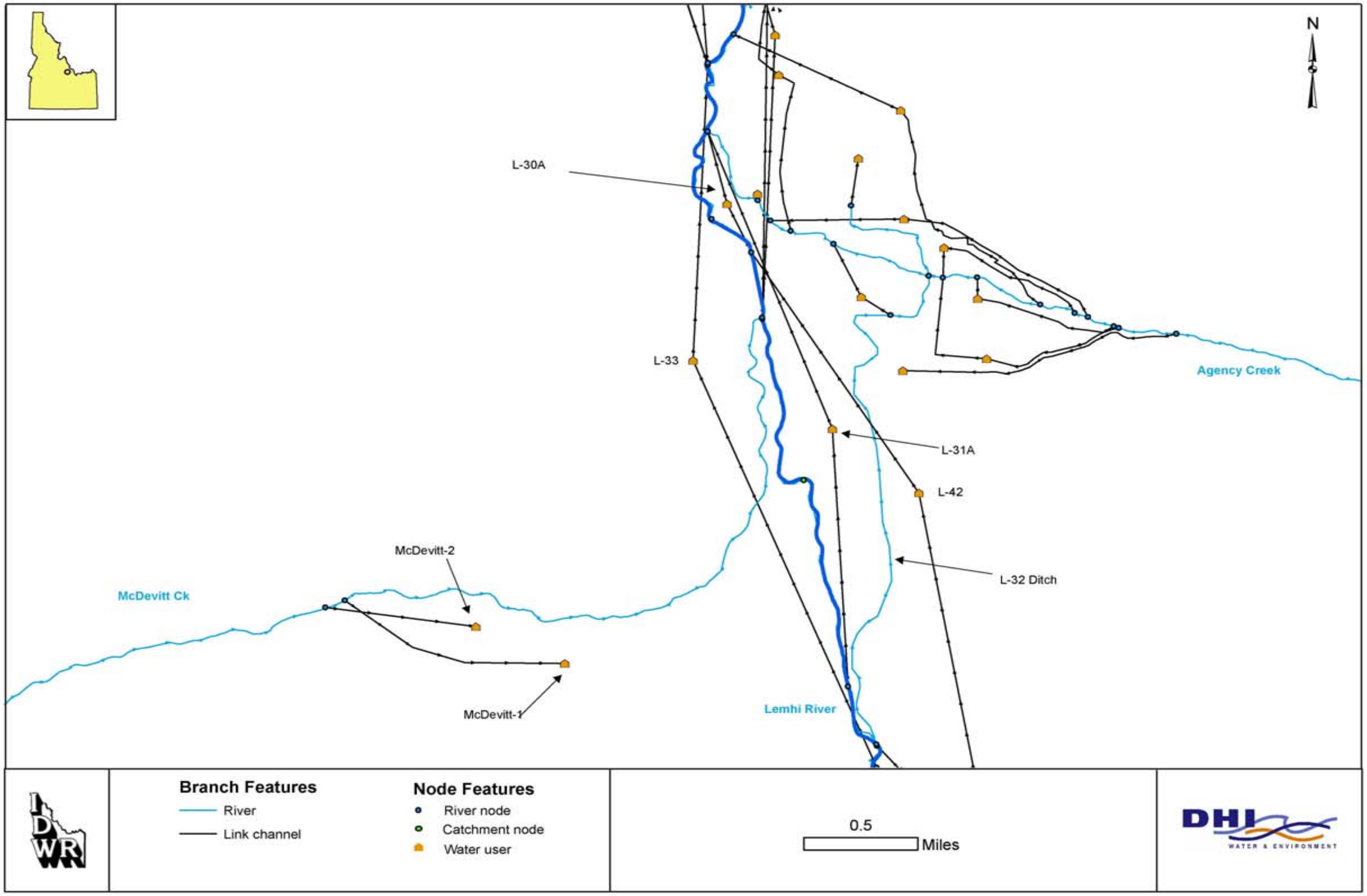

Figure 5. Map of McDevitt Creek in the lower LRMBM

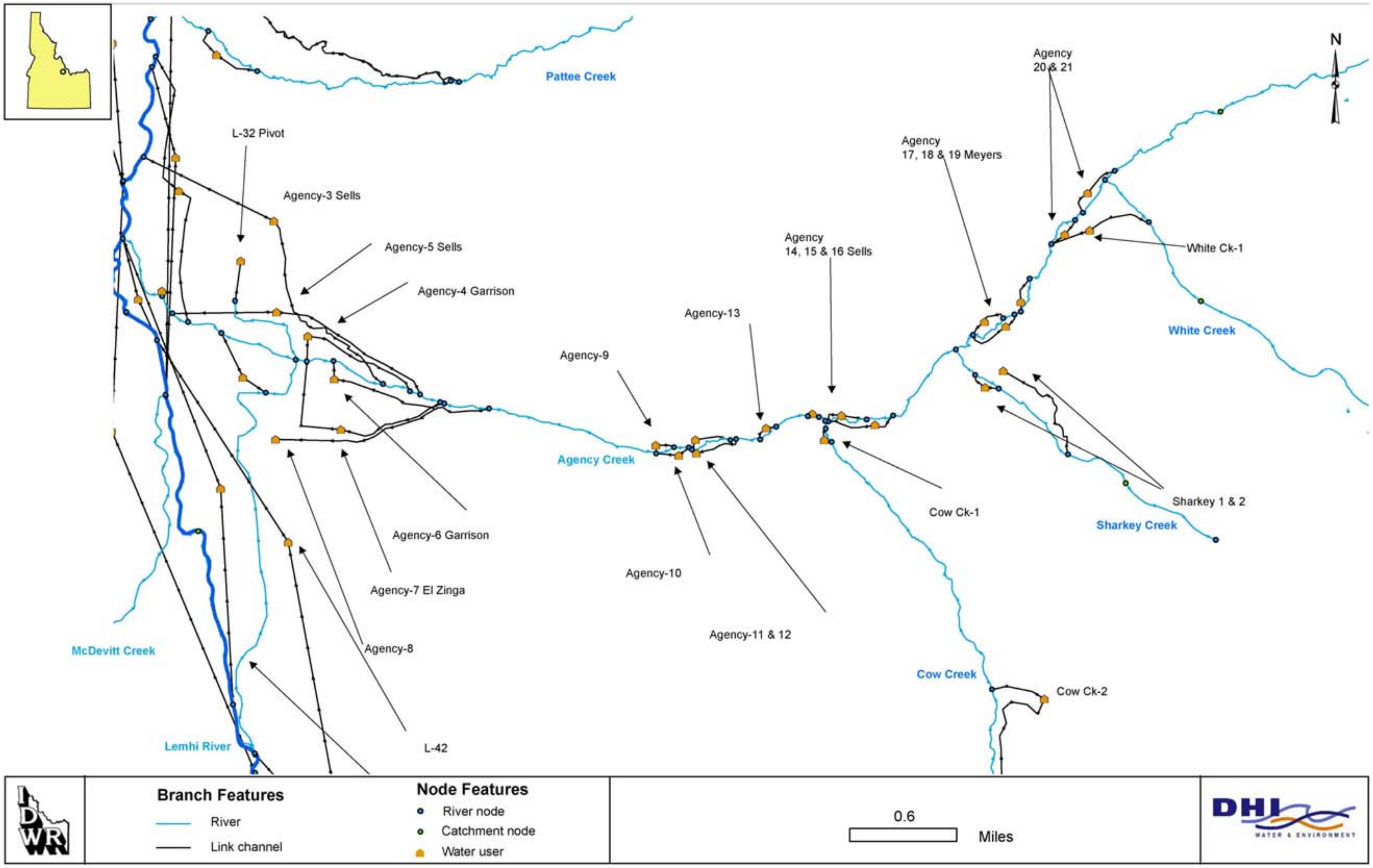

Figure 6. Map of Agency Creek in the lower LRMBM

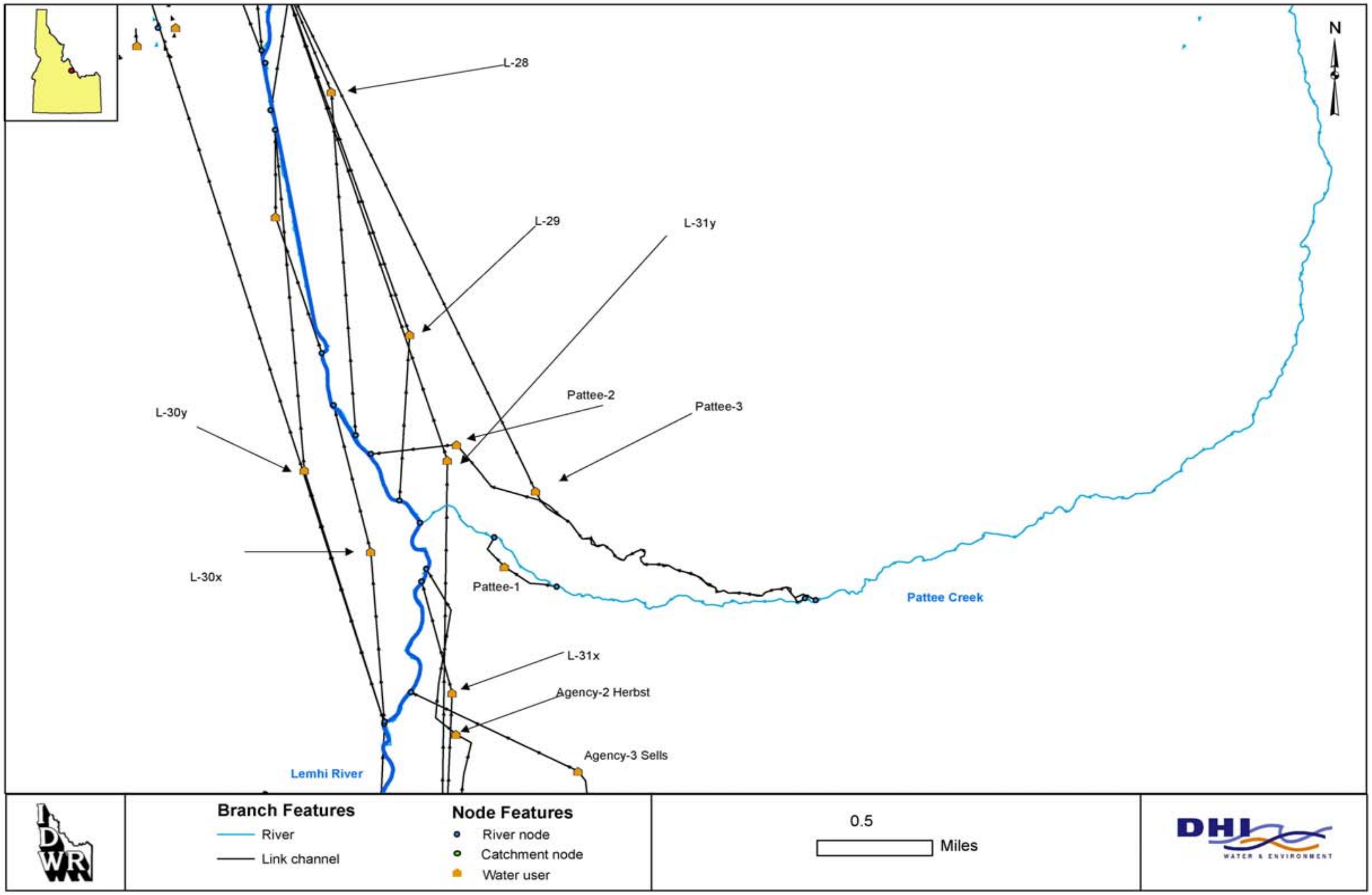

Figure 7. Map of Pattee Creek in the lower LRMBM

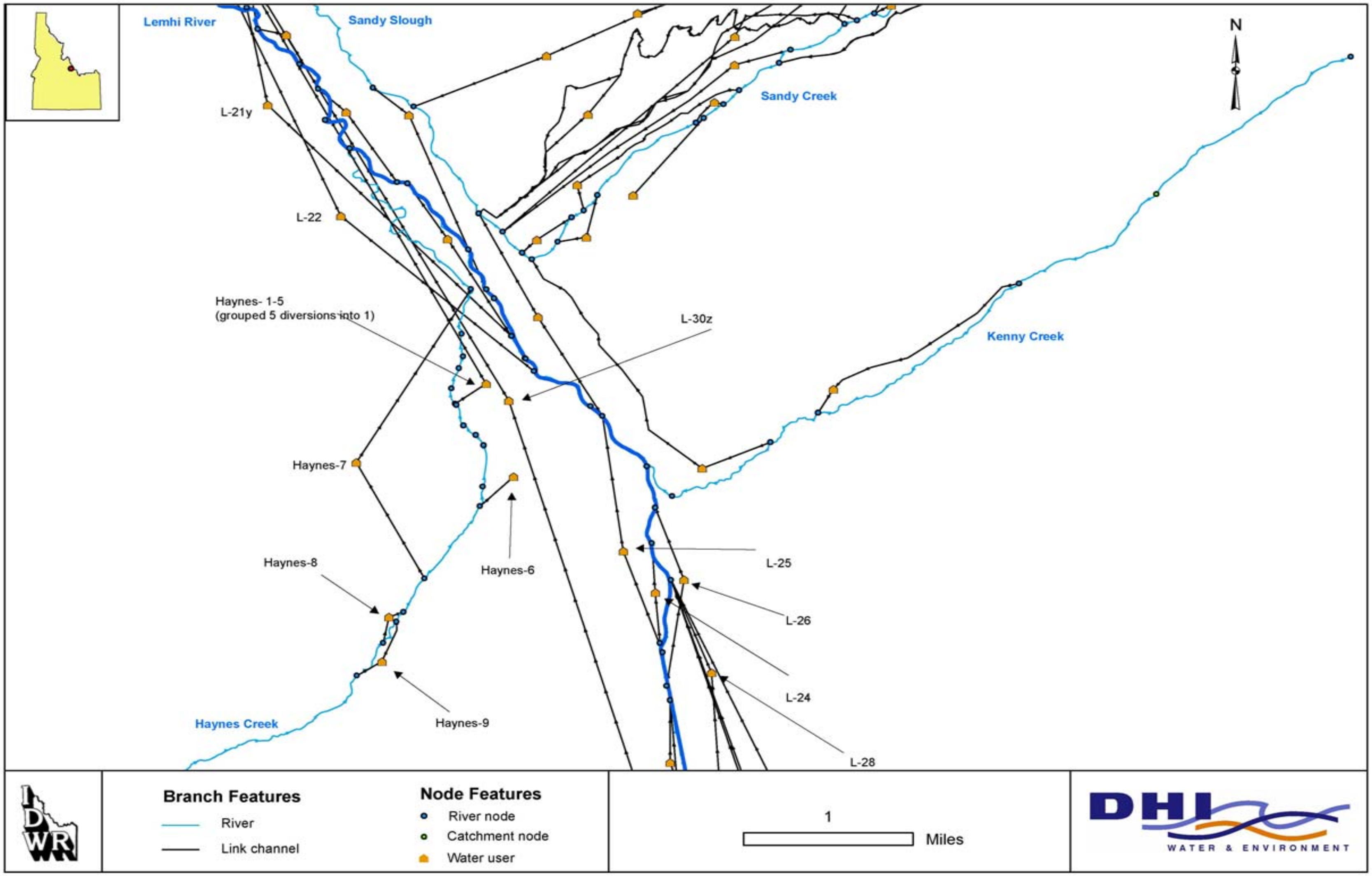

Figure 8. Map of Haynes and Kenney Creeks in the lower LRMBM

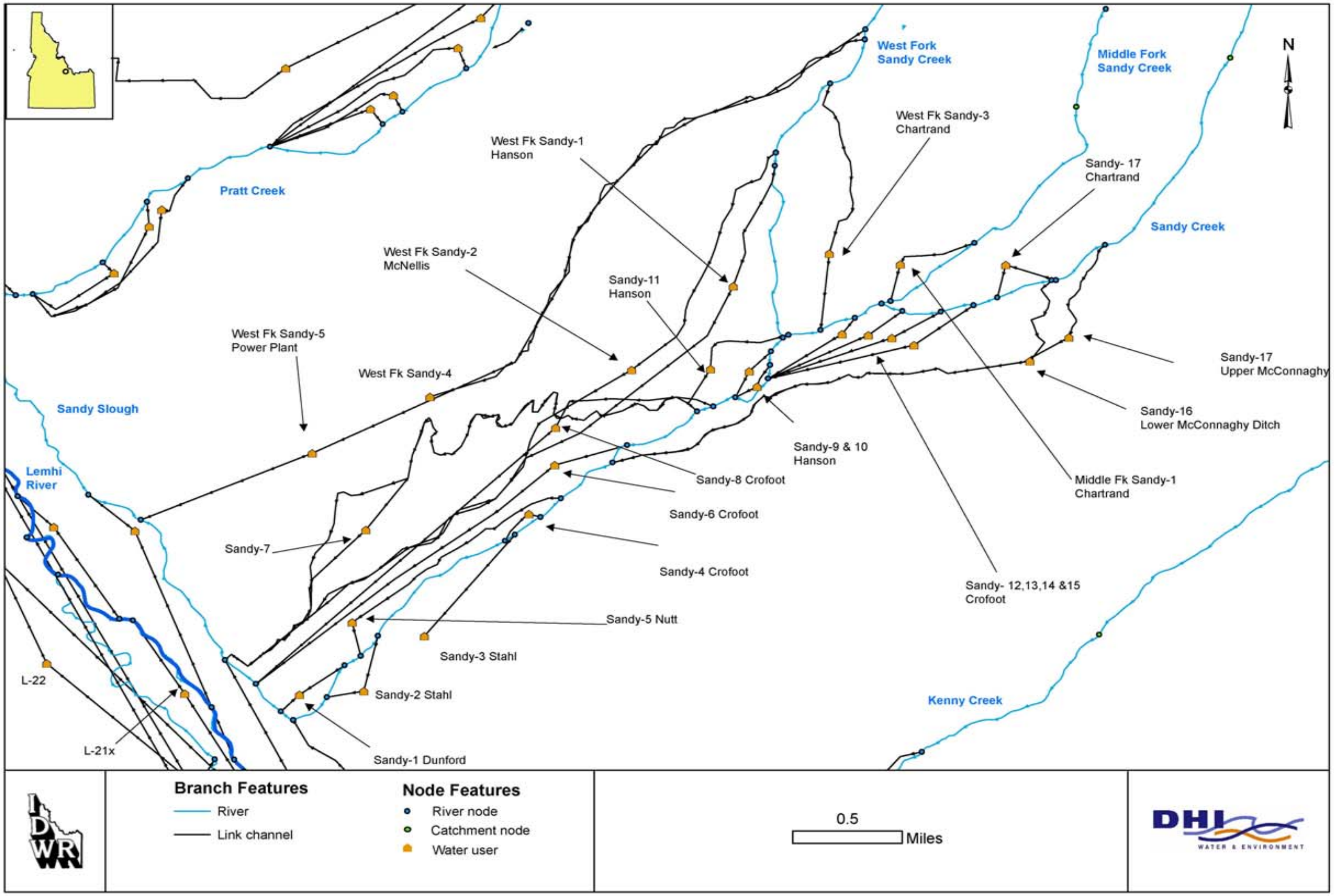

Figure 9. Map of Sandy Creek in the lower LRMBM

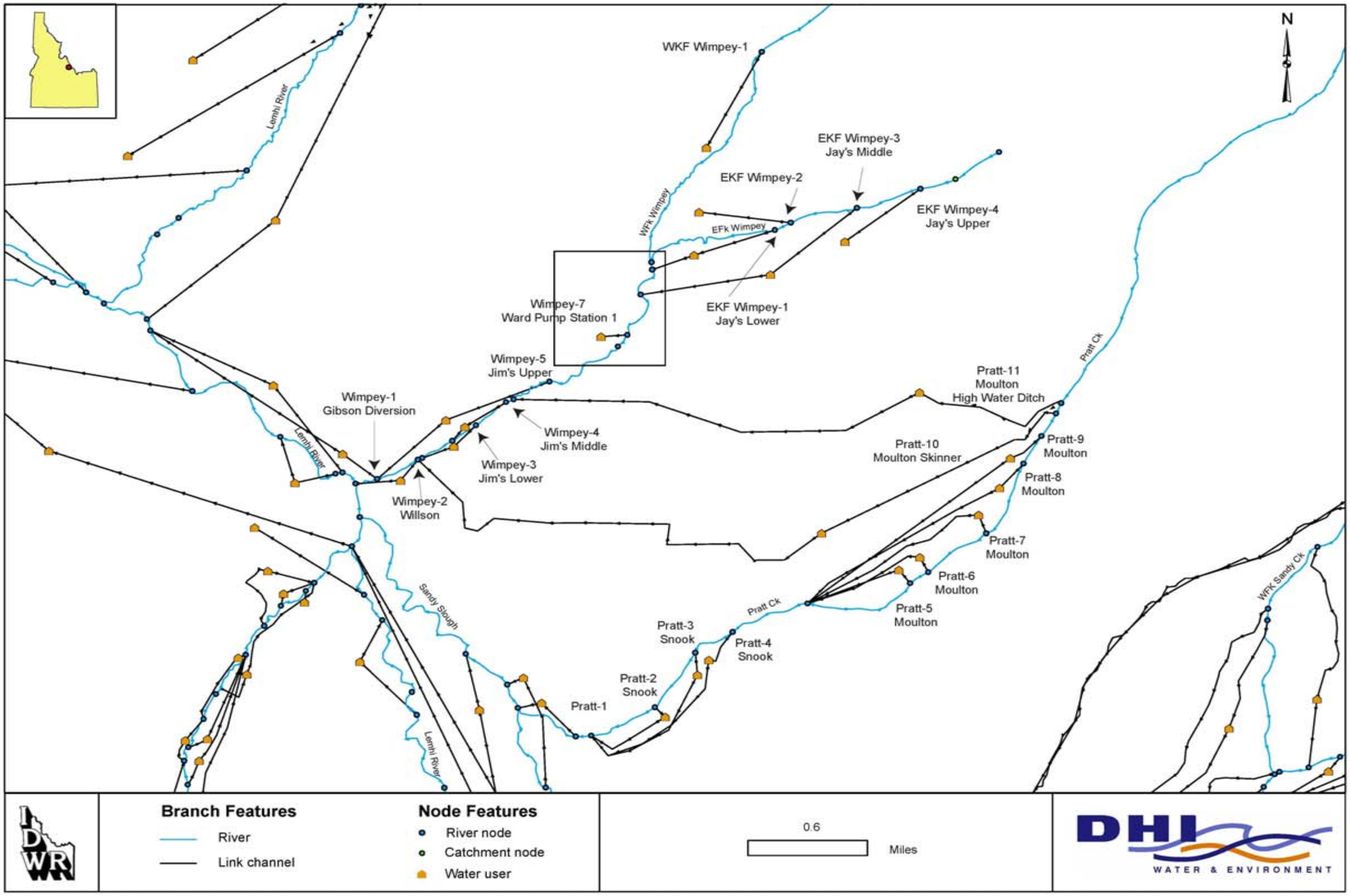

Figure 10. Map of Pratt Creek in the lower LRMBM

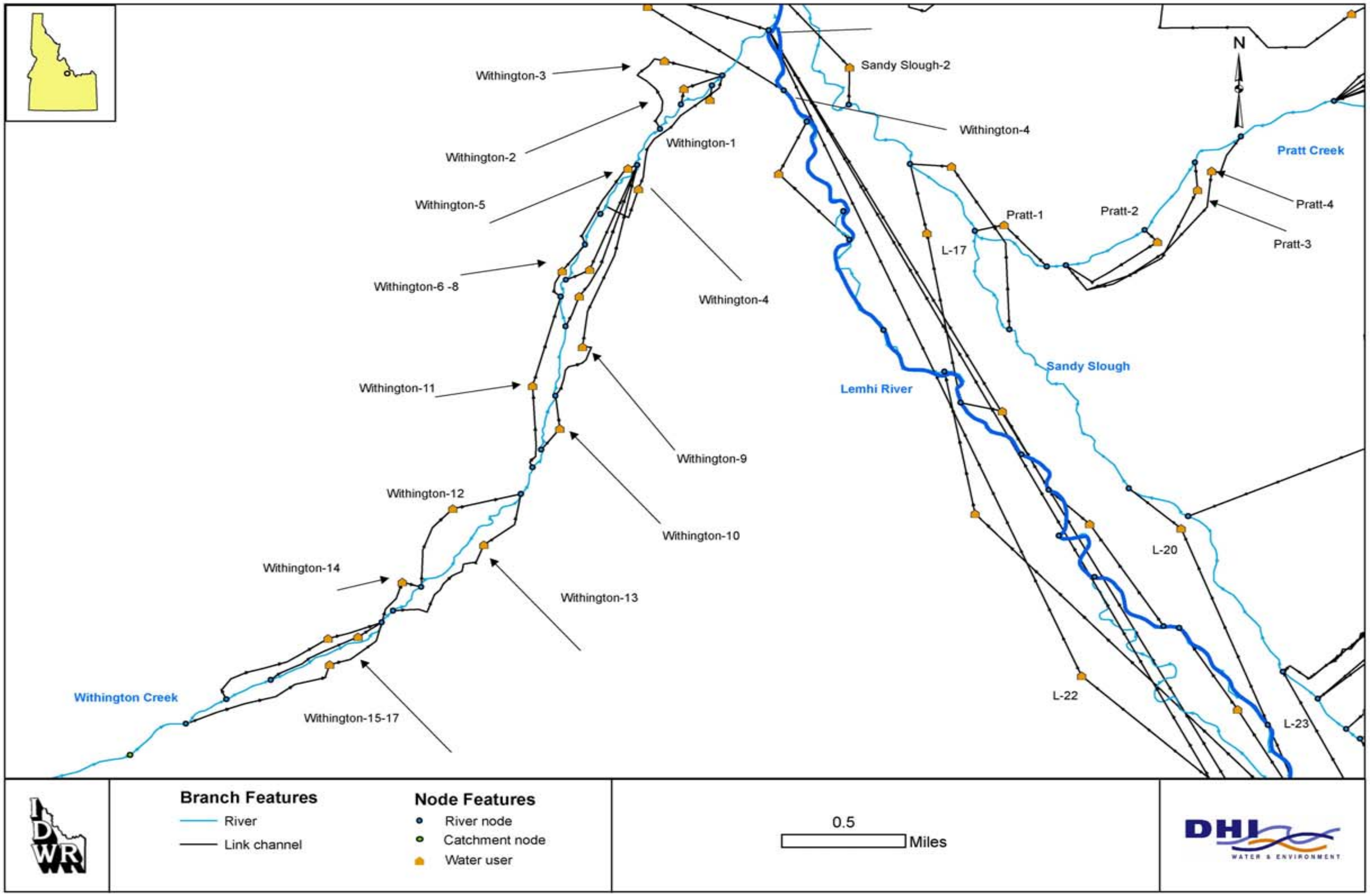

Figure 11. Map of Withington Creek in the lower LRMBM

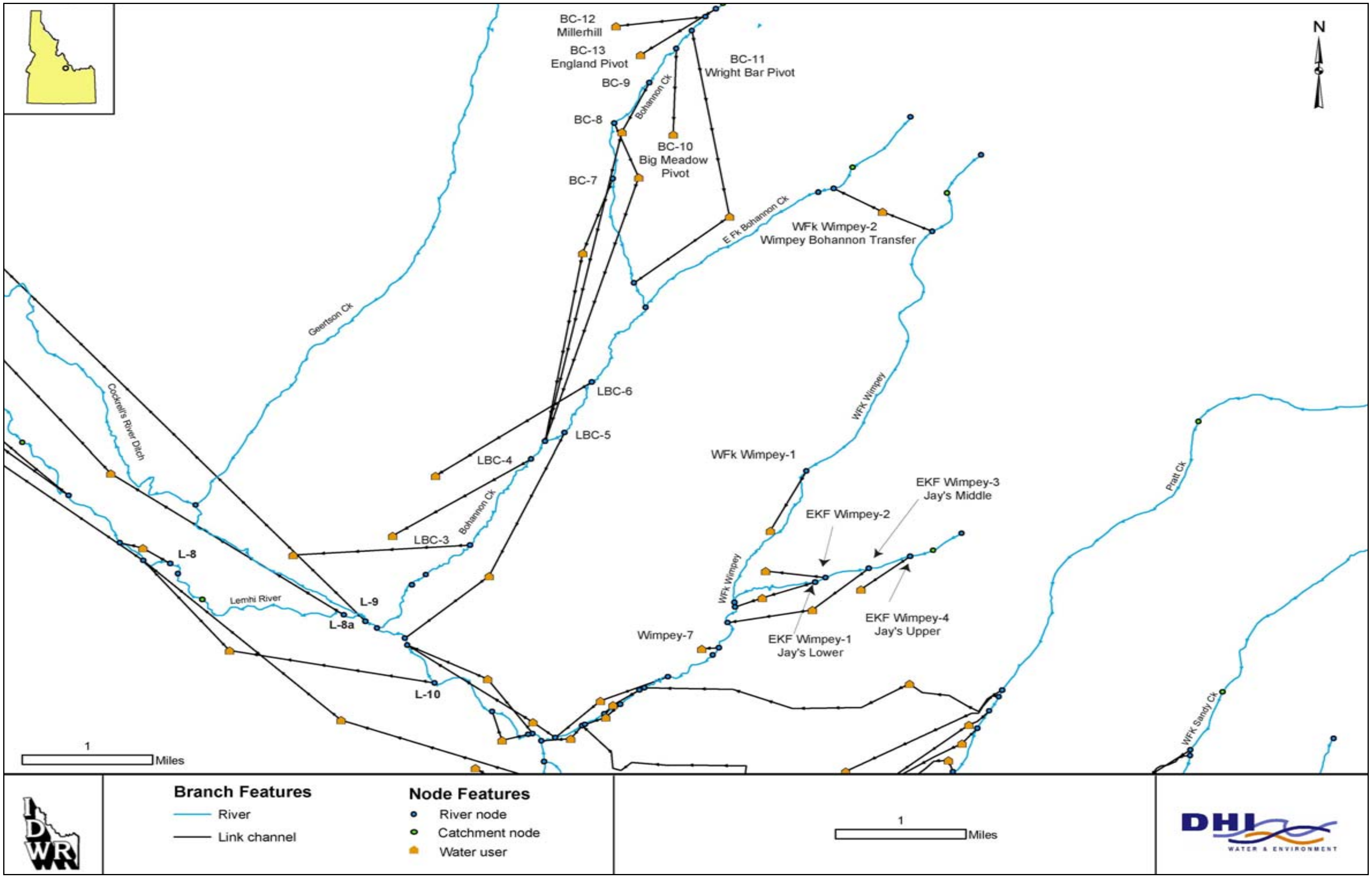

Figure 12. Map of Wimpey and Bohannon Creeks in the lower LRMBM

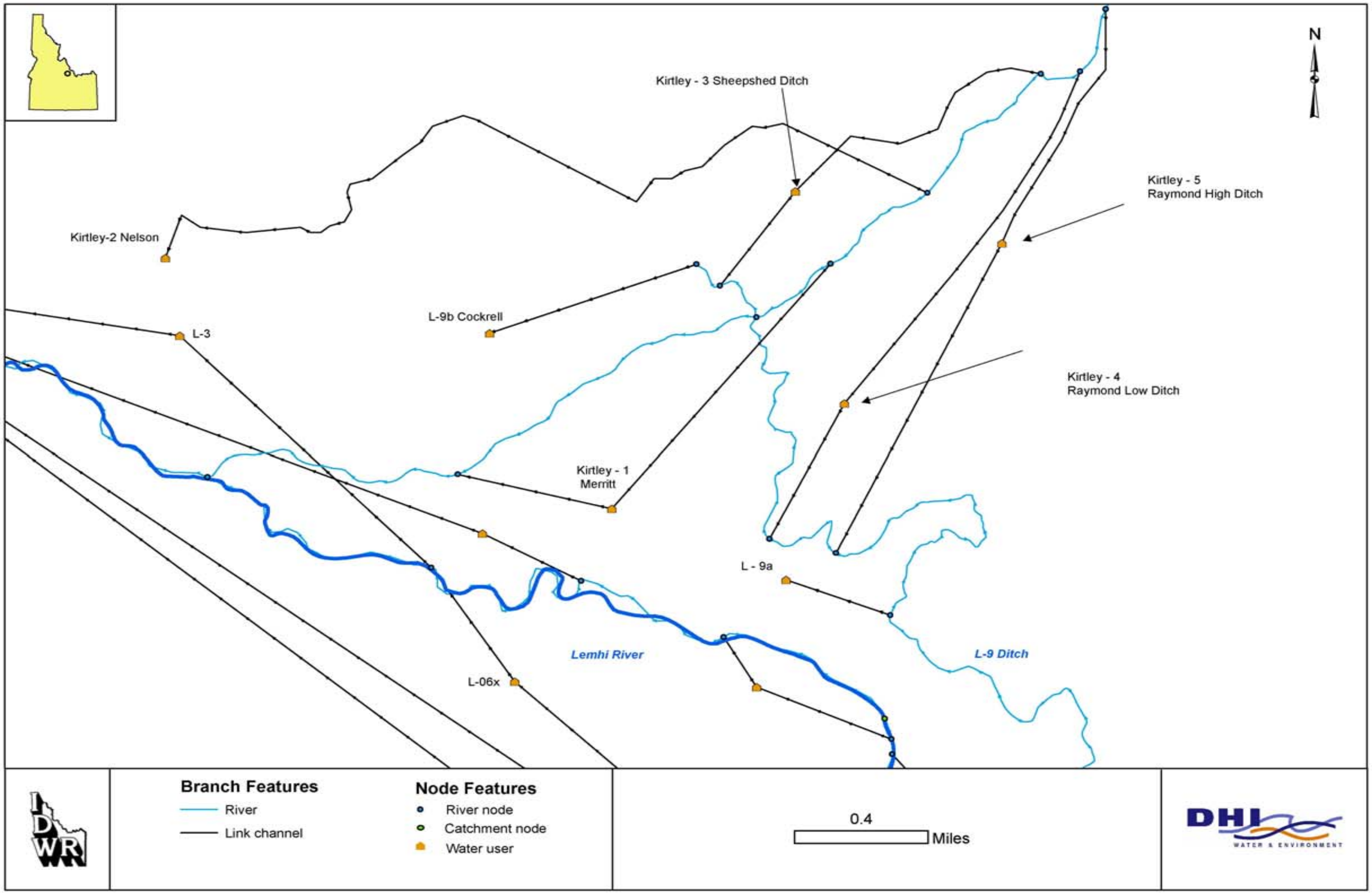

Figure 13. Map of Kirtley Creek in the lower LRMBM

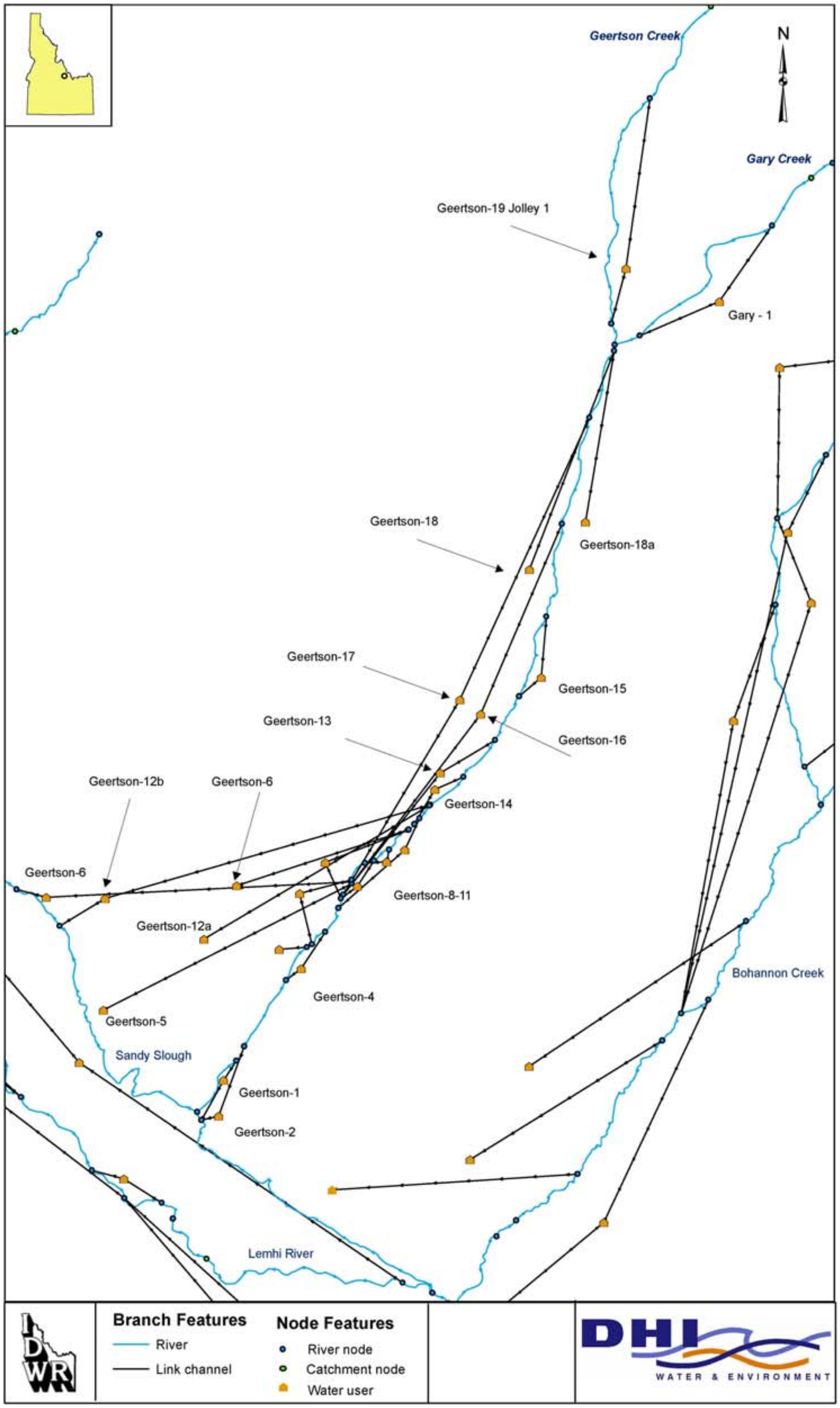

Figure 14. Map of Geertson Creek in the lower LRMBM

4.1 Network Setup

The river network for the mainstem Lemhi River was established in 2003 when DHI developed the Lemhi River MIKE BASIN Model (DHI 2003). For this update, the mainstem Lemhi River network was largely kept in the same condition as the original LRMBM with only minor modifications made to account for major ditches and tributary confluences. The network was extended by adding 14 tributary watersheds. For each tributary, network information was compiled from GIS coverages, aerial photographs, IDWR GIS shapefile for point of diversion (POD) and place of use (POU) locations, and USGS gaging station locations. DHI and IDWR staff met with water masters and landowners on each tributary in order to verify position of each POD and POU (Table 1). The planar course of the tributaries was extracted from the 1:24,000 National Hydrography Dataset shapefile (up_sal_24k.shp) (Figure 2).

Table 1. List of water masters and landowners contacted during the development of the lower LRMBM

Tributary	*Contact Person*	*Title*	*Date of Meeting*
Yearian Creek	Dean Shiner	Water User	December 6, 2005
Hayden Creek	Rick Sager	Water Master	October 27, 2005
McDevitt Creek	Rick Sager	Water Master	October 27, 2005 December 8, 2005
Agency Creek	Jerry Eastman	Water Master	December 8, 2005
Pattee Creek	-	(inactive Water District)	-
Kenney Creek	Rick Sager	Water Master	October 27, 2005
Sandy Creek	Steve Crofoot & Pat McConnaghy	Water Master & Landowner	December 7, 2005
Pratt Creek	Jim Skinner	Land Owner (inactive Water District)	December 7, 2005
Wimpey Creek	Rick Sager	Water Master	October 27, 2005
Bohannon Creek	John Tracy	Water Master	October 28, 2005
Geertson Creek	Verdell Olson	Water Master	March 2006
Kirtley Creek	Lamar Cockrell	Water Master	December 8, 2005
Haynes Creek	Rick Sager	Water Master	October 27, 2005 December 8, 2005
Withington Creek	Bob Loucks	Land Owner (inactive Water District)	December 9, 2005

The Lemhi River offtake nodes and water users were transferred directly from the original LRMBM. Tributary offtake nodes were determined by IDWR's POD shapefile (diver903_idtm.shp) and from discussions with local water masters. The irrigation nodes, representing the irrigated area associated with each offtake node, were determined by matching the adjudicated POU location with the point of diversion. These POU's were verified through discussion with water masters and landowners on each tributary.

For most offtake nodes (diversions) along the mainstem Lemhi River, multiple irrigators share the diverted water throughout the irrigation season. In the LRMBM, a single irrigation node is used to represent locations where multiple water users are applying diverted water in the same general area. However, on the 14 modeled tributaries described in this document, most diversions only service a single irrigator, thus there are few instances where water users are 'lumped' along modeled tributaries. The exception is the Haynes Ck-1-5 Diversion where 5 water users are grouped together.

Exact location, timing, and quantity of return flows are a function of flood irrigation practices and the physical conditions of the irrigated area. In many cases, irrigation returns re-enter the river through surface and subsurface paths that are disseminated along reaches bordering the irrigated fields. In the LRMBM, return flow nodes are associated with respective irrigation nodes and are located at a downstream point along the Lemhi River or the selected tributaries where the majority of the return flow was considered to return. In many instances, the return flow path is quite long because return flows are frequently captured and re-used several times before re-entering the river network. Diverted water that is not lost to evapotranspiration and does not re-enter the stream by the return node enters either the intermediate ground water system (IGW) or the regional ground water system (RGW). The IGW system returns to the stream within the study reach; the RGW system contains water assumed no longer to interact with the surface water river system and, consequently, is no longer tracked with the LRMBM.

There are several water supply reservoirs located in the lower Lemhi Basin. These reservoirs appear in the IDWR water rights databases and are operated to supplement irrigation diversions during the dry season. The reservoirs included in the MIKE BASIN model are: Bohannon Creek Reservoir and the Shiner and McKinney Reservoirs on Yearian Creek. While other reservoirs may exist, these were specifically identified by water masters and water users as significant. The reservoirs were modeled in MIKE BASIN with place holder values so that IDWR can populate the reservoirs with more accurate data and operating rules in the future. The operation and current status of these reservoirs should also be verified as reservoirs such as the McKinney Reservoir have not been active for several years (Dean Shiner, personal communication 2005).

In many locations along the lower Lemhi River Basin, tributaries and diversions are intersected by a complex network of irrigation ditches. Of the 14 modeled tributaries, only 8 are directly hydraulically connected with the Lemhi River (Bohannon, Wimpey, Withington, Kenney, Pattee, McDevitt, Hayden and Yearian Creeks). The remaining 6 tributaries (Geertson, Pratt, Sandy, Haynes, Kirtley and Agency Creeks) are either diverted into ditches or nearly dry along their lower reaches. These situations, and the approach used to model such complex hydraulic situations, are described below:

- *Kirtley Creek & L-9 Ditch* - The L-9 Ditch, known locally as Cockrell's River Ditch, collects water from Geertson and Kirtley Creeks. The ditch begins at the L-9 Diversion and supplies water to several users before intercepting Kirtley Creek and watering Lamar Cockrell's lower fields on the west side of Kirtley Creek. Return flows from the Kirtley Ck-3 Ditch (Sheep Shed Ditch), the Kirtley Creek-4 Ditch (Raymond High Ditch), and

Kirtley Creek -5 Ditch (Raymond Low Ditch) also enter the L-9 Ditch near its confluence with Kirtley Creek (Figure 13).

The L-9 Ditch is used to supplement diversions from Kirtley and Geertson Creek. In wet years, the L-9 Diversion is not used until very late in the irrigation season because tributary flows are sufficient to meet the water users demands. For example, the first 100 miner inches (approximately 2 cfs) in Kirtley Creek is allotted to Clyde Nelson, so during low flow when Kirtley Creek is essentially dry below the Nelson Diversion (Kirtley Ck-2), Lamar Cockrell relies upon the L-9 Ditch to water his lower fields. The L-9 Ditch also captures Kirtley Creek water so that the lower reaches of Kirtley Creek only flow during high flow periods (Rick Sager and Lamar Cockrell, personal communication 2005).

In the original LRMBM, the L-9 Ditch was modeled as a simple extraction with a single POU. There were no modeled return flows because very little return flow re-enters the Lemhi River from this diversion (Figure 3). With the addition of tributaries, it was necessary to model the L-9 Ditch as a branch in MIKE BASIN in order to account for tributary inflows and return flows from Geertson and Kirtley Creeks that enter the L-9 Ditch. In order to maintain simplicity, a single water user (L-9a) is used to represent the multiple water users along the L-9 Ditch upstream of its confluence with Kirtley Creek. As in the original LRMBM, the modeled L-9 Ditch does not have modeled return flows which re-enter the Lemhi River system because the final POU on the L-9 Ditch (L-9b) is a sprinkler irrigated field. Rules quantifying the portion of Kirtley Creek water captured by the L-9 Ditch are defined at the confluence of the two branches.

A lookup table containing placeholder values is used to specify the portion of Kirtley Creek water that is diverted into the L-9 Ditch. Currently, the table is configured so that the ditch is filled to capacity whenever sufficient flow exists at the confluence of Kirtley Creek and the L-9 Ditch. DHI arbitrarily assumed that ditch capacity is 15 cfs because ditch capacities and flow rates in Kirtley Creek were unknown at the conclusion of this modeling phase. Although these rules contain placeholder values, the rules can easily be updated when better data is available.

- *Sandy Slough* - The Sandy Slough (approximately 4.5 miles in length) collects flow from Sandy and Pratt Creeks before joining the Lemhi River near the L-11 Diversion (Figure 10). Sandy and Pratt Creeks are not directly connected to the Lemhi River, rather, all flows reaching the lower sections of these tributaries are collected in the Sandy Slough. The Sandy Slough also receives return flows from tributary diversions and Lemhi River diversion L-20 and L-17. The Sandy Slough-1 and Sandy Slough-2 Diversions extract water from the Sandy Slough.

  In the original LRMBM, the Sandy Slough was not explicitly modeled. Instead, return flows from the L-17, L-20, and L-23 Ditches that are captured in the Sandy Slough were modeled to return at the confluence of the Sandy Slough and the Lemhi River. In the 2006 LRMBM, Sandy Slough is modeled as a river branch that begins at the downstream end of Sandy Creek and flows into the Lemhi River (Figure 4). This modeling approach enables the Sandy Slough to capture return flows and tributary inflows while also supplying irrigation water to Sandy Slough 1 and Sandy Slough-2 Ditches.

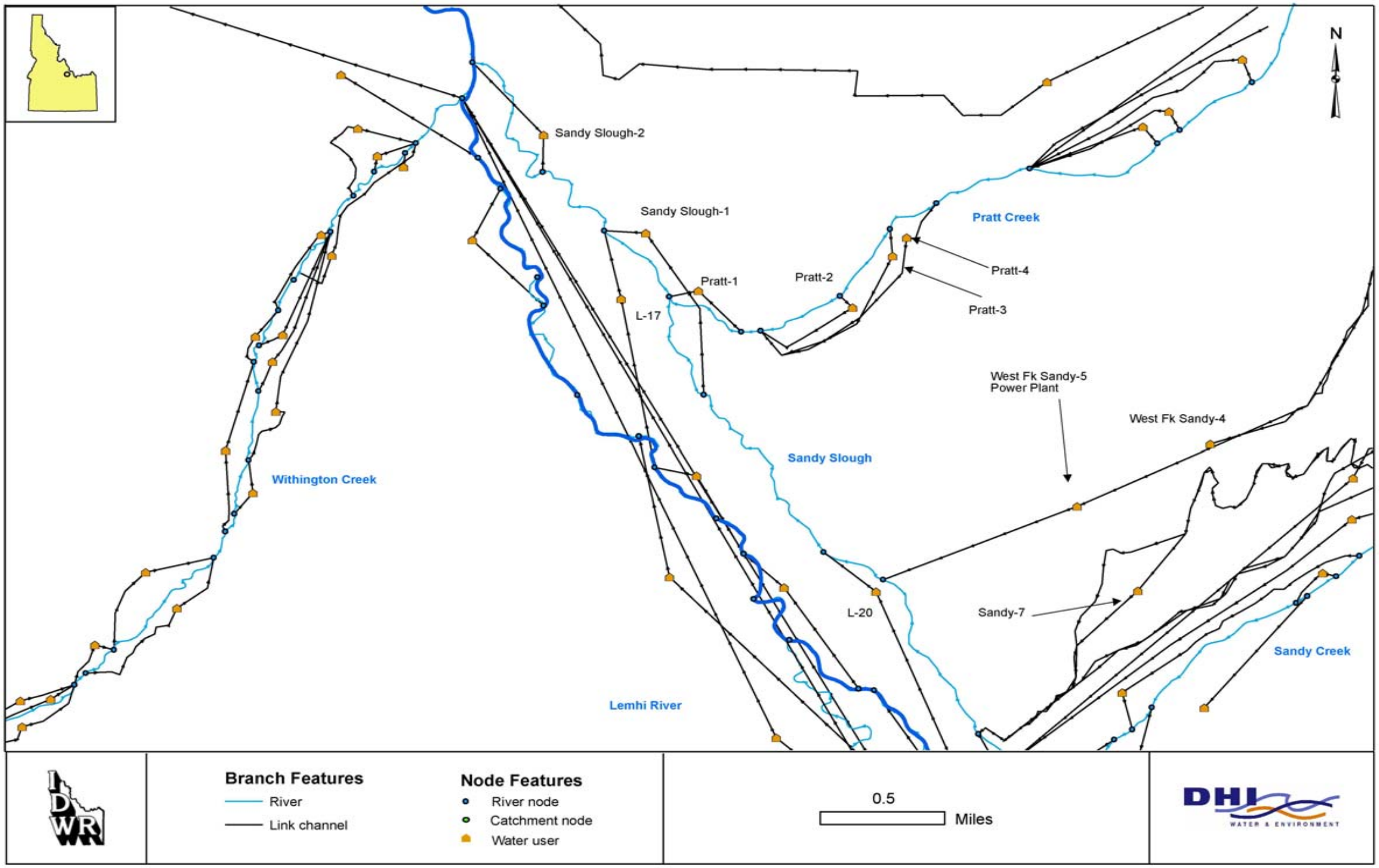

Figure 14. Map of Sandy Slough in the lower LRMBM

- *Agency Creek & the L-32 Ditch* - The L-32 Ditch (approximately 3.0 miles in length) diverts Lemhi River water to fields along the eastern side of the Lemhi Valley (Figure 18). The L-32 Ditch services multiple water users before crossing Agency Creek and irrigating a center pivot field on the north side of Agency Creek. A dam across Agency Creek diverts most of the flow in the creek into the L-32 Ditch, causing Agency Creek to go dry, or nearly dry, for a short distance downstream of the dam(Sager, personal communication 2006). Water percolates back into Agency Creek in the lower reaches so that the first diversions on the creek (e.g., Agency-1) generally have irrigation water. During high flows, water discharges over and seeps through the dam so that the lower reaches only run dry in periods of low flow.

  In the original LRMBM, the L-32 Ditch was modeled with a single water user where return flows re-entered the Lemhi River near its confluence with Agency Creek. In the 2006 LRMBM, the L-32 Ditch is modeled as a river branch with two water users. The first water user, the L-32 Ditch, represents all usage upstream of the ditch's confluence with Agency Creek and its return flows enter lower Agency Creek downstream of the L-32 Ditch dam. The second water user, the L-32 Pivot, represents the center-pivot irrigation field on the north side of Agency Creek and hence, does not have return flows. Rules are specified at the confluence of the L-32 Ditch and Agency Creek in order to properly distribute flows between the ditch and lower reaches of the creek.

  At the point where the L-32 Ditch crosses Agency Creek, a lookup table is used to apportion water between the ditch and Agency Creek. DHI arbitrarily assumed that ditch capacity is 15 cfs because ditch capacities and flow rates in Agency Creek were unknown at the conclusion of this modeling phase. Although these rules contain placeholder values, the rules can easily be updated when better data is available.

- *Haynes Creek & L-30z Ditch* - The L-30z Ditch (approximately 6.0 miles in length) intercepts Haynes Creek (Figure 5). For much of the recent past, all discharge reaching the lower sections of Haynes Creek has been diverted into the L-30z Ditch. While the upper 5.5 miles of the L-30z Ditch contain primarily L-30z water, the lower two miles of the ditch contain intermingled Haynes Creek and Lemhi River water. There are a number of diversions along the lower, commingled reach of the L-30z Ditch. Although water users along this reach have water rights to a specific source (e.g., 0.02 cfs from the Lemhi River), it is difficult to track how much water from each source is used at each diversion. In general, if there is sufficient flow at the mouth of Haynes Creek, then less water may be diverted from the Lemhi River to the L-30z Ditch. Water users therefore adjust the timing and magnitude of their diversions based on the availability of water from both Haynes Creek and the L-30z Ditch.

  For modeling purposes, DHI has lumped the water users along the commingled L-30z Ditch/Haynes Creek reach into a single Haynes Creek water user (Haynes Ck 1-5) and a single L-30z water user (L-30z). The Haynes Ck 1-5 water user represents the 4 adjudicated diversions from Haynes Creek (lemhi_rec_pods.shp, February 2006) whereas the L-30z water user represents all diversions from the L-30z Ditch as modeled in the original LRMBM (DHI, 2003). Modeled return flows from both users re-enter the Lemhi

River near the L-13 Diversion after getting re-diverted to the L-22 and L-21 Ditches and used to water other fields on the southwest side of the Lemhi River.

4.2 Diversion Naming Convention

The naming convention for the diversions along the tributaries was developed in a manner that is consistent with convention applied to the mainstem Lemhi River, while also upholding local names that are familiar with water masters and water users. Each offtake node (POD) is assigned a label consisting of the tributary name, followed by a number indicating the position of the POD relative to other diversions on that tributary. Diversion numbers generally start with 1 near the mouth of each tributary and increase upstream. For example McDevitt-1 is the first diversion upstream from the confluence of McDevitt Creek and the Lemhi River and McDevitt-10 is the 10th diversion (and hence further upstream). Where applicable, local names are added to the label to signify landowner or well-known diversion names. In this manner, the tributary name, diversion number and local name are all specified. For example, the third diversion from the mouth of Kirtley Creek is labeled: Kirtley-3 Sheep Shed Ditch. To assist in record keeping, IDWR and DHI personnel maintained records of the naming conventions used in the LRMBM, along with the name used by the water masters, the BLM name, and any other labels applied to a particular diversion.

Because the LRMBM consists of a complex network of nodes, water users and channels, many of these features were assigned names in order to provide clarity for future model users. Link channels representing ditches linking POUs with PODs were assigned labels denoting the diversion name and the type of channel (e.g. return flow, extraction). Water user nodes (irrigation nodes) were labeled with the same name as that assigned to their corresponding user node. For the mainstem Lemhi River, each offtake node and water user is named according to the official diversion name.

4.3 Catchment Nodes

Catchment nodes are placed in locations where water is gained or lost directly to the river system. For the LRMBM, catchment nodes were placed at the upstream end of the Lemhi River (at McFarland Campground) and 14 tributaries (Figure 2, Table 2). The LRMBM has a total of 15 catchment nodes. Values were collected from the USGS StreamStats site for the 50%excedence probability for March through November. December, January, and February were assumed to have 0 cfs inflow. As this is a period with no irrigation and because there is not significant storage in the system, setting the inflows to 0 cfs has no impact on evaluating diversion operations during the irrigation season.

4.4 Branch Reach Losses/Gains

Reach losses/gains were placed at 5 locations along the mainstem Lemhi to account for reach gains due to precipitation, ground water inputs, and other components that are not explicitly included in the model. Such reach gains were assumed to represent residual between simulated and observed stream flow measurements at a gaging station (Figure 2, Table 3).

Table 2. Inflow data for tributary catchments in the Lower Lemhi MIKE Basin Model. Inflows represent average monthly discharge in cubic feet per second (cfs) as prepared by IDWR staff from StreamStats database. January, February, and December are set to 0 cfs as the streams are frozen.

	Creek	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Basin Creek Watershed	Lake	0.00	0.00	0.28	0.58	0.83	0.97	0.43	0.21	0.19	0.29	0.28	0.00
	Dry	0.00	0.00	0.27	0.57	0.81	0.94	0.42	0.21	0.18	0.28	0.27	0.00
	Bear	0.00	0.00	0.24	0.51	0.72	0.84	0.37	0.19	0.16	0.25	0.24	0.00
	Unnamed	0.00	0.00	0.09	0.19	0.28	0.32	0.14	0.07	0.06	0.1	0.09	0.00
	McNutt	0.00	0.00	0.24	0.5	0.71	0.83	0.36	0.18	0.16	0.24	0.24	0.00
	Basin	0.00	0.00	0.49	1.04	1.48	1.73	0.76	0.38	0.33	0.51	0.5	0.00
	Trail	0.00	0.00	0.76	1.6	2.29	2.68	1.18	0.59	0.52	0.79	0.77	0.00
	Grouse	0.00	0.00	0.92	1.94	2.76	3.23	1.42	0.71	0.63	0.95	0.93	0.00
	Kirtley	0.00	0.00	2.66	5.06	4.76	5.21	1.81	1.07	1.01	3.17	2.85	0.00
Geertson Watershed	Geertson	0.00	0.00	3.78	5.88	11.5	18.1	7.61	4.46	3.52	5.53	4.44	0.00
	Gary	0.00	0.00	0.69	1.08	2.11	3.31	1.39	0.82	0.64	1.01	0.81	0.00
Bohannon Watershed	W.F. Bohannon	0.00	0.00	2.71	3.72	12.0	22.4	11.1	6.41	4.54	4.52	3.39	0.00
	E.F. Bohannon	0.00	0.00	1.84	2.53	8.14	15.3	7.53	4.36	3.09	3.08	2.31	0.00
Wimpey Ck Watershed	E.F. Wimpey	0.00	0.00	0.97	1.77	6.39	9.77	2.11	1.18	0.93	1.31	1.1	0.00
	W.F. Wimpey	0.00	0.00	1.6	2.91	10.5	16.1	3.47	1.94	1.54	2.15	1.81	0.00
	Wimpey	0.00	0.00	1.17	2.14	7.71	11.8	2.55	1.42	1.13	1.58	1.33	0.00
	Pratt	0.00	0.00	2.19	4.56	11.8	13.4	3.46	1.84	1.57	2.54	2.32	0.00
Sandy Ck Watershed	Sandy	0.00	0.00	1.11	2.32	5.98	6.81	1.76	0.94	0.8	1.29	1.18	0.00
	M.F. Sandy	0.00	0.00	0.31	0.64	1.65	1.87	0.49	0.26	0.22	0.36	0.32	0.00
	W.F. Sandy	0.00	0.00	0.89	1.85	4.78	5.44	1.41	0.75	0.64	1.03	0.94	0.00
	Kenney	0.00	0.00	6.92	14.4	37.2	42.3	11.0	5.83	4.95	8.03	7.32	0.00
	Pattee	0.00	0.00	3.38	7.2	14.0	10.5	3.87	2.09	1.87	3.79	3.54	0.00
Agency Ck Watershed	Agency	0.00	0.00	5.01	11.4	15.6	14.2	4.81	2.62	2.34	2.64	3	0.00
	White	0.00	0.00	0.25	0.57	0.78	0.71	0.24	0.13	0.12	0.13	0.15	0.00
	Sharkey	0.00	0.00	0.56	1.27	1.74	1.58	0.54	0.29	0.26	0.29	0.33	0.00
	Cow	0.00	0.00	1.54	3.52	4.8	4.37	1.48	0.81	0.72	0.81	0.92	0.00
Hayden Ck Watershed	E.F. Hayden	0.00	0.00	3.64	5.74	26.5	47.1	15.8	7.75	6.02	4.81	4.17	0.00
	Hayden	0.00	0.00	11.5	18.1	83.8	149	50.0	24.5	19.0	15.2	13.2	0.00
	Bear Valley	0.00	0.00	9.42	14.8	68.6	122	41.0	20.1	15.6	12.5	10.8	0.00
	Yearian	0.00	0.00	1.76	4.02	5.48	4.99	1.69	0.92	0.82	0.93	1.06	0.00
	Yearian Trib2	0.00	0.00	0.39	0.9	1.22	1.11	0.38	0.21	0.18	0.21	0.24	0.00
	McDevitt	0.00	0.00	3.89	7.47	13.7	12.6	4.82	3.17	2.71	5.5	5.48	0.00
	Haynes	0.00	0.00	3.36	6.46	16.1	16.5	3.91	2.65	2.26	4.98	4.84	0.00
	Withington	0.00	0.00	2.48	4.25	11.3	13.4	3.17	2.25	1.87	4.14	3.77	0.00

Table 3. List of stream gages along the lower Lemhi River that are used to calculate reach losses/gains

Gage Name	*Data Source**	*MIKE BASIN Branch Name*	*Period of record*
Lemhi River at Barracks Lane	WD 74	USBR Barracks Lane Gage	1993-2001
Lemhi River nr Lemhi Idaho	USGS	USGS Lemhi Gage	1938-present
Lemhi River below L5	USGS	USGS L-5 Gage	1992-present
Lemhi River at Steel Bridge	WD 74	USBR L-3 Gage	1993-present
Lemhi River at Baker	IPCO	Lemhi River at Baker IP Gage	2004-present
Bohannon Creek abv Diversions	USGS	Bohannon Ck USGS Gage	2004-present
Kenney Ck	IPCO	Kenney Ck USGS Gage	2004-present
Agency Ck	IPCO	Agency Ck IP Gage	2005-present
Lemhi River at Hayden	IPCO	Lemhi IP gage abv Hayden Ck	2004-present
Hayden Ck	WD 74	Hayden Ck WD74 Gage	1997-present

* "WD 74" denotes Water District 74, "USGS" denotes U.S. Geological Survey, and "IPCO" denotes Idaho Power Company

4.5 Time Series Input Data

In MIKE BASIN, the movement of water in and out of the river system is specified with time series data. Catchment, reach gain/loss branches, reservoirs, and irrigation nodes require time series data in the LRMBM. The catchment node, time-series data are used to describe stream inflows. For each irrigation node, time series information is used to define irrigation demand, ground water fraction (fraction of demand satisfied by ground water), return fraction (fraction of demanded water that returns to the stream at specified return locations), deficit carryover (in the event of a deficiency in the demand, the amount that can be made up in the subsequent time steps), and lag time (the linear routing of return flow from the irrigated fields back to the river). Reservoir nodes require physical characteristics and operational rules.

For the LRMBM, time series data for the mainstem Lemhi diversions were previously collected, formatted and linked with the corresponding water users during the development of the initial Lemhi River model. In this phase of the modeling development, additional data describing tributary inflows and diversions was collected. The following section describes the required datasets for the catchment, branch losses/gains, reservoir, and irrigation nodes as well as branch losses/gains and specifies the required datasets are currently missing.

4.5.1 Catchment Nodes

Catchment runoff represents locations in the model where water is introduced directly to the stream system. For the LRMBM, data is needed at the upstream end of modeled tributaries and at gauging stations. In the LRMBM, limited time series input information from stream flow gaging station records is available as only 2 of the 14 tributaries have gaging stations. On the 2 gaged tributaries (Agency Creek and Kenney Creek), the stream flow gages are located downstream of several diversions, so observed stream flows may vary slightly from the actual inflows entering the upper reaches of the creeks. Inflows to the Lemhi River are simulated using gage data from the Bureau of Reclamation gage at McFarland Campground.

To estimate the stream flow at each catchment node for each modeled tributary basin, the USGS StreamStats tool was used (http://water.usgs.gov/osw/streamstats/index.html). StreamStats is a GIS based program that determines the contributing area for a user-specified site, measures physical characteristics of the basin, and uses regression equations to estimate stream flow statistics. In this project, IDWR personnel used StreamStats to obtain catchment inflows for the 14 modeled tributary basins. Where possible, IDWR staff calibrated the Streamstats data with observed measurements at nearby gages (Nick Scheidt, personal communication 2006). The drainage area ratio method was used to linearly adjust calibrated Streamstats data when input locations were out of the Streamstats range or where observed flows were not available. Unadjusted Streamstats data were used in the Haynes Creek, McDevitt Creek, and Withington Creek watersheds where adequately comparable basins did not exist to use the drainage area ratio method (Nick Scheidt, personal communication 2006).

4.5.2 Branches with Reach Losses/Gains

Reach losses/gains account for contributions to the Lemhi River from precipitation, ground water gains/losses, and unmodeled tributary inflow. In the LRMBM, the reach gains/losses are the difference between the observed and simulated conditions for each time step during the simulation period. Catchment nodes were inserted in the original LRMBM at 5 locations: the Water District 74 (WD74) gage just downstream of Hayden Creek, the WD 74 gage at Barracks Lane, the USGS Lemhi River Gage at Lemhi, the USGS L-5 Diversion gage, and the WD 74 gage at L-1 Diversion (DHI, 2003).

4.5.3 Irrigation Nodes

Irrigation Demand - Daily stage data was available for the mainstem diversions in paper format for the simulation period. Accompanying stage discharge measurements were also available to develop rating curves for the stage data. However, due to this data was not processed and therefore, to provide a coarse demonstration of the system, the water right discharge determined by IDWR was routed for the entire irrigation season (Table 4). According to Rick Sager (personal communication 2005), most diversions are operated so that water is continually diverted from late April or May through the remainder of the irrigation season. In most years, the tributaries do not have sufficient flow to satisfy all water rights for the entire irrigation season, so tributary diversion are distributed according to the adjudicated priority dates of each diversion. In the future, the stage data for the mainstem diversions can be input as the irrigation demand.

Ground Water Fraction – Ground water is not used to augment irrigation in this portion of the Lemhi River Basin. This value in all irrigation nodes was set at zero.

Deficit Carryover – At the completion of this project, this model is not being used in an operational mode so the deficit carryover is assumed to be zero.

Return Fraction - The quantity of water returning to the system at the downstream return node is a function of antecedent soil moisture, initial ground water levels, crops irrigated, irrigated area, evapotranspiration rates, distance from the river, ditch loss, and the portion of the infiltrated water that seeps into the intermediate ground water system. The IGW system for these calculations represents the portion of the diverted water that will infiltrate to the subsurface but is not expected to return to the Lemhi River and modeled tributaries, in this particular model, until the next downstream gauging station node.

For the LRMBM, a return fraction calculator was developed in Microsoft Excel to assimilate these factors and compute the return fraction on a daily time step. The return fraction calculator equation is:

$$RF = Demand * DL * IGW_{DL} + (Demand + ER * \sum_{i=1}^{n} A_{CT} - DL - (\sum_{CT=1}^{n} (ET_{CT} * A_{CTS})) * IGW_{IS} + (\sum_{CT=1}^{n} (ET_{CT} * A_{CTF})) * IGW_{IF})$$

RF is the return fraction.

Demand is the diverted water.

DL is the fraction of the demand that is lost to ditch loss.

CT denotes the crop type (pasture, grass hay, and alfalfa hay in the Lemhi River basin); in this equation, this value is constant.

ET_{CT} is the evapotranspiration associated with the crop type.

A_{CTS} is the irrigated area for a crop type for sprinkler irrigation; here, this value is constant.

A_{CTF} is the irrigated area for a crop type for flood irrigation; in this equation, this value is constant.

ER is the effective rain.

n is the number of crop types.

The variables IGW_{DL}, IGW_{IS}, and IGW_{IF} are the portions of the infiltrated flow from ditch loss, sprinkler, and flood irrigation that enter the IGW.

The return fraction equation is simply the mass balance of the water entering an irrigation node. Irrigated area was calculated from the POU coverage provided by IDWR. The crop type was determined from conversations with water masters. For fields irrigated with sprinklers, sprinkler rates were assumed to be 0.75 inches per day per acre (Sager, personal communication, 2003).

To determine the irrigated areas (A_{CT}) associated with each diversion, the POD and POU shapefiles revised by IDWR in February 2006 were linked by water right number. Assignment of the place of use areas of each water right to a point of diversion was confirmed by IDWR personnel.

Most individual points of diversion serve several POUs. For example, a particular diversion may irrigate several fields that are linked by a network of ditches or pipelines. For modeling purposes, multiple places of use associated with an individual point of diversion were aggregated. Precipitation, evapotranspiration, amount of water applied, and losses to ground water were determined for each aggregate polygon. Because some lands receive water from multiple diversions, some polygons overlapped in small areas. For each overlap instance, the area was assigned to only one point of diversion.

Evapotranspiration (*ET*) can be determined by using the Allen-Brockway (A-B) method, Agrimet stations, or SEBAL data. In the original LRMBM, *ET* data from the Corvallis, Montana Agrimet Station were applied to the Lemhi agricultural areas (DHI, 2003). This same approach is applied

Table 4. Summary of the diversions in the LRMBM. Associated with each diversion is the irrigation type, crop type used in the irrigated area, the total diversion amount as specified by the water rights, and the total irrigated area. Note the data is incomplete and reflects May 2006 conditions in therefore it should be used with caution.

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Bohannon Creek MBM Diversions				
LBC-1	?	?	?	?
LBC-2	?	?	?	?
LBC-3	Sprinkler	Alfalfa	9.2 (18)	404
LBC-4	Sprinkler	Alfalfa	7.96 (12)	202
LBC-5	Flood	Grass	4.4	172.5
LBC-6	Sprinkler	Grass	2.11 (10.5)	253
BC-7	Flood	Grass	6.5 (10)	291
BC-8	Flood	Grass	2.46 (10)	473
BC-9	Flood	Grass	0 (2)	0
BC-10 Big Meadow Pivot	Sprinkler	Grass	?	?
BC-11 Wright Bar Pivot	Flood	?	0 (2)	0
BC-12 Millerhill	Flood	Grass	2.5 (5)	74
BC-13 England Pivot	Sprinkler	?	?	?
Wimpey Creek MBM Diversions				
Wimpey Ck-1 Gibson Diversion	Flood	Pasture	0.23	12.1
Wimpey Ck-2 Wilson Diversion	Flood	Pasture	0.16 (2.4)	8.1
Wimpey Ck-3 Jim's Lower	Flood	Pasture	0.25 (0.25)	7.2
Wimpey Ck-4a Jim's Middle	Flood	Pasture	0.25 (3.5)	7.3
Wimpey Ck-4b	Flood	Pasture	0.63 (12.4)	24.3
Wimpey Ck-5 Jim's Upper	Flood	Pasture	1.24 (4.5)	42.5
Wimpey Ck-6 Ward Pump Station 1	?	?	?	?
Wimpey Ck-7 Ward Pump Station 2	Sprinkler	Pasture	0.49	35.7
W. Fork Wimpey-1	Sprinkler	Pasture	0.36 (5.2)	29.4
W. Fork Wimpey-2 Wimpey-Bohannon Transfer	Flood	Alfalfa	11.83	524
E. Fork Wimpey-1 Jay's Lower	Flood	Alfalfa, Grass	0.36 (3.1)	14
E. Fork Wimpey-2	Flood	Alfalfa, Grass	0.12 (3.59)	22
E. Fork Wimpey-3 Jay's Middle	Flood	Alfalfa, Grass	3.59 (8.2)	144

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
E. Fork Wimpey-4 Jay's Upper	Flood	Alfalfa, Grass	1.02 (1.2)	52
Geertson Creek MBM Diversions				
Geertson-1 Santos 2	Flood	Pasture	0.74	51.9
Geertson-2 Santos 1	Flood	Hay	0.3 (4)	51.9
Geertson-3 Olson 4	Flood	Hay	0.8 (0.34)	66
Geertson-4 Olson 3	Flood	Hay	0.34 (2.94)	18.6
Geertson-5 Tonsmire 1	Sprinkler	Hay	2.94 (4)	119.5
Geertson-6 Vergil Olson 1	Flood	Hay	1.49 (5)	40.9
Geertson-7 Olson 2	Flood	Hay	0.23 (0.23)	38
Geertson-8 Antonelli 4	Flood	Pasture	0.23 (0.23)	12.4
Geertson-9 Antonelli 3	Flood	Pasture	0.23 (2.94)	12.4
Geertson-10 Antonelli 2_Olson 1	Flood	Pasture	2.94 (0.23)	183.4
Geertson-11 Antonelli 1	Flood	Pasture	0.23 (0.7)	12.4
Geertson-12 Jolley 3	Sprinkler	Hay	0.7 (0.2)	130.5
Geertson-12 Jolley 3 excess	Flood	Pasture	0.2 (0.5)	36.5
Geertson-13 Martin 4	Flood	Pasture	0.5 (0.5)	23
Geertson-14 Martin 3	Flood	Pasture	0.5 (0.16)	23
Geertson-15 Martin 2	Flood	Pasture	0.16 (1.55)	8
Geertson-16 Jeffery 2	Flood	Pasture	1.55 (1.55)	55
Geertson-17 Jeffery 1	Flood	Pasture	1.55 (6.54)	55
Geertson-18 Martin 1	Sprinkler	Pasture	6.54 (2.77)	1320
Geertson-19 Jolley 1	Flood	Pasture	2.77 (8)	67.2
Gary Cr-1 Jolley 2	Flood	Pasture	0.859 (3)	28
Gary Cr-?? Tarkalson 1	Flood	Pasture	0.341	11
Pratt Creek MBM Diversions				
Pratt-1 Mulkey	Flood	Pasture	1.5 (7.2)	58.7
Pratt-2 Snook	Flood	Pasture	1.91 (8)	106
Pratt-3 Snook	Flood	Pasture	0.15 (3)	12
Pratt-4 Snook	Flood	Pasture	0.5 (8.6)	40
Pratt-5 Moulton	Flood	Pasture	0.6 (7.25)	30
Pratt-6 Moulton	Flood	Pasture	0.59 (2.5)	16
Pratt-7 Moulton	Flood	Pasture	0.29	8
Pratt-8 Moulton	Flood	Pasture	0.36	17
Pratt-9 Moulton	Flood	Pasture	2.05 (6.9)	115

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Pratt-10 Moulton Skinner	Flood	Pasture	13.01	593.3
Pratt-11 Moulton High Water Ditch	Flood	Pasture	3.06 (5.02)	162
Pattee Creek MBM Diversions				
Pattee-1	Flood	Grass	0.46 (8.8)	15.2
Pattee-2	Flood	Grass	0.3	15
Pattee-3	Flood	Grass	5.84 (13.5)	253
Withington Creek MBM Features				
Withington-1 Sager	Sprinkler	Grass	0.5 (1)	3.3
Withington-2 Jakovac	Flood	Alfalfa	1.405	31.6
Withington-3 Peets	Flood	Pasture	0.01 (3.7)	4
Withington-4 Jakovac	Flood	Alfalfa, Grass	1.405 (6.5)	31.6
Withington-5 Colston	Flood	Grass Pasture	0.28 (8.2)	3
Withington-6 Colston	Flood	Grass Pasture	0.28	13.8
Withington-7 Colston	Flood	Grass Hay	0.28 (2.4)	13.8
Withington-8 Colston	Flood	Grass	0.28 (8.2)	13.8
Withington-9 Thomas	Flood	Grass	1.4	26
Withington-10 Thomas	Flood	Grass	1.4 (7.29)	26
Withington-11 Colston	Flood	Grass	0.28 (5.2)	13.8
Withington-12 Thomas	Flood	Grass	0 (7.29)	0
Withington-13 Colston	Flood	Grass	1.36 (7.29)	30.7
Withington-14 Loucks	Flood	Grass	0.21 (1.4)	4.8
Withington-15 Peets	Flood	Grass	0.14 (6.1)	4
Withington-16 Thomas	Flood	Grass	0.76 (1)	34
Withington-17 Thomas	Flood	Grass	0.04 (1.5)	2.9
Agency Creek MBM Diversions				
Agency-1 Naveau	Sprinkler?	Lawn (Grass)	? (1.8)	0
Agency-2 Herbst	Flood	Alfalfa	0.3 (0.15)	15.5
Agency-3 Sells	Flood	Alfalfa	2	64.5
Agency-4 Garrison	Flood	Grass	1.92 (5.4)	37.4
Agency-5 Sells	Flood	Alfalfa	0.39 (5.9)	14.8
Agency-6 Garrison	Flood	Grass	1.99 (3.2)	38.5
Agency-7 Elzinga	Flood	Grass	0.5 (6.2)	23
Agency-8 Loudy	Sprinkler	Alfalfa	1.9 (3.4)	73
Agency-9 Olmer	Flood	Grass	0.19 (2.2)	6.7

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Agency-10 Olmer	Flood	Grass	0.13	4.3
Agency-11 Short	Flood	Grass	0.1 (1.9)	3.55
Agency-12 Short	Flood	Grass	0.13 (2.25)	4.45
Agency-13	Flood	Grass	0.07	3.4
Agency-14	Flood	Grass	0.02	1
Agency-15	Flood	Grass	0.07 (1.4)	3.2
Agency-16	Flood	Grass	0.13 (1.7)	6.3
Cow Ck-1 Sells	Flood	Grass	0.1 (0.25)	4.6
Cow Ck-2 Sells	Flood	Grass	0.25	12.2
Sharkey Ck-1	Flood	Grass ?	0.05 (2.7)	2
Sharkey Ck-2	Sprinkler	Grass	0.49 (2.7)	19
Agency-17 Meyers	Flood	Grass	0.7 (4.2)	12
Agency-18 Meyers	Flood	Grass	0.35 (4.2)	6
Agency-19 Meyers	Flood	Grass	0.35 (1.8)	6
Agency-20 Meyers	Flood	Grass	0.23 (2.7)	11.2
Agency-21 Adams	Flood	Grass	0.14 (2.2)	7.2
White Ck-1 Meyers	Sprinkler	Grass	0.2 (1.2)	10
Sandy Creek MBM Diversions				
Sandy-1 Dunford	Flood	Pasture	0.28	16.2
Sandy-2 Stahl	Flood	Pasture	0.97	13
Sandy-3 Stahl	Sprinkler	Alfalfa, Grass	1.08	80.6
Sandy-4 Crofoot	Flood	Pasture	2.06	76
Sandy-5 Nutt	Flood	Grass	?	?
Sandy-6 Crofoot	50% Flood	Grass	1.97	146
Sandy-7 Fayle	Flood	Grass	2.4	194
Sandy-8 Crofoot	Flood	Grass	1.52	76
Sandy-9 Hanson	Flood	Pasture	?	?
Sandy-10 Hanson	Flood	Pasture	0.735	37
Sandy-11 Hanson	Flood	Grass	1.335 (0.6)	55.25
Sandy-12 Crofoot	Flood	Grass	0.6	18.25
Sandy-13 Crofoot	Flood	Grass	0.125	18.25
Sandy-14 Crofoot	Flood	Grass	0.125	18.25
Sandy-15 Crofoot	Flood	Grass	0.6	18.25
Sandy-16 Lower McConnaghy Ditch	Flood	Grass	1.59	89.2

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Sandy-17 Chartrand	Flood	Pasture	0.44	27.6
Sandy-18 Upper McConnaghy	Flood	Grass	0.83	41.5
M. Fork Sandy-1 Chartrand	Flood	Grass	1	84
W. FORK Sandy-1 Hanson	Flood	Pasture	1.92 (1.6)	98
W. FORK Sandy-2 McNellis	Flood	Pasture	1.6	128
W. FORK Sandy-3 Chartrand	Flood	Grass Pasture	1.72	92
W. FORK Sandy-4 McNellis	Sprinkler	Grass	3	365
W. Fork Sandy-5 Power Plant	Flood	Grass	1	48
Kenney Creek MBM Diversions				
Kenney-1	50% Flood	Alfalfa, Grass	5.83	193.1
Haynes Creek MBM Diversions				
Haynes1-5	Flood	Alfalfa	4.7 (18.5)	240
Haynes-6	Sprinkler	Alfalfa	4.5	147
Haynes-7	Flood	Pasture	1.8	90
Haynes-8	Flood?	Grass?	0.13 (1.5)	5.76
Haynes-9	Flood	Grass	0.205	9.54
McDevitt Creek MBM Diversions				
McDevitt-1	Sprinkler	Alfalfa	1.86	93
McDevitt-2	Sprinkler	Grass	8.48	420
McDevitt-3	?	?	Not Active	?
Kirtley Creek MBM Diversions				
Kirtley-1 Merrit	Flood	Alfalfa, Grass	1.51	65.1
Kirtley-2 Nelson	Sprinkler	Alfalfa	2	155
Kirtley-3 Sheep Shed Ditch	Flood	Alfalfa, Grass	2.1	254.7
Kirtley-4 Raymond Low Ditch	Flood	Grass	5.99	329
Kirtley-5 Raymond High Ditch	Flood	Alfalfa, Grass	1.75	97.5
Hayden Creek MBM Diversions				
HC-1	Flood	Pasture	2.48 (6.4)	91
HC-3	50% Flood	Pasture	4.37 (13.8)	146.6
HC-5	Flood	Pasture	2.39 (8.5)	79.4
HC-7	Flood	Pasture	4.16 (17)	137.9
HC-8	?	Hay, Alfalfa	3.26 (7)	131.6
HC-8a	Flood	Pasture	? (2.3)	?
HC-8b	60% Flood	Pasture	1.77 (6.8)	59

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
HC-9	40% Flood	Alfalfa, Grass	8.43 (15.5)	321.4
HC-10	10% Flood	Pasture	12.85 (14.8)	396.4
HC-11	20% Flood	Alfalfa (30% Grass)	21.43	715.1
HC-13	Flood	Pasture	2.5 (8)	84
E.F. KHC-1	Sprinkler	Pasture (30% Alfalfa)	11.68	250.8
Basin Creek MBM Diversions				
Basin-0	?	?	0.06	3.2
Basin-1	Sprinkler	Pasture	0.32 (?)	15.8
Basin_1A	?	?	0.05 (0.08)	2.3
Basin-2	Flood	Pasture	0.08 (?)	4.2
Basin-3	Flood	Pasture	0.84 (?)	29.6
Basin-4	Sprinkler	Pasture	?	?
Basin-5	Sprinkler	Pasture	?	?
Basin-6	Flood	Pasture	0.1 (4.5)	16
Basin-7	Flood	Pasture	2.82 (?)	141
Basin-8	Flood	Pasture	?	?
Basin-9	40% Flood	Alfalfa, Grass	16.08 (?)	738
Basin-10	Flood	Pasture	1.71	49.5
Basin-11	Flood	Alfalfa, Grass	1.69	85.5
McNutt-1	Flood	Pasture	0.9 (?)	35
McNutt-2	Flood	Pasture	0.39	30
Trail-0	?	?	0.1 (?)	2
Trail-1	?	?	0.55 (?)	30
Trail-2	Flood	Pasture	0.43	29
Grouse-1	Flood	Pasture	0.35 (?)	21
Bear-1	Flood	Pasture	?	?
Bear-2	Flood	Pasture	2 (1)	101
Bear-3	Flood	Pasture	1 (0.34)	21
Lake-1	Flood	Pasture	0.34 (?)	16.7
Dry-1	Flood?	Pasture	?	?
Yearian Creek MBM Diversions				
Yearian-1 Shiner Ranch	Flood	Pasture	0.1 (4.5)	3
Yearian-2 Shiner Ranch	50% Flood	Alfalfa	4.853 (4.5)	182

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Yearian-3	Flood	Pasture	2.4	48
Yearian-4	Sprinkler	Alfalfa, Grass	7.78 (10)	304
Yearian-5	Sprinkler	Alfalfa	2.67 (8.5)	63
Yearian-6 McKinney Reservoir	Sprinkler	Alfalfa, Grass	3	150
Yearian-7 Shiner Reservoir	50% Flood	Alfalfa	?	440
Ditch Diversions added to Lower Lemhi Tributary MBM Model				
L-32	Flood	Alfalfa	?	?
L-32 Pivot	Pivot	Alfalfa	3.8	209.8
Sandy Slough-1	Flood	Pasture (?)	?	?
Sandy Slough-2	Flood	Pasture (?)	1.76	88
L-9a	Sprinkler	Alfalfa	?	-
L-9b	Sprinkler	Alfalfa	11.04	349

* Irrigation types found in the Lemhi River Basin are flood, sprinkled, or pivot. If it states 70% flood, the other 30% is assumed to be sprinkled.
** The values in parentheses are the high flow water rights in cfs.

to the modeled tributaries. SEBAL (the Surface Energy Balance Algorithm for Land) was used to determine ET rates for the Lemhi River POU's for the 2001 irrigation season during the development of the original LRMBM (DHI, 2003). Although time constraints prevented the incorporation of this data into the MIKE BASIN model, such data may be useful for future studies. Efforts could also be made to use the SEBAL technique to develop ET rates for irrigated areas along tributary streams.

Conveyance loss or ditch loss (*DL*) is the loss of water during transport from the POD to the POU. Water is lost through seepage through the soil, leakage through headgates and other structures, evaporation from the water surface, and transpiration from plants growing in or near the channel. For the soil loss, a calculator was developed to implement the Worstell Method seepage loss estimation (Hubble, 1991), a method commonly used by IDWR. This method requires an estimation of the soils seepage rate, measurement of the top width of the water surface at various points along the canal, and the canal length. The estimated seepage loss is multiplied by the canal length (miles) to determine the canal's total conveyance loss. Tables in the *Guidelines for the Evaluation of Irrigation Diversion Rates* (Hubble, 1991) are useful in determining soil textures and the appropriate seepage rates. Conveyance losses were not calculated in the original or 2006 LRMBM. Rather, such losses are accounted for by specifying reach gains and losses.

For the mainstem Lemhi River, the intermediate ground water portion (*IGW*) of the *return fraction* is added to the reach gains and losses because previous studies have shown that the Lemhi is primarily a gaining river (Donato, 1998). Thus, in the LRMBM, all water entering IGW will return to the river in the next downstream reach gain/loss (DHI 2003). A calibration parameter in the LRMBM is the *IGW*. For subsets of the LRMBM where stream flow and diversion flow are measured (along the mainstem Lemhi River), the IGW was used to adjust the water balance to best match observed discharges. For the tributaries where stream flows and diversion are not measured, the *IGW* was set at 0.10, which was the average of the mainstem Lemhi River water user nodes. These factors can be calibrated at a the time when stream and diversion flows have been measured.

Lag Time - Timing of return flows from irrigated lands to the Lemhi River and modeled tributaries depends on the irrigated field's location in relation to the closest water, the degree of channel surface flow returns, and ground water flow direction and rate. In MIKE BASIN, one option for delaying the return flow is by using a linear reservoir equation (DHI 2006). The user can specify the lag time to control the timing of the return fraction. In the original LRMBM, lag times vary for each irrigation node along the mainstem Lemhi and were used to calibrate the model. For the 2006 LRMBM, lag times are re-computed for each Lemhi River diversion as part of the calibration process. Due to a lack of data, tributary diversions were assigned a universal lag time of 7 days which can be refined later when more data is available.

4.5.4 Reservoir nodes

For the standard reservoir, the time series information required includes bottom, crest, spillway, top of dead storage, and minimum operation pool elevations; minimum and maximum valve releases; precipitation, seepage loss, and evaporation; and flood control and operational rules levels for any water users attached to the reservoir. Though not a time series, the height-volume-area relationship describing the reservoir bathymetry is additional input information required for the model. For the 2006 LRMBM, all the reservoirs had default time series data and the reservoirs do not store stream flow. These data can be replaced with real data at a later date.

4.6 Irrigation Flow Water Rights

In order to sort out the river network and obtain irrigated area and water rights flow amounts for each irrigation node, IDWR and DHI conducted an extensive review of the water right records and POD/POU coverages for each node in the model. The result is a good inventory of the area, use rate, and water right data with each irrigation node (Table 4). In addition to supporting this modeling endeavor, the water rights inventory is expected to assist IDWR staff in the adjudication of the Lemhi River Basin (Basin 74).

4.7 Microsoft Excel Interface

To expedite the processing, formatting, and entering of data into the model, as well as the calibration and running of scenarios, DHI personnel developed a series of Microsoft Excel files and associated macros that interface with the LRMBM. These files and macros provided a more user-friendly platform and helped automate repetitive tasks, organize the data, and prevent errors in data handling. Important Microsoft Excel files include:

- *LRMBMInput.xls* – Organizes the input data for all the irrigation and catchment nodes. For the irrigation nodes, the workbook contains the daily values for the demand and return fraction. This workbook contains the return flow calculator and macros that automatically load the data into the proper LRMBM input files. Parameters needed for the return flow calculator include irrigated area, percent sprinkled, percent of each crop type that is flood and sprinkler irrigated, the sprinkler irrigation rate, and ditch loss. This workbook should be used when running scenarios where diversion schemes are altered and need to be loaded into the LRMBM. Macros automate the loading of the time series in the Microsoft Excel file into the appropriate MIKE BASIN time series files. The macro supports both daily and monthly time steps.

- *LRMBMCalib.xls* – Assists in model calibration. The files run repetitive MIKE BASIN simulations for calibration, load results from previous simulations for viewing, load the results into the comparative analysis with the 1999 Lemhi River and its tributaries seepage run, and calculate reach gains used in the first calibration effort for the LRMBM. Macros automate the loading of the time series in the Microsoft Excel file into the appropriate MIKE BASIN time series files.

5 COARSE DEMONSTRATION OF THE LRMBM

A course demonstration of the LRMBM was created for public demonstration purposes and to ensure the model was correctly constructed. The model incorporates the mainstem and 14 tributaries. At this phase, the LRMBM is missing required times series data and remains uncalibrated for the tributaries. Except for conceptual demonstration, no results should be used from the model until the proper data has been input and the LRMBM calibrated. The course demonstration can be used to demonstrate the capabilities of the model and is a repository for the current data available.

Because the gage data along the Lemhi River is sparse, two accuracy zones have been identified to characterize model results. High accuracy zones are between a gage and the next downstream node where irrigation returns flow into the Lemhi River. Here, inflows and outflows are explicitly defined. Therefore, the unknown calibration variables for ground water fraction and lag time can be estimated more accurately. With well-known reach gains and losses, the calculated in-stream flow should be quantitatively accurate.

The remainder of the Lemhi River and the tributaries belongs in the low accuracy zone. Calculated in-stream flows should be used only to determine trends in the influence of operations on flows; they should not be used to quantify flow at specific points in the river. Flow indicated by model results in low accuracy zones may be much less or much greater than what the actual result would be for a specified operation. Additional gaging station records in the mainstem of the river would provide additional reference points. The reference points can help better define inflows and outflows and improve model results.

Given the assumptions for the inflow and diversions along the tributaries, calibration tools in LRMBMCalib.xls will aid IDWR in recalibration of reach gains/losses of the mainstem. Once the tributaries have diversion data, similar procedures can be conducted to determine their reach loss/gain and lag time can be calibrated. Note that not all tributary watersheds need be calibrated at once. Based on importance, individual tributary watersheds can be calibrated as needs and data dictate.

6 LIMITATIONS ASSOCIATED WITH ADDING TRIBUTARIES TO THE LRMBM

There are limitations and uncertainties associated with any modeling endeavor. In this project, the primary sources of uncertainty arise from a lack of data for tributary inflows and diversion practices. In addition, the inherent complexity of the irrigation network (e.g., commingled ditches and tributaries) makes it difficult to accurately track some diversions from their original offtake points to their ultimate return flow destinations. In this section limitations associated with modeling tributary diversions are discussed.

- *Lack of data describing catchment inflows* – There are 14 modeled watersheds downstream of McFarland Campground comprising a total of 28 modeled tributary streams. Of these 28 streams, only 4 had actual gage data (Kenney Creek, Agency Creek, Hayden Creek and Bohannon Creek). Futhermore, the gaging period for some tributaries is quite short (e.g., less than 1 year of data) and some of the gaging sites were downstream of diversions (e.g., the Hayden Creek gage is near its confluence with the Lemhi). In order to obtain inflows for each tributary, IDWR used the USGS's StreamStats (2006) which calculates specific runoff based on statistical relationships from other nearby gaged basins. There is some uncertainty associated with StreamStats because the program estimates the physical characteristics of the site based on topography, hydrography and data from nearby gaged sites. While some of the physical characteristics (e.g., drainage area, stream slope) can be easily estimated from GIS datasets, other parameters (e.g., mean annual precipitation) can vary widely across the Lemhi Valley due to topography. In addition, the empirical basis for the StreamStats limits the lower range range of the catchment sizes that it can accurately predict (typically basins under 2 square miles are not represented as well as larger basins). Extrapolating outside of the range may result in unrealistic predictions. Finally, while the regression equations may provide valid estimates of runoff, actual inflows will likely vary from the estimated values due to temporal and spatial variability in weather patterns, soil types, forest canopy, and orographic effects. However, applied correctly, the USGS StreamStats provides a good first order tool for approximately monthly inflows.

- *Lack of data describing diversion practices* - In the current LRMBM, the diversions along the tributaries are simulated by assuming that each water user takes their full decreed amount each day of the irrigation season. In actuality, diversion demands may fluctuate daily or weekly depending on weather patterns, crop needs, and other farming practices. In order to better simulate irrigation diversions on tributary streams, daily records of water usage for each diversion would aid in the calibration of the model. Such records are typically kept by water masters, but the data quality and temporal resolution of such records can vary widely between water masters. Despite differences in data quality, it would be instructive to use these records to create more realistic time series depicting actual daily water usage for each diversion.

  In many locations along the lower reaches of tributaries, water users rely upon multiple water sources to satisfy their irrigation demand. As such, the amount of water diverted from each source will vary daily and seasonally depending on where water is needed and the availability of water from each source. Examples of this type of scenario occur along the lower reaches of Kirtley Creek where Lamar Cockrell can draw upon Kirtley Creek water or flows from the L-9 Ditch (which also include Geertson Creek water). Water users along the lower reaches of Haynes Creek also rely upon multiple sources of water as they can use water from the Lemhi River (via the L-30Z Ditch) and Haynes Creek.

- *Complexity of physical network* - The irrigation system in the Lemhi River Basin consists of a complex network of ditches, tributary streams and ditches, and return drains in the tributary basins and along the Lemhi River. Irrigation water is frequently reused several times as return flows from one field are captured in ditches for use on lower fields. This system results in commingling of irrigation waters which can be difficult to track. Examples of commingled irrigation waters occur when a ditch intercepts a tributary (e.g., Sandy Slough captures Sandy and Pratt Creeks plus return flows from both creeks thus water users along Sandy Slough divert water from a variety of possible sources). Commingling also occurs when a ditch intercepts another ditch, which happens frequently along the Lemhi Valley floor and results in very long return flow paths. While we attempt to capture this reuse for the Sandy Slough and the L-9 Ditch, other systems are lumped into a single use node with a single return path where the recycling is represented by a single return path.

  Ground water plays an important role in the Lemhi irrigation system because much of the water from flood irrigation seeps into the shallow subsurface, flows down slope, and supplies water to down slope fields. There are also instances where the lower portions of some tributaries run dry for short reaches (e.g., lower Agency Creek). This occurs due to low flows or when upstream water users divert all available flow. In such places, it is most likely that any remaining stream flow will seep into the cobbly gravel bed and the creek will run dry for a short distance before the water re-emerges from the ground and creates surface flow.

  Ground water is not modeled explicitly in this version of the LRMBM. Along the mainstem Lemhi River diversions, ground water is accounted for by adjusting lag times on return flow paths. In places where return flows follow subsurface flow paths, the lag times will be greater than for places where return flows return to the stream via overland flow paths. For the tributaries, lag times were not computed due to insufficient data. However, DHI and IDWR personnel did make notes indicating the estimated return flow times as recorded during meetings with water masters. Where available, such notes are included in the LRMBMInput.xls.

- *Limitations with network models* - A computer model of a river network is a simplification of the real-world physical system. The model is intended to represent the significant functions and inter-relations that occur in the natural system. However, no model can represent all the intricate details of the processes and inter-relations that could occur in a real-world system.

  Network models are insufficient for answering physically-based questions such as flood propagation and attenuation, flood extent, ground water-surface water interactions distributed over the landscape, and stage within the river. To address these questions, a one- or two-dimensional physically-based model, such as MIKE 11 or MIKE 21, for surface water, and MIKE SHE, for ground water-surface water interaction, would need to be employed. While these models could be used to answer physically-based questions in the Lemhi River basin, they do require more input data, setup, and computational time. For the questions being proposed in this project, the added modeling complexity associated with these physically-based models was unnecessary. Furthermore, the additional detailed data required for these physically-based models were not available at the completion of this phase of the LRMBM.

If physically-based questions need to be addressed for the Lemhi River system, and if one of these models is under consideration for evaluating these questions, an analysis of costs and time required to obtain the necessary field data need by the model should first be completed.

7 RECOMMENDATIONS FOR FURTHER DEVELOPMENT OF THE LRMBM

Though IDWR and DHI personnel completed the initial phase of adding tributaries to the LRMBM, incomplete data will require additional analysis and data collection to develop a calibrated model. These recommendations for developing a basic, calibrated model and do not reflect any additional data and analysis that may be required to address specific questions posed to the model in the future. However, implementing these recommendations will provide greater insight into water movement in the Lemhi River and its tributaries, and thus can provide a greater foundation for the LRMBM.

7.1 Data Collection

The quantity and location of data collection will be a function of time, budget, and the questions users would like to address using the LRMBM. As the limiting element in the calibration of the LRMBM is the stream flow and diversion discharge time series information, these are of utmost importance for development of the model. Specific data needs are:

- *Daily inflow rates for all the tributaries* – Ideally, stream flow gages would be installed on each modeled tributary upstream of any diversion. This gage would provide measurements of actual inflows to the tributary and thus could be used to calibrate the rainfall-runoff model or StreamStats analysis.

  If permanent gages cannot be established on all the tributaries, a method must be devised that combines stream gaging on select tributaries with statistical means of extrapolating the record to other basins. For example, a statistical relationship could be developed between observed flows on gaged basins and StreamStats estimates for the same basin. This relationship could then be applied to other similar, ungaged basins in order to 'adjust' the Streamstats estimate to better account for local hydrologic conditions.

- *Stream gauging upstream and downstream of sensitive areas on tributaries* – The original LRMBM accounted for contributions to the Lemhi River from precipitation, ground water gains/losses, and tributary inflow by modeling reach gains/losses. This same approach has not been applied to the tributaries due to lack of discharge data for the tributaries. However, it would be highly instructive to have gages installed below sensitive reaches where flow is a limiting factor to fish habitat. Such reaches could be identified by IDWR and other agencies and the data could be used to model reach gains and losses do to natural and anthropogenic impacts.

- *Daily diversion discharge* – Operation of the diversions significantly influences flow in the modeled tributaries. Because the total natural discharge to these streams is typically minimal, the diversions typically cause the tributaries to go dry during much of the irrigation season. In order to more accurately model the tributary diversions, daily measurements of discharge should be measured for each diversion. The discharge can be measured directly using a structural measuring device, such as a weir or flume, or indirectly by measuring water level from a staff gage or measured with a pressure transducer. If the water level is obtained, a stage-discharge rating curve is necessary to convert the stage records to discharge.
- *Use of METRIC data in the return flow calculation* – To determine the consumption rate in the LRMBM, the ET rate is based on the reference ET data from Corvallis, Montana. IDWR currently calculates the actual ET rate throughout the Lemhi River Basin from satellite imagery. It is recommended that the calculated ET rate replace the reference ET rate to improve accuracy of the agriculture nodes.

7.2 Modeling

The primary modeling tasks that need to be completed involve populating the tributaries with inflow and diversion data and calibrating the entire model. Calibration involves adjusting the lag times and IGW values to attempt to match the simulated and observed discharges for each tributary. Once the tributaries are calibrated, the mainstem Lemhi River will need to be re-calibrated in order to account for the revised tributary inflows. The Microsoft Excel file LRMBMCalib.xls has been developed to aid in this process.

If the analysis is found limiting due to precision of diversion operation for water users receiving water from multiple sources, the secondary modeling task would be to refine the model network to include the complex ditch systems in the Lemhi River Valley. In 2006, only the L-9 and L-32 Ditches are explicitly modeled, and these systems were implemented using simplified rules to distribute water among tributaries, ditches, and diversions. A more refined approach might involve implementing a more detailed distribution system where actual time series data is used to create rules or explicitly distribute water among multiple diversions.

The reservoir time series and height-volume-area data are placeholders at the end of 2006 phase of modeling. The operational rules and bathymetric data will need to be included to include the reservoirs in the analysis.

7.3 Additional Analysis

Analysis not crucial to development of a calibrated model, but would increase the understanding of water movement in the basin is studies of precipitation, seepage runs, and ground water.

- *Precipitation analysis* – Currently precipitation is incorporated into the LRMBM as reach gains along the mainstem Lemhi River and the tributaries. However, early in the irrigation season when large frontal storms enter the basin, stream flow may be influenced. In the original LRMBM, it was proposed that "local design storms" could be developed to account for the temporal and spatial distribution of these large storms. Here, we propose that the precipitation analyses be extended to the modeled tributaries so that precipitation from large storms can be added to reach gains for each tributary.

- *Seepage runs on selected tributaries* – A concurrent seepage run and simulation on selected high-priority tributaries would provide greater foundation for calibrating and refining the LRMBM. Seepage runs are recommended at both the onset of the irrigation season when flow in the Lemhi River and its tributaries diminishes and late in the irrigation season during low-flow.

- *Ground Water* – Ground water levels and return periods are important in dictating the instream flows during the spring runoff period and late summer and early fall when the snowmelt contribution is negligible. In the LRMBM, the parameters most affected by the ground water-surface water interaction are the initial abstraction early in the irrigation season and IGW lag time later in the irrigation season. Further analysis of ground water well hydrographs, sensitivity of the initial abstraction duration and magnitude, and IGW lag time would improve the model representation of the natural system. Coupling ground water analyses with field studies, such as seepage runs or piezometer studies, could further improve the understanding of ground water behavior in both the Lemhi River and its tributaries.

8 CONCLUSIONS

From October 2005 through June 2006, IDWR and DHI personnel extended the original Lemhi River MIKE BASIN model to include 14 tributaries downstream of McFarland Campground. The surface water budget model is developed in MIKE BASIN, a river network model that is based on an ArcGIS platform. In general terms, MIKE BASIN is a mathematical representation of the river basin encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing as well as potential major water use schemes and their various demands for water.

This project has resulted in the development of calibrated mainstem LRMBM with skeleton surface water budget models for the 14 tributary basins. DHI and IDWR have worked carefully to ensure that the tributary connections to the Lemhi River and key ditch systems are accurately represented in the model by conferring with local stakeholders familiar with the water movement in the Lemhi River Basin. As part of the model development, DHI assisted IDWR with clarifying the complex water rights and diversion schemes that comprise the lower Lemhi irrigation system. Although the portion of the LRMBM representing the tributaries is in development, this project has provided a solid foundation for better understanding diversion practices in the lower Lemhi River Basin and a guide for future data collection efforts.

Developing the LRMBM involved building the river network and compiling, computing, formatting, and inputting the data. The river network configuration primarily reflects water masters knowledge of the Lemhi River and its tributaries. The LRMBM encompasses the Lemhi River downstream of McFarland Campground to its confluence with the Salmon River near Salmon Idaho. Selected tributaries are also included in the model including: Yearian, Hayden, McDevitt, Agency, Pattee, Kenney, Sandy, Pratt, Wimpey, Bohannon, Geertson, Kirtley, Haynes, and Withington Creeks.

The model network has 240 offtake nodes along the Lemhi River and its tributaries and 244 irrigation nodes representing the irrigated area associated with the offtake nodes. Multiple irrigation nodes are used on several offtake nodes where water is applied in several distinct locations and the water allocation to those separate fields has been determined. Return locations for each irrigation node represent the downstream location where the majority of the return fraction is believed to have returned to the Lemhi River and select tributaries. Catchment nodes at the upstream end of the Lemhi River and selected tributaries represent direct flow input into the model.

Model data required for this project includes stream gage records; daily discharge data for each diversion; reservoir physical characteristics and operational rules; and irrigated area, *ET* rates, crop type, and area serviced by sprinkler irrigation within each irrigated area. At the completion of 2006 model development effort, there were insufficient time series data to develop a calibrated model for the entire model area. Although the original LRMBM containing only the mainstem Lemhi River had been calibrated (DHI, 2003), the 2006 LRMBM is more extensive spatially and therefore requires a substantial amount of additional data in order to develop a defensible calibration.

In addition to the MIKE BASIN model of the lower Lemhi River and its tributaries, DHI developed a set of Microsoft Excel workbooks to assist IDWR with future model developments. These workbooks include: a file that will automatically generate empty time-series files with the appropriate names and a file to assist in calibration, calculate return flows, and load reach/gain data into the time-series files.

At this phase of the project, the LRMBM is not calibrated as there are numerous data gaps and uncertainties associated with the time series used for the tributary diversions and tributary inflows. Once these issues are resolved, the model can be calibrated; a process that can be expedited using the dedicated Microsoft Excel. Upon calibration, these tools will also enable the user to evaluate operation plans by viewing the simulation results with a GIS background that can show the river, points of diversion and return flows, irrigation canals, and canal service areas superimposed on aerial photography of the area. An additional advantage to the Microsoft Excel interfaces is that users with little operational knowledge of MIKE BASIN can run scenarios directly from Microsoft Excel and can use MIKE BASIN as the computational kernel instead of having to interact directly with MIKE BASIN.

Though IDWR and DHI personnel completed this second phase of the LRMBM development, additional analysis and data collection are needed to develop a fully calibrated model. Further data collection for stream and diversion flow is essential to accurately quantify water movement throughout the basin. Areas of concern where data is limited or poorly understood should receive additional stream flow measurements. Additional data and information describing water use along commingled diversions (e.g., lower Haynes Creek, Sandy Slough) would also be instructive.

The LRMBM is a dynamic model that can be refined and expanded as data becomes available and as new questions are identified. The LRMBM's first phase of development involved the construction of a calibrated MIKE BASIN model for the mainstem Lemhi River. In this second phase, the model was extended to include 14 tributary basins and key ditch systems. With additional data this extended model can be used to demonstrate how the irrigation diversions along the Lemhi River and its tributaries can be operated to meet stream flow targets.

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DEVELOPMENT OF A MIKE BASIN MODEL FOR THE UPPER LEMHI RIVER BASIN: A TOOL FOR EVALUATING STREAM FLOWS, DIVERSION OPERATIONS AND SURFACE WATER-GROUND WATER RELATIONSHIPS

1 INTRODUCTION

This document describes the initiative by the Idaho Department of Water Resources (IDWR) to develop a surface water budget model for the Lemhi River, Idaho. A MIKE BASIN model for the mainstem Lemhi River downstream of McFarland Campground was previously developed by DHI, Inc. (DHI) personnel in 2003. In the spring of 2006, this existing Lemhi River MIKE BASIN Model (LRMBM) was extended to include selected tributary basins which enter the Lemhi downstream of McFarland Campground, (e.g., the lower LRMBM). In this phase of the project, the LRMBM was extended to include the upper Lemhi River and selected tributaries upstream of McFarland Campground. In this text the term ‘upper LRMBM” to the network upstream of McFarland Campground. This upper LRMBM also includes a ground water model to account for the interaction between subsurface flows and surface water diversions and rainfall-runoff modeling in order to predict inflows for the modeled tributaries. The upper LRMBM was merged with the lower LRMBM in order to create a comprehensive watershed model for the entire Lemhi River watershed. This 2006 LRMBM will enable IDWR and other stakeholders to better quantify and represent sources and uses of stream flow throughout the entire Lemhi River Basin. This report documents the process by which the upper LRMBM, together with the ground water model and the rainfall-runoff models, was developed. The report also documents the merging of the upper and lower LRMBM and summarizes the status of the various modeled components.

Model construction occurred from February to June 2006. During this period, IDWR and DHI personnel worked to build the LRMBM for the mainstem Lemhi River and 12 tributaries, compile and populate the model with available data, and identify data gaps. The model consists of a defined network for the upper Lemhi River and each tributary basin, data files ready for population with data, developing rainfall-runoff and ground water models, and customized supporting spreadsheet files for processing and loading data and aiding in the calibration of the model. The result is a “skeleton model” of the upper Lemhi River and tributaries which can easily be populated with actual diversion data. A calibrated model was not possible at the conclusion of this phase due to insufficient stream flow and diversion data throughout the basin. Once the tributary inflow and diversion data have been collected and the tributaries have been calibrated, the model described herein will be able to evaluate mainstem and tributary diversion operations throughout the upper Lemhi River Basin.

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

- A brief description of the numerical model used for the demonstration
- Summaries of data and assumptions used in the model setup

- Description of the ground water model
- Description of the rainfall-runoff model
- Limitations to the modeling effort
- Data gaps to be filled
- Recommended studies to further refine the model.

Appendices A and B describe the ground water and rainfall-runoff model in greater detail. As this report supplies a summary of the activities for adding the tributaries to the original LRMBM, much of the background material for the modeling effort can be found in *Evaluation of Diversion Operation Plans to Meet Negotiated Flow Targets for Salmon and Steelhead in the Lemhi River Basin Using the MIKE BASIN Model* (DHI, 2003).

2 BACKGROUND

The State of Idaho, local landowners and irrigators, NOAA Fisheries, the U.S. Fish and Wildlife Service, and a number of other local, State, and Federal agencies developed a Conservation Agreement to outline measures for landowners and water users in the Lemhi area that would conserve and restore fish species listed under the Endangered Species Act. Some of these measures focus on improving stream flow during the spring runoff period and improving the hydrological connection between the Lemhi River and its tributaries. Currently, IDWR is coordinating with other agencies to improve fish passage and minimum flows on Eighteenmile and Big Timber Creeks (Morgan Case, personal communication 2006). MIKE BASIN will be used to evaluate various strategies such as water conservation and leases in order to determine the most optimal method of improving fish passage while minimizing the impact to irrigators.

During average and wet runoff years, the mainstem of the Lemhi River generally provides enough water for year-round upstream and downstream migration of salmon and steelhead. However, in dry years, there is not always enough instream flow during the spring runoff and during the irrigation season in a short reach of the river at the L-6 Diversion. Furthermore, the lower reaches of many of the tributaries run dry, or nearly dry, for much of the summer in low flow years due to a combination of upstream diversions and minimal inflows from headwater areas (Idaho Department of Fish and Game (IDFG), in preparation). Without sufficient tributary flows, migrating salmon, steelhead and bull trout are unable to reach spawning habitat along the upper reaches of tributaries. In cases where spawning has successfully occurred along tributaries, low flows may block salmon, steelhead trout and bull trout fry from accessing rearing habitat in the Lemhi River (IDFG, in preparation).

Water management along the mainstem upper Lemhi River and its tributaries is a critical issue because the Lemhi River Basin is a semi-arid environment and there is a limited supply of water available to satisfy the needs of irrigators and endangered fish species. The physical network of the Lemhi River irrigation system lends complexity to water management because the irrigation system is composed of a network ditches and diversions that often intersect tributaries, tributary diversions or other Lemhi River diversions. In addition, several tributary basins in the upper Lemhi River Basin are “inactive water basins” that are not actively managed by local water masters and thus there is uncertainty about the use of diversions along these streams (Morgan Case, personal communication, 2006).

Irrigation water causes ground water levels to rise seasonally (Donato, 1998) as many irrigators along the upper Lemhi River Basin and its tributaries open their diversions to fill their canals and soak their fields during high flows (Rick Sager and Thomas Udy, personal communication 2006). It is widely believed that this shallow ground water storage is slowly released back to the Lemhi River which sustains stream flows later in the irrigation season (e.g., Rick Sager, personal communication 2005). Water masters and water users did not identify return flow paths for flood irrigated fields situated atop the terraces. When queried about this, the water users indicated that return flows from such fields were often negligible because there was often a great deal of ditch loss associated with long earthen ditches, evapotranspiration rates could be quite high on the large, open fields, and any available return flow was likely used in lower fields or absorbed into the ground.

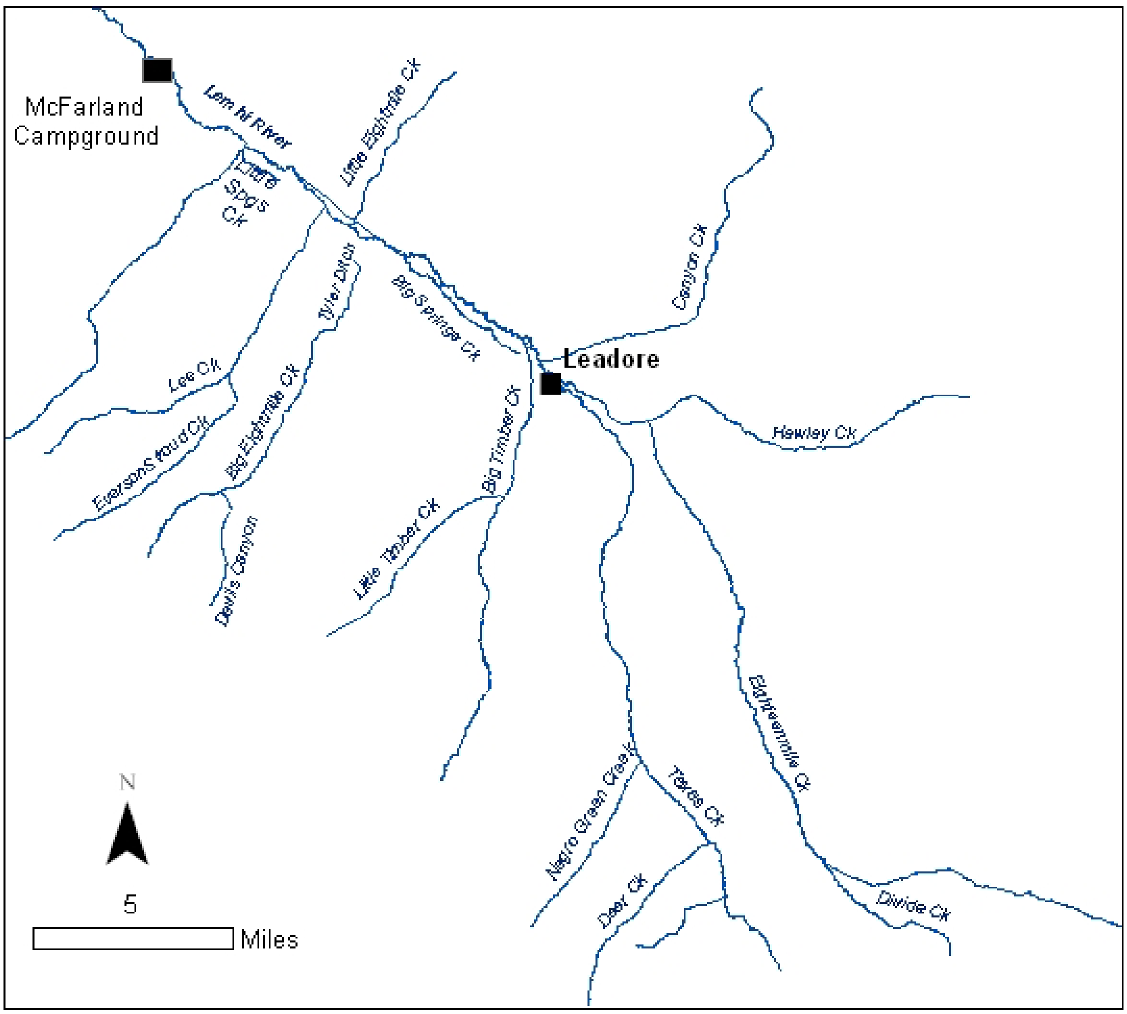

Figure 1. Upper Lemhi River Basin (Basin #74). The study reach extends upstream from McFarland Campground to the headwaters of the Lemhi River near Leadore, Idaho. Included in the model network are 12 tributary basins including: Little Springs, Big Springs, Mill, Lee, Big Eightmile, Big Timber, Little Timber, Texas, Eighteenmile, Hawley, Canyon, and Little Eightmile Creeks.

In order to better understand and manage the complex water resources within the Lemhi River Basin, IDWR is developing and using new technologies such as Geographic Information System

(GIS) GIS and watershed modeling tools. IDWR is using GIS to assist with prioritizing watersheds while MIKE BASIN is being used to understand water allocation in river basins. MIKE BASIN is surface water budget tool that IDWR and other stakeholders will use to:

- Evaluate watershed priorities
- Move forward with existing water transaction proposals
- Develop new water transactions with special focus on Basin 74
- Implement monitoring and evaluation processes.

3 MODEL USED: MIKE BASIN

MIKE BASIN is an integrated water resource management and planning computer model that integrates a GIS with water resource modeling (DHI, 2006). This gives managers and stakeholders a framework within which they can address multisectoral allocation and environmental issues in a river basin. In general terms, MIKE BASIN is a mathematical representation of the river basin, including the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing as well as potential major water use schemes and their various demands for water.

MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. Branches represent individual stream sections while the nodes represent confluences, diversions, locations where certain water activities may occur (municipal, industrial, reservoir, and hydropower water uses), or important locations where model results are required. The river system is represented in the model by a digitized river network that can be generated directly on the computer screen in ArcMap 9.1 (a GIS software package). All information regarding the configuration of the flow simulation network, location of water users, reservoirs and intakes, and outlets of return flow are also defined by on-screen editing.

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

In MIKE BASIN, reservoirs and lakes can be modeled using three methods: standard reservoir, allocation pool reservoir, and lake. For the reservoirs, the performance of specified operating policies using associated operating rule curves can be simulated. Rule curves define the desired storage volumes, water levels, and releases at any time as a function of existing water level, the time of the year, demand for water and possibly expected inflows. For periods of drought, release from reservoirs can be reduced a certain factor for each of several critical (also termed reduction) water levels. The lake method has no operation rules, but a water level-dependent outflow. All methods take into account evaporation, direct precipitation, and leakage losses.

The standard reservoir and allocation pool reservoir methods differ in the accounting of the water available to downstream users. The standard reservoir method, all water users draw water from the same storage volume and operation rules regulate the water user's extraction from the storage pool. The allocation pool reservoir is similar in that water is drawn from a storage volume and operation rules regulate the water user's extraction from the storage pool. However, the allocation pool method subdivides the storage by user's storage right. An accounting procedure keeps track of the actual water storage in one pool for downstream minimum flow releases and in the individual pools allocated for water supply.

The MIKE BASIN Ground Water Module (GW) is a conceptual model of an aquifer that interacts with surface water resources via the following fluxes: stream seepage (river to aquifer), ground water recharge (catchment to aquifer), and ground water discharge (aquifer to river). While the first two fluxes must be specified by the user (as time series), ground water discharge is a hydraulic response and as such computed within MIKE BASIN. The underlying conceptual hydraulic model is the linear reservoir model with one or two aquifers (fast/slow response). Ground water users can impact the behavior of the linear reservoir through pumping (aquifer to user). In the MIKE BASIN GW, ground water sources can be limited in quantity allowing for conjunctive use studies. A full discussion of the MIKE BASIN GW and its application in the LRMBM are presented in Appendix A.

The MIKE BASIN Rainfall-Runoff Module (RR) uses the NAM model: a lumped, conceptual rainfall-runoff model simulating overland flow, interflow and baseflow as a function of the moisture content in each of four mutually interrelated storages: snow storage, surface storage, root zone storage, and ground water storage. Given rainfall and evaporation data, NAM calculates a runoff time series that is automatically assigned to MIKE BASIN for use in the river flow simulation. A full discussion of the MIKE BASIN RR and its application in the LRMBM are presented in Appendix B.

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

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

MIKE BASIN has additional capabilities, including the ability to simulate municipal, industrial, and hydropower water users; and simulate transport and degradation of substances affecting water quality in rivers and reservoirs. Water quality substances that MIKE BASIN simulates include ammonia/ammonium, nitrate, oxygen, total phosphorus, and organic matter. Organic matter is represented in terms of biological oxygen demand and chemical oxygen demand.

4 UPPER LEMHI RIVER MIKE BASIN MODELING METHODS

Building the upper LRMBM involved expanding the river network to include the mainstem Lemhi upstream of McFarland Campground and the tributary basins; compiling, formatting, and inputting the available data for the tributaries; and developing customized Microsoft Excel spreadsheets. The model network has the following criteria:

- Upper LRMBM encompasses the Lemhi River upstream from McFarland Campground as well as 12 tributary basins (Figure 2) including Little Springs , Big Springs, Mill, Lee, Big Eightmile, Big Timber, Little Timber, Texas, Eighteenmile, Hawley, Canyon, and Little Eightmile Creeks (Figures 3-8).
- The original LRMBM network was extended approximately 14 miles upstream to include the headwaters of the Lemhi River. All diversions and water users were also added to the model so that the current model includes all diversions along the mainstem Lemhi River from the L-1 Diversion to the L-62 Diversion.
- Model simulations are run on a daily time step from 128 offtake nodes along the Lemhi River and its tributaries and 129 irrigation nodes (representing the irrigated area associated with the offtake nodes).
- Multiple irrigation nodes are used in diversions along the mainstem Lemhi River where water is applied in several distinct locations and the water allocation to those separate fields has been determined.
- Return locations for each irrigation node represent the downstream location where the majority of the return fraction is believed to have returned to the Lemhi River and its tributaries.
- Reach/gain loss time series were attached to the branches upstream of the 3 stream gage sites along the mainstem Lemhi River and 4 locations along tributaries represent points where reach gains/losses can be incorporated (Table 3).
- The model is currently populated with predictive (tributary inflow) and idealized (diversion demand) data, but all the appropriate time-series files have been created and are associated with each model feature. Actual stream flow and diversion amounts are available from stream gages and mainstem diversions, respectively. DHI has created customized Microsoft Excel sheets that will automatically upload diversion data into the MIKE BASIN model.
- DHI has developed an inventory of water-rights, diversion amounts, crop types, irrigation types and comments for each modeled water user on the 12 tributary watersheds. For the mainstem Lemhi, a list of comments, irrigation type and crop type was prepared.
- Ground water models have been created for Big Springs Creek (Figure 8) and Little Springs Creek (Figure 7). Once refined, the ground water model can be extended to the entire upper Lemhi River Valley floor (Appendix A).
- Rainfall-Runoff modeling was conducted to predict catchment inflows for the 18 tributaries entering the upper Lemhi River Basin (Appendix B).

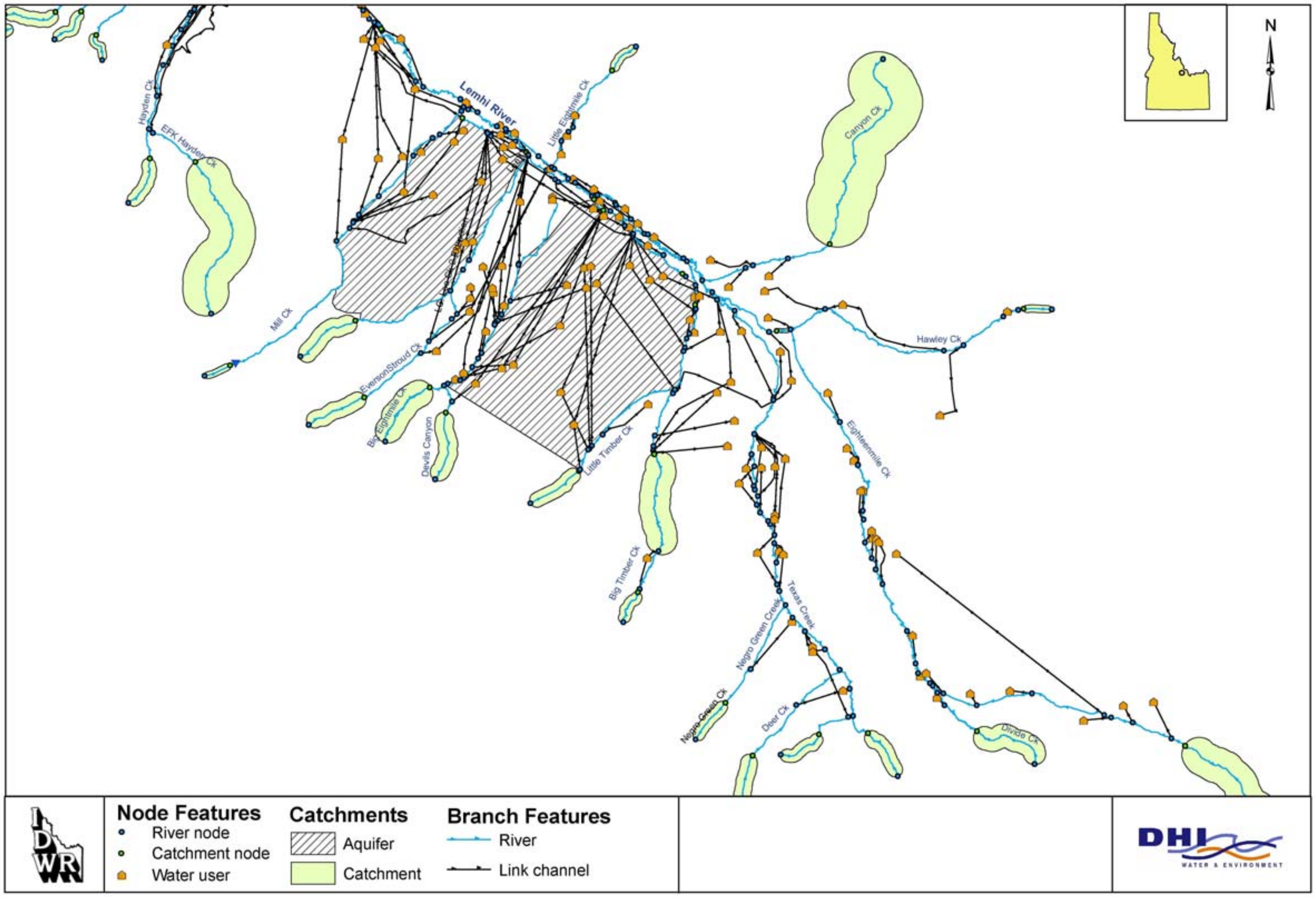

Figure 2. Overview map of the upper LRMBM.

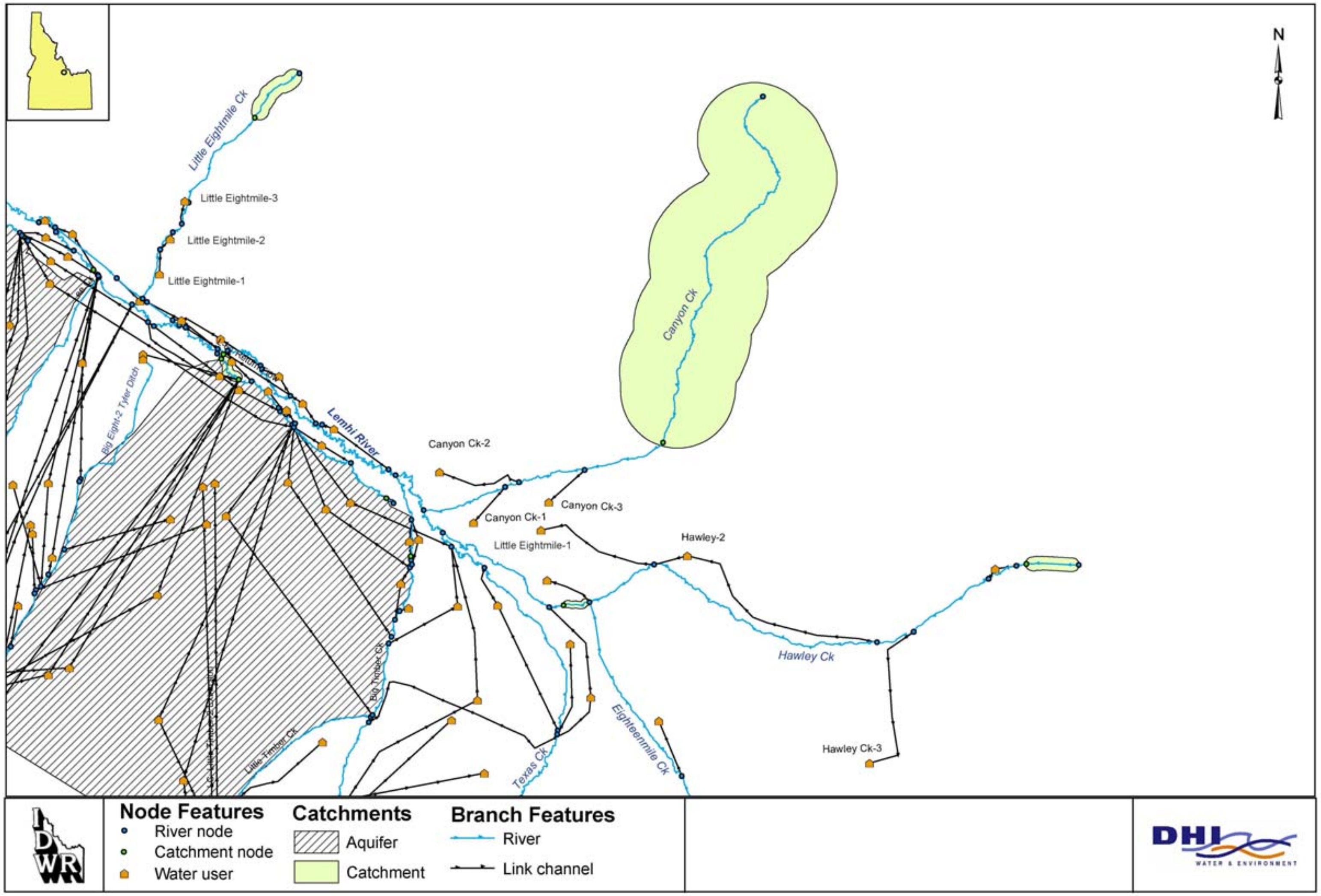

Figure 3. Map of Little Eightmile Creek, Canyon Creek, Hawley Creek, and the mainstem Lemhi River in the upper LRMBM.

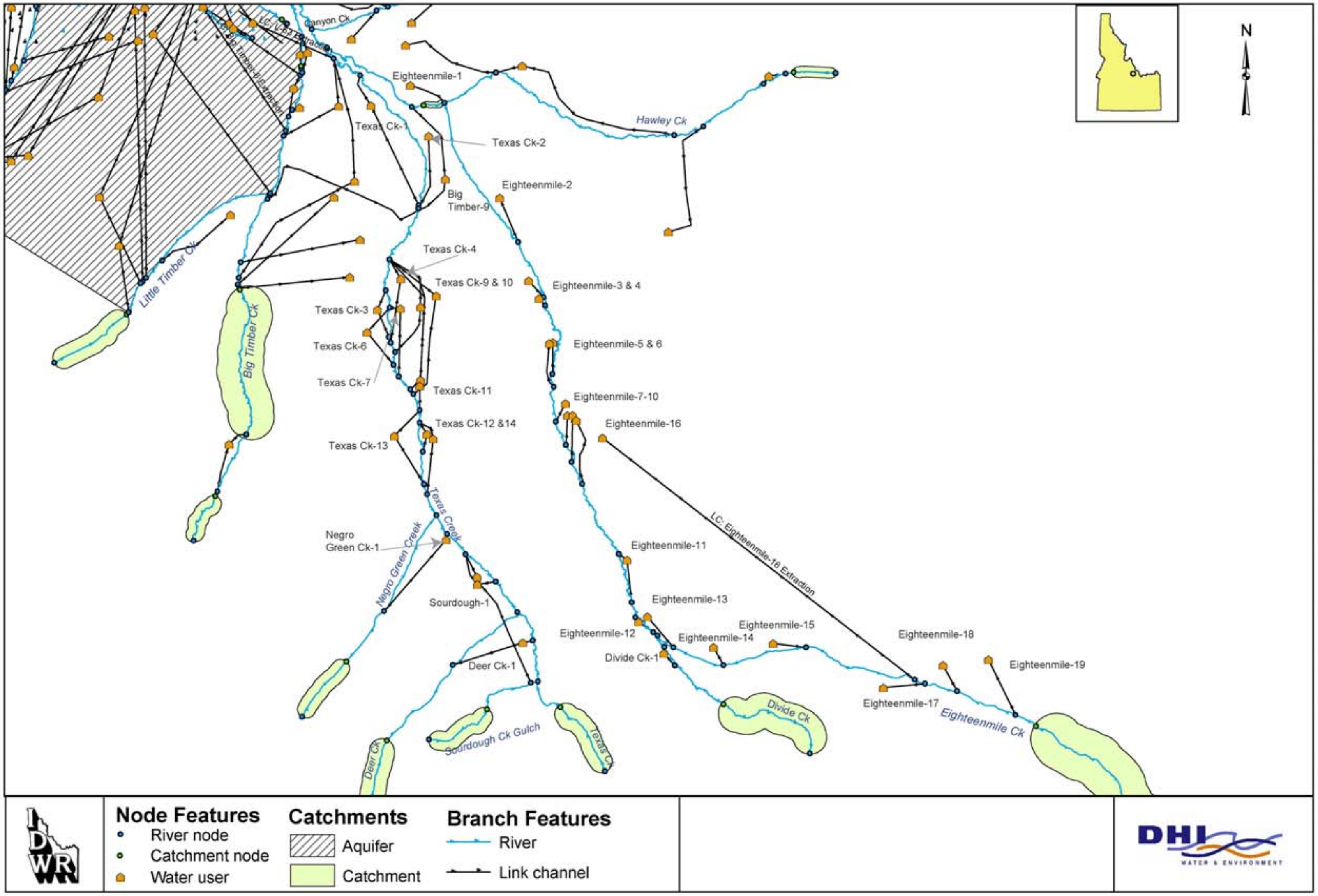

Figure 4. Map of Texas Creek, Eighteenmile Creek, and Hawley Creek in the upper LRMBM.

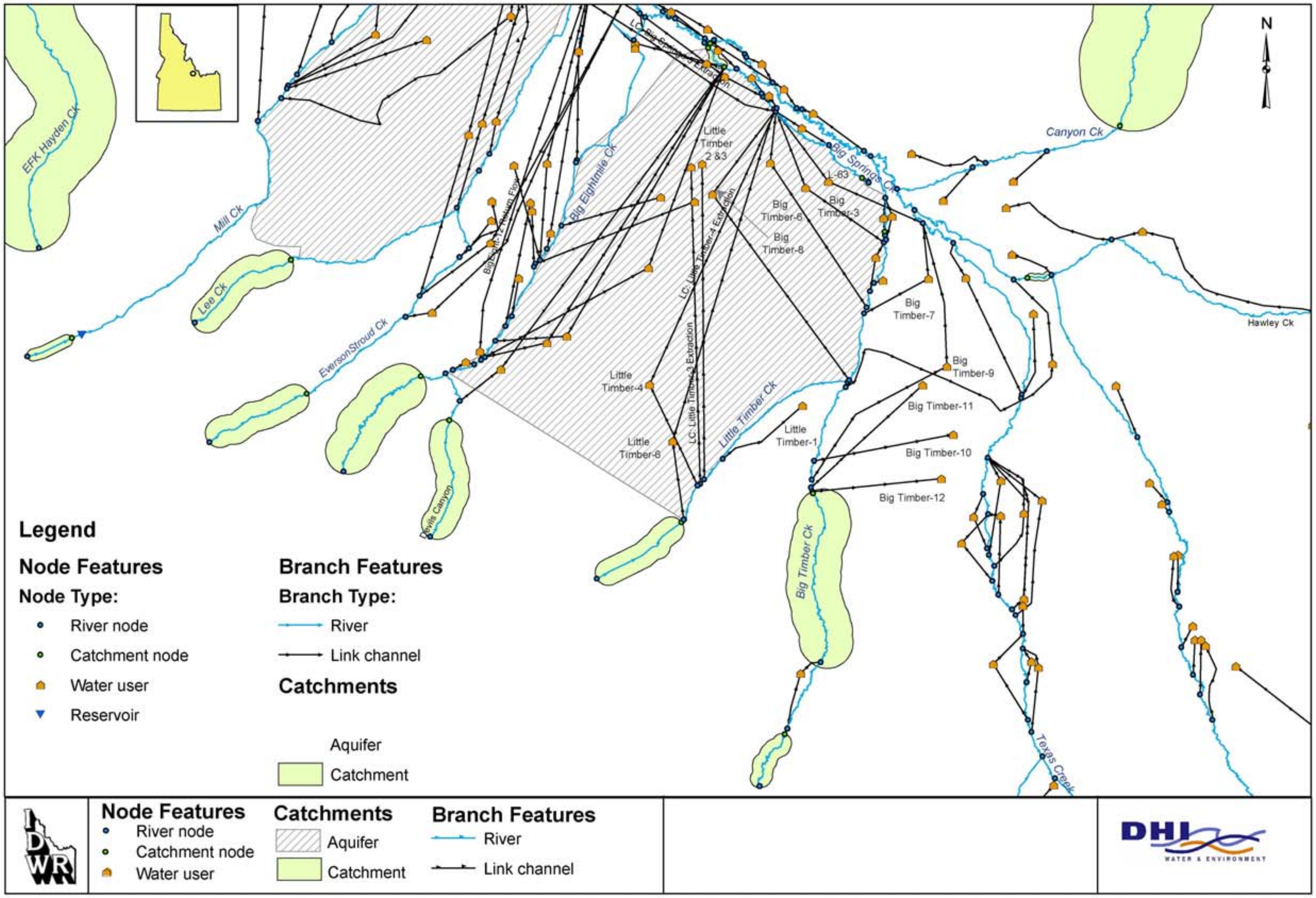

Figure 5. Map of Big Timber, Little Timber, Big Eightmile, Lee, and Mill Creeks in the upper LRMBM.

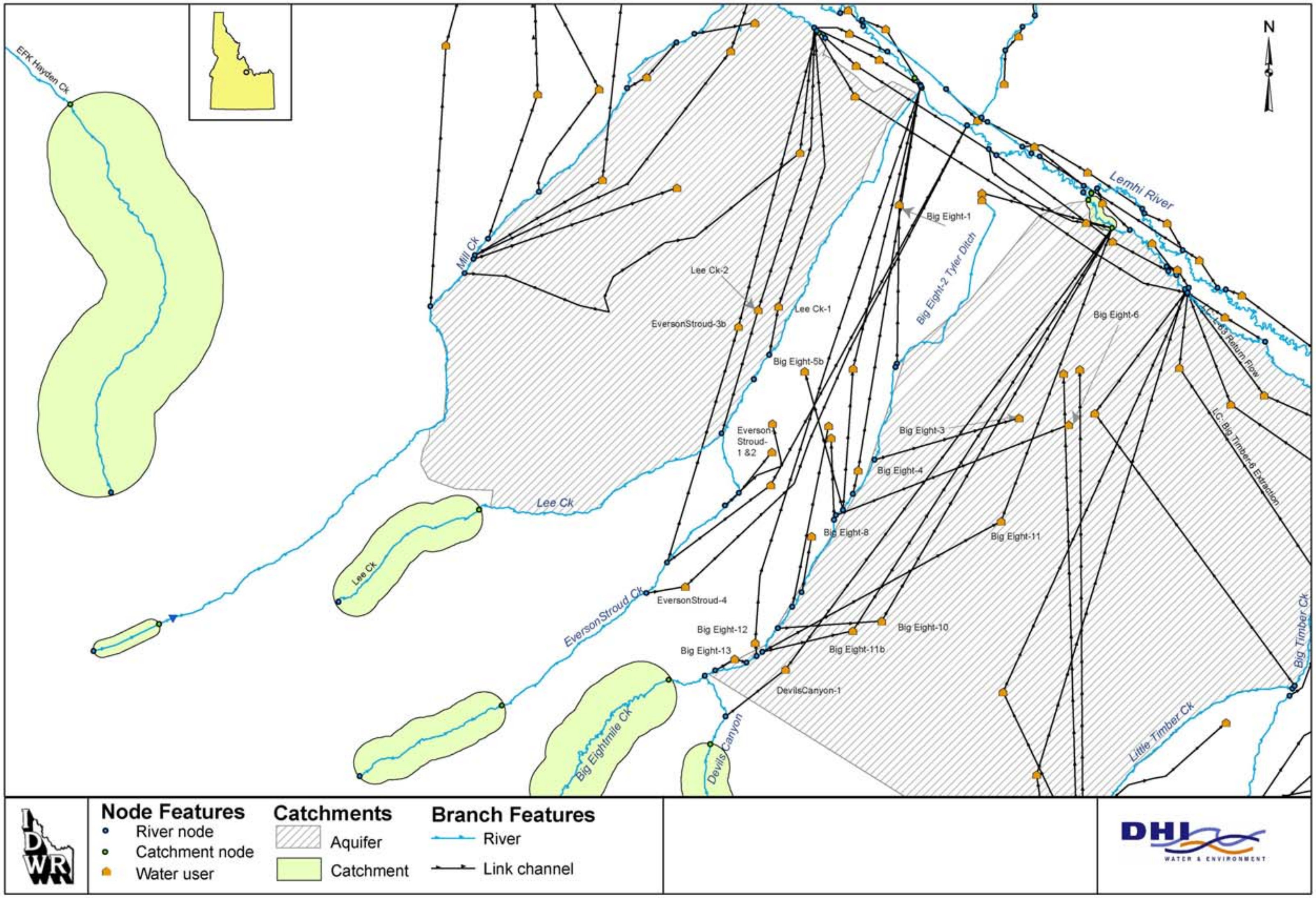

Figure 6. Map of Big Eightmile and Lee Creeks in the upper LRMBM.

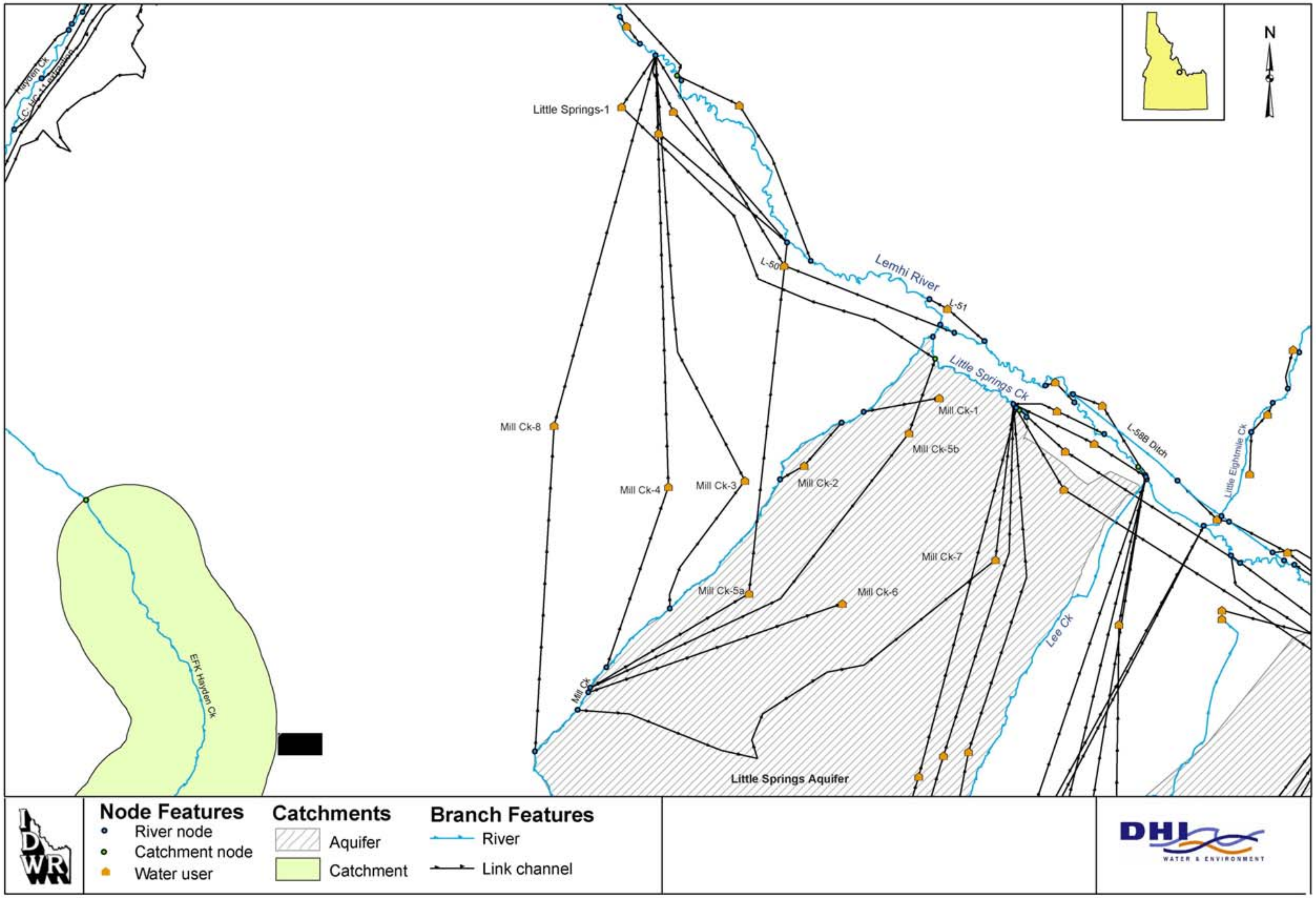

Figure 7. Map of Mill and Little Springs Creeks in the upper LRMBM.

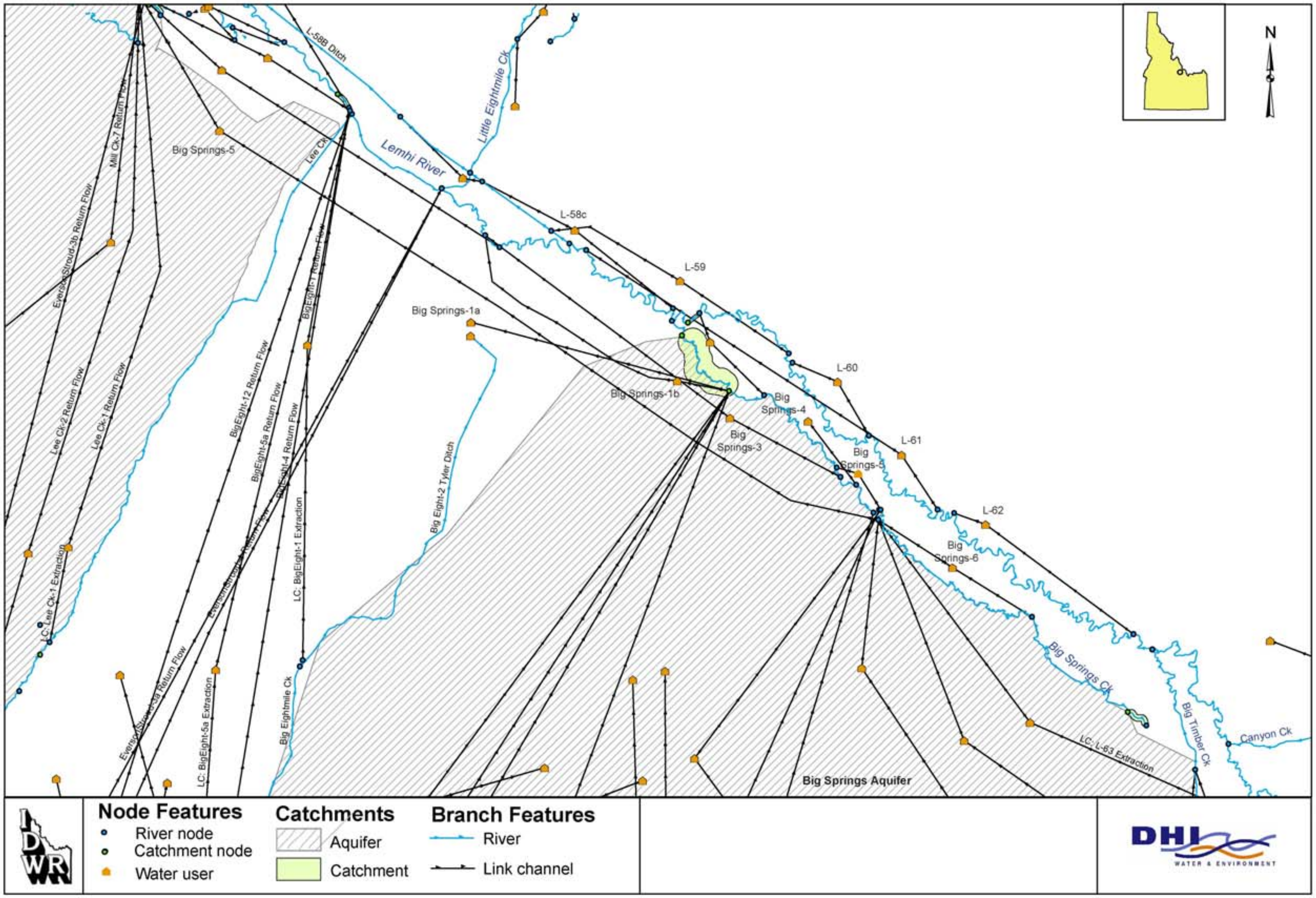

Figure 8. Map of the mainstem Lemhi River and Big Springs Creek in the upper LRMBM.

The following section describes the construction methods, data availability, and assumptions associated with extending the LRMBM to include diversions along the mainstem upstream of McFarland Campground and 12 additional tributaries.

4.1 Network Setup

The river network for the Lemhi River above McFarland Campground (in this text referred to as the upper Lemhi River) and its tributaries (Figure 2) was developed by using previously existing datasets and through discussions with water masters and water users familiar with the study area (Table 1). In general, the planar course of the Lemhi River and tributaries was extracted directly from the 1:24,000 National Hydrography Dataset shapefile (IDWR shapefile: up_sal_24k.shp). Where applicable, the coverage was edited when the water masters indicated that the hydrography was incorrect or that the stream had changed course. Comments detailing discrepancies between the hydrography dataset and actual conditions are provided in the water rights inventory. For Big Springs Creek and Little Springs Creek that are not explicitly defined in the 1:24,000 National Hydrography Dataset shapefile, the network was approximated using aerial photographs and other available GIS coverages.

Table 1. List of water masters and landowners contacted during the development of the upper LRMBM

Tributary	*Contact Person*	*Title*	*Date of Meeting*
Lemhi River	Rick Sager	Water Master	February 23, 2006
Little Springs Creek	Rick Sager	Water Master	February 23, 2006
Big Springs Creek	Rick Sager	Water Master	February 23, 2006
Mill Creek	John Amonson	Water Master	February 22, 2006
Mill Creek	Rick Snyer	Landowner	February 22, 2006
Lee Creek	Thomas Udy	Water Master	February 22, 2006
Big Eightmile Creek	Thomas Udy	Water Master	February 22, 2006
Big Timber Creek	Dan Smith	Water Master	February 24, 2006
Little Timber Creek	Dan Smith	Water Master	February 24, 2006
Big Timber Creek	Dan Smith	Water Master	February 24, 2006
Eighteen Mile Creek	Dan Smith	Water Master	February 24, 2006
Hawley	Dan Smith	Water Master	February 24, 2006
Canyon Creek	Dan Smith	Water Master	February 24, 2006
Little Eighteenmile	Rick Sager	Water Master Lemhi River	February 23, 2006

Similar to the river network, the diversion locations, irrigated lands, and water rights information was extracted from electronic files and then checked by water masters and local stakeholders. The electronic data used includes the diversion GIS shapefiles (IDWR shapefile: diver903_idtm.shp), point of diversion (POD) GIS shapefiles (IDWR shapefile: lemhi_rec_pods.shp), and place of use (POU) GIS shapefile (IDWR shapefile:

lemhi_rec_pods.shp). Following discussions with local water masters, the PODs and POUs were adjusted to correct for actual conditions. In many instances, the water masters were uncertain of the specific location of a POU or had other questions regarding the location or use of a particular diversion. In each of these instances, DHI and IDWR made notes of any uncertainty and documented these in the Microsoft Excel file Upper_Lemhi_diversions.xls. In cases where the water master was uncertain of the POU or POD location, this information was taken directly from the water rights databases. There were also several locations where the water masters were fairly certain that the POD location displayed in the water rights databases were incorrect (e.g., the EversonStroud-2 Diversion). In such instances, the diversion location in the MIKE BASIN model was changed to reflect the POD locations as defined by the local expert and notes were made in the Microsoft Excel sheet.

The irrigation nodes, representing the irrigated area associated with each offtake node, were determined by matching the adjudicated POU location with the POD. These POUs were verified through discussions with water masters and landowners on each tributary (Table 1).

For most offtake nodes (diversions) along the mainstem Lemhi River, multiple irrigators share the diverted water throughout the irrigation season. For the mainstem Lemhi River diversions above McFarland Campground, a single irrigation node is used to represent locations where multiple water users are applying diverted water in the same general area. However, on the 12 modeled tributaries described in this document, most diversions only service a single irrigator, thus there are few instances where water users are 'lumped' along modeled tributaries. The exceptions are the Mill Ck-6 (Figure 7), Big Springs-1b, Big Springs-3, and Big Springs-5 Diversions (Figure 8) where a single water user is used to represent multiple fields. The grouping scheme applied in the LRMBM was done in accordance with recommendations from Rick Sager (water master for Big Springs Creek) and John Amonson (water master for Mill Creeks).

Exact location, timing, and quantity of return flows are a function of flood irrigation practices and the physical conditions of the irrigated area. In many cases, irrigation returns re-enter the river through surface and subsurface paths that are disseminated along reaches bordering the irrigated fields. In the LRMBM, return flow nodes are associated with respective irrigation nodes and are located at a downstream point along the Lemhi River or the selected tributaries where the majority of the return flow was considered to return. In many instances, the return flow path is quite long because return flows are frequently captured and re-used several times before re-entering the river network. Diverted water that is not lost to evapotranspiration and does not re-enter the stream by the return node enters either the intermediate ground water system (IGW) or the regional ground water system (RGW). The IGW system returns to the stream within the study reach; the RGW system contains water assumed no longer to interact with the surface water river system and, consequently, is no longer tracked with the LRMBM.

There is a single water supply reservoir included in the upper LRMBM. While there may be other reservoirs located in the upper Lemhi River Basin, the Mill Creek Reservoir was the only reservoir identified by the water masters as being actively used and decreed. The Mill Creek Reservoir is listed in the IDWR water rights databases and is operated to supplement irrigation diversions during the dry season. According to John Amonson (personal communication, 2006), the reservoir has a storage volume of approximately 140 acre feet and is used to supplement the second growth of grass hay that is grown near the Mill Ck-8 DC Weirs. The reservoir modeled in LRMBM uses place-holder values so that IDWR can populate the reservoirs with more accurate data and operating rules in the future.

In many locations along the lower Lemhi River, tributaries and diversions are intersected by a complex network of irrigation ditches. Of the 12 modeled tributaries, at least three do not have a direct hydraulic connection to the Lemhi River: Little Eightmile Creek, Mill Creek and Big Eightmile Creek. These situations, and the approach used to model other such complex hydraulic situations are described below:

- *Little Eightmile Creek & the L-58B Ditch* - The L-58B Ditch collects return flows from the L-59 and L-58C Ditches before intercepting Little Eightmile Creek (Figure 3). The Ditch begins at the L-58B Diversion and supplies water to at least one user before joining the L-57 Ditch. The L-58B Ditch was modeled using a river branch in the upper LRMBM in order to more accurately capture its interaction with Little Eightmile Creek. At the conclusion of this modeling phase, it is unknown whether the L-58B Ditch collects all the flows in Little Eightmile Creek or just a portion of the flows. The operation of the ditch with respect to its interaction with Little Eightmile Creek needs to be determined so that the confluence can be more accurately modeled.

  By modeling the ditch as a river branch in MIKE BASIN, the L-58B Ditch can collect inflows from Little Eightmile Creek, supply water to the L-58B Ditch water user and receive return flows from the L-59 and L-58C Ditches. In addition, rules can be specified at the confluence of the L-58B Ditch and Little Eightmile Creek in order to apportion water between the two branches. A lookup table containing placeholder values is used to specify the portion of Little Eightmile Creek that is diverted into the L-58B Ditch. Currently, the lookup table is configured so that the majority of the flow in Little Eightmile Creek is diverted to the ditch during much of the irrigation season and only a small amount of discharge (5-10 cfs) is diverted to lower Little Eightmile Creek to simulate seepage through the channel bed and banks. During high water, which is arbitrarily defined as the point when discharge exceeds 75 cfs at the junction of Little Eightmile Creek and the L-58B Ditch, it is assumed that all flows exceeding the capacity of the ditch (15 cfs) enter lower Little Eightmile Creek. These rules were arbitrarily defined and can easily be updated when actual data is available.

- *Big Eightmile Creek* - Historically, Big Eightmile Creek flowed northeastward to join the Lemhi River in the vicinity of the L-58a Diversion (Figure 6). Currently, Big Eightmile Creek is not hydraulically connected to the Lemhi River as all water along the lower portions of the stream enter either the BigEight-1 Ellsworth or BigEight-2 Tyler Diversions. According to Thomas Udy (personal communication, 2006), water master for Big Eightmile Creek, very little surface water enters lower Big Eightmile even during high water. The lower reaches of Big Eightmile Creek do not occupy a regular stream channel and there are a series of beaver dams in the area that once constituted the Big Eightmile Creek-Lemhi River confluence. Thomas Udy also noted that there are a series of springs that emerge along the margin of the Lemhi Valley floor that contribute approximately 0.5 cfs into the lower reach of Big Eightmile Creek.

  Big Eightmile Creek is modeled as a typical stream channel with catchments, diversions and water users in the upper LRMBM. However, because the stream does not have a direct surface water connection with the Lemhi River, there is no river branch linking the two streams. Instead, any flows reaching the lowermost river node in Big Eightmile Creek are diverted into the Tyler Ditch (BigEight-2 Tyler Ditch) that is also modeled as a river branch in order to give IDWR additional flexibility in the future. For example, because the Tyler Ditch essentially acts as a stream channel, this ditch may be used to re-connect Big Eightmile Creek with the Lemhi River. By modeling the ditch as a river, the model can more easily simulate various re-connect strategies.

- *Cruikshank Creek and Canyon Creek* - Cruikshank Creek, a tributary to Canyon Creek, is modeled in the upper LRMBM. Dan Smith (personal communication, 2006) indicated that many of the diversions along Canyon Creek were in disrepair or inactive (Figure 3). Using maps of the Canyon Creek, he identified diversions he thought were active, but emphasized that all diversions needed to be verified with local landowners. He believed that several diversions on Cruikshank Creek were active and these diversions were included in the MIKE BASIN model. After a preliminary review of the upper LRMBM, IDWR staff indicated that the Cruikshank Creek diversions did not have a significant impact on the overall flow in Canyon Creek and recommended that Cruikshank Creek be removed from the model. The current version of the upper LRMBM does therefore not include Cruikshank Creek and the modeled portion of Canyon Creek only extends 5 miles upstream from the Lemhi River encompassing 3 diversions.

- *Lower Mill Creek* - According to John Amonson and Rick Snyder, (personal communication, 2006) a permanent dam was constructed across lower Mill Creek in the 1970's to divert water into the Tyler property (a.k.a. Rock Pile). Below the Mill Ck-3 Diversion, flow diminishes substantially so that the creek bed between the Mill Ck-3 and Mill Ck-2 Diversions is nearly dry during much of the year. Some flow returns to the creek via subsurface seepage near the Mill Ck-2 Diversion, but this small amount of water seeps back into the streambed by the Mill Ck-1 Diversion. Some flow returns to the creek again by the lower reaches of Mill Creek just above its confluence with Little Springs Creek (Figure 7).

  The dam on Mill Creek and the subsequent subsurface interaction is not directly accounted for in the current MIKE BASIN model. The dam can be simulated at a later date by inserting rules at the Mill Ck-3 Diversion apportioning water between the lower reaches of Mill Creek and the Tyler Diversion. Examples of these rules can be found in the MIKE BASIN model of the lower Lemhi River on Kirtley Creek and Agency Creek. The seepage patterns described by the Mill Creek landowners is difficult to model without having discharge records quantifying stream gains and losses at various locations. Although Mill Creek is connected to a shallow aquifer via a ground water model (Appendix A), water that is lost to the aquifer returns to Little Springs Creek and does not re-enter Mill Creek. The methods to simulate the observed seepage patterns is to specify seepage amounts for each stream reach or establishing discrete locations of reach gains and losses. Either strategy can be implemented at a later date when more data is available.

- *Return Flow Paths* - For many diversions along tributary streams, the water masters did not specify explicit return flow paths because they believed that return flows were minimal, they were unsure where the water returned, or both. In the interest of building a flexible, comprehensive model, DHI added return flow paths for flood irrigators even in places where the water masters did not define return flow paths (e.g., Mill Creek, Big Timber Creek, Lee Creek, and other streams). The model was constructed in this manner to symbolize where flows are likely to travel through the subsurface and return to the stream network. Once additional data is collected, the actual locations of the return flow paths and the lag times can be updated to better reflect actual conditions.

4.2 Diversion Naming Convention

The naming convention for the diversions along the Lemhi River and its tributaries was developed in a manner that is consistent with convention applied to the mainstem Lemhi River, while also upholding local names that are familiar with water masters and water users. Diversions along the mainstem Lemhi River are named identically to their official IDWR decreed diversion name (e.g. L-52, L-52b). Tributaries are labeled in the same way that tributaries in the lower LRMBM were named. Each offtake node (POD) is assigned a label consisting of the tributary name, followed by a number indicating the position of the POD relative to other diversions on that tributary. Diversion numbers generally start with 1 near the mouth of each tributary and increase upstream. For example, the BigEight-1 Diversion is the first diversion upstream from the confluence of BigEightmile Creek and the Lemhi River and the BigEight-10 Diversion is the 10th diversion (and hence further upstream). Where applicable, local names are appended to the label to signify landowner or well-known diversion names. In this manner, the tributary name, diversion number and local name are all specified. For example, the third diversion from the mouth of Mill Creek is labeled: Mill Ck-3 Tyler Rockpile to signify that the diversion is owned by Karl Tyler and irrigates an area known as the Rockpile. To assist in record keeping, IDWR and DHI personnel maintained records of the naming conventions used in the upper LRMBM, along with the name used by the water masters, and any other labels applied to a particular diversion.

Because the upper LRMBM consists of a complex network of nodes, water users and channels, many of these features were assigned names in order to provide clarity for future model users. Link channels that represent ditches in that they link POU’s with POD’s were assigned labels denoting the diversion name and the type of channel (e.g., return flow, extraction). Water user nodes (irrigation nodes) were labeled with the same name as that assigned to their corresponding user node.

4.3 Catchment Nodes

Catchment nodes are placed in locations where water is gained along the river system. For the upper LRMBM, catchment nodes were placed at the upstream end of each modeled tributary (Figure 2, Table B1). Inflow was approximated using the rainfall-runoff model in MIKE BASIN. Full description of the model is outlined in Appendix B.

4.4 Branch Reach Losses/Gains

Reach losses/gains can also be modeled along branches to account for reach gains and losses due to precipitation, ground water inputs, seepage and other components that are not explicitly included in the model. Such reach gains and losses are assumed to represent residual between simulated and observed stream flow measurements at a gaging station. Currently, the reach gains along the upper Lemhi River are modeled using catchment nodes, but this representation could easily be changed to add reach gains/losses along branches which would allow users to simulate gains or losses.

Table 2. List of stream gages along the upper Lemhi River that are used to calculate reach losses/gains

Gage Name	*Data Source**	*MIKE BASIN Branch Name*	*Period of record*
Lemhi River at Barracks Lane	WD 74	USBR Barracks Lane Gage	1993-2001
Lemhi River nr Lemhi Idaho	USGS	USGS Lemhi Gage	1938-present
Lemhi River below L5	USGS	USGS L-5 Gage	1992-present
Lemhi River at Steel Bridge	WD 74	USBR L-3 Gage	1993-present
Lemhi River at Baker	IPCO	Lemhi River at Baker IP Gage	2004-present
Bohannon Creek abv Diversions	USGS	Bohannon Ck USGS Gage	2004-present
Kenney Ck	IPCO	Kenney Ck USGS Gage	2004-present
Agency Ck	IPCO	Agency Ck IP Gage	2005-present
Lemhi River at Hayden	IPCO	Lemhi IP gage abv Hayden Ck	2004-present
Hayden Ck	WD 74	Hayden Ck WD74 Gage	1997-present

* "WD 74" denotes Water District 74, "USGS" denotes U.S. Geological Survey, and "IPCO" denotes Idaho Power Company

4.5 Time Series Input Data

In MIKE BASIN, the movement of water in and out of the river system is specified with time series data. Catchment, reach gain/loss branches, reservoirs, and irrigation nodes require time series data in the LRMBM. The catchment node, time-series data are used to describe stream inflows. For each irrigation node, time series information is used to define irrigation demand, ground water fraction (fraction of demand satisfied by ground water), return fraction (fraction of demanded water that returns to the stream at specified return locations), deficit carryover (in the event of a deficiency in the demand, the amount that can be made up in the subsequent time steps), and lag time (the linear routing of return flow from the irrigated fields back to the river). Reservoir nodes require physical characteristics and operational rules.

At this phase, the upper Lemhi River as represented in the LRMBM is populated with skeleton datasets, whereby all appropriate time-series files have been created, formatted and linked with the corresponding water users. The actual data used in diversion time-series files is currently placeholder data that can easily be populated with more accurate data at a later date using customized Microsoft Excel sheets. The following section describes the required datasets for the catchment, branch losses/gains, and irrigation nodes and specifies the required datasets are currently missing.

4.5.1 Catchment Nodes

Catchment runoff represents locations in the model where water is introduced directly to the stream system. For the LRMBM, data is needed at the upstream end of modeled tributaries and at gaging stations. In the LRMBM, limited time series input information from stream flow gaging station records is available as only 3 of the 12 modeled tributary streams have gaging stations. Rainfall-runoff models (Appendix B) were developed for each of the tributary basins in order to develop inflow hydrographs.

4.5.2 Branch Reach Losses/Gains

Reach losses/gains account for contributions to the Lemhi River from precipitation, ground water gains/losses, and unmodeled tributary inflow. In the LRMBM, the reach gains/losses are the difference between the observed and simulated conditions for each time step during the simulation period. Branch reach losses/gains were inserted in the LRMBM at 7 locations: the Idaho Power gage on the Lemhi River at Cottom Lane (near the L-57 Diversion) , the Idaho Power gage on the Lemhi River above Big Springs Creek (near the L-58c Diversion), the Idaho Power Gage on Big Springs Creek (near its confluence with the Lemhi River), the Idaho Power gages on Upper and Lower Big Timber Creek (near the Big Timber-1 and 12 Diversions) and the Idaho Power gage on Eighteenmile Creek (below the Eighteenmile-1 Diversion). At this phase, the reach gains/losses time-series have been created, formatted and linked with the corresponding branches. However, the current data in these time-series files is placeholder data that can easily be updated during the model calibration.

4.5.3 Irrigation Nodes

Irrigation Demand - Daily diversion data was unavailable in an electronic format at the completion of the modeling effort and thus the model is populated with skeleton data. However, DHI assembled a water rights inventory of diversion amounts and high water rights for all modeled diversions. Once verified by IDWR, this inventory can be used to develop time series data by routing the diversion amount for the entire irrigation season. According to Rick Sager (personal communication, 2006), most diversions are operated so that water is continually diverted from late April or May through the remainder of the irrigation season. In most years, the tributaries do not have sufficient flow to satisfy all water rights for the entire irrigation season, so tributary diversion are distributed according to the priority dates of each diversion.

Ground Water Fraction – Ground water is used by a few water users to augment irrigation in this portion of the Lemhi River Basin. By default, this value in all irrigation nodes was set at zero. As the information becomes available, the nodes representing irrigators using ground water can be implemented in the model.

Ground Water Fraction – Ground water is not used to augment irrigation in this portion of the Lemhi River Basin. This value in all irrigation nodes was set at zero.

Deficit Carryover – At the completion of this project, this model is not being used in an operational mode so the deficit carryover is assumed to be zero.

Return Fraction - The quantity of water returning to the system at the downstream return node is a function of antecedent soil moisture, initial ground water levels, crops irrigated, irrigated area, evapotranspiration rates, distance from the river, ditch loss, and the portion of the infiltrated water that seeps into the intermediate ground water system. The IGW system for these calculations represents the portion of the diverted water that will infiltrate to the subsurface but is not expected to return to the Lemhi River and modeled tributaries, in this particular model, until the next downstream gauging station node.

For the LRMBM, a return fraction calculator was developed in Microsoft Excel to assimilate these factors and compute the return fraction on a daily time step. Once the diversion amounts are finalized, the return flow calculator can be used to compute daily return flows. The return fraction calculator equation is:

$$RF = Demand * DL * IGW_{DL} + (Demand + ER * \sum_{i=1}^{n} A_{CT} - DL - (\sum_{CT=1}^{n} (ET_{CT} * A_{CTS})) * IGW_{IS}$$
$$+ (\sum_{CT=1}^{n} (ET_{CT} * A_{CTF})) * IGW_{IF})$$

RF is the return fraction.
Demand is the diverted water.
DL is the fraction of the demand that is lost to ditch loss.
CT denotes the crop type (pasture, grass hay, and alfalfa hay in the Lemhi River basin); in this equation, this value is constant.
ET_{CT} is the evapotranspiration associated with the crop type.
A_{CTS} is the irrigated area for a crop type for sprinkler irrigation; here, this value is constant.
A_{CTF} is the irrigated area for a crop type for flood irrigation; in this equation, this value is constant.
ER is the effective rain.
n is the number of crop types.
The variables IGW_{DL}, IGW_{IS}, and IGW_{IF} are the portions of the infiltrated flow from ditch loss, sprinkler, and flood irrigation that enter the IGW.

The return fraction equation is simply the mass balance of the water entering an irrigation node. Irrigated area was calculated from the POU coverage provided by IDWR. The crop type was determined from conversations with water masters. For fields irrigated with sprinklers, sprinkler rates were assumed to be 0.75 inches per day per acre (Sager, personal communication, 2003).

At the conclusion of this phase, the irrigated area (A_{ct}) for each diversion has not been fully determined. Irrigated acreages have been determined for approximately half of the tributaries by linking each diversion with the POD and POU GIS shapefiles revised by IDWR in February 2006. However, the areas calculated by DHI and the assignment of the place of use for each water right will need to be confirmed by IDWR personnel.

Evapotranspiration (*ET*) can be determined by using the Allen-Brockway (A-B) method, Agrimet stations, or SEBAL data. In the original LRMBM, *ET* data from the Corvallis, Montana AgriMet Station were applied to the agricultural areas (DHI, 2003). This same approach is applied to the modeled tributaries in the lower Lemhi River Basin. The Surface Energy Balance Algorithm for

Land (SEBAL) was used to determine *ET* rates for the Lemhi River POU's for the 2001 irrigation season during the development of the original LRMBM (DHI 2003). Although time constraints prevented the incorporation of this data into the MIKE BASIN model, such data may be useful for future studies. Efforts could also be made to expand SEBAL technique to develop *ET* rates for irrigated areas along the upper Lemhi River.

Conveyance loss or ditch loss (*DL*) is the loss of water during transport from the POD (at the source) to the POU. Water is lost through seepage through the soil, leakage through headgates and other structures, evaporation from the water surface, and transpiration from plants growing in or near the channel. For the soil loss, a calculator was developed to implement the Worstell method seepage loss estimation (Hubble, 1991), a method commonly used by IDWR. This method requires an estimation of the soils seepage rate, measurement of the top width of the water surface at various points along the canal, and the canal length. The estimated seepage loss is multiplied by the canal length (miles) to determine the canal's total conveyance loss. Tables in the *Guidelines for the Evaluation of Irrigation Diversion Rates* (Hubble, 1991) are useful in determining soil textures and the appropriate seepage rates. Conveyance losses were not calculated in the original or 2006 LRMBM. Rather, such losses are accounted for by specifying reach gains and losses.

The intermediate ground water portion (*IGW*) of the *return fraction* may be added to the reach gains and losses at a future point in the modeling effort because previous studies have shown that the Lemhi is primarily a gaining river (Donato, 1998). In the lower LRMBM, all water entering IGW will return to the river in the next downstream reach gain/loss (DHI, 2003). Because *IGW* is a calibration parameter, this can be updated during a later phase of the modeling. For example, where stream flow and diversion flow are measured, the IGW can be used to adjust the water balance to best match observed discharges.

Lag Time - Timing of return flows from irrigated lands to the Lemhi River and modeled tributaries depends on the irrigated field's location in relation to the closest water, the degree of channel surface flow returns, and ground water flow direction and rate. In MIKE BASIN, one option for delaying the return flow is by using a linear reservoir equation (DHI, 2006). The user can specify the lag time to control the timing of the return fraction. Due to a lack of data, lag times were not assigned to water users in the upper Lemhi River Basin, but this parameter can be updated at a later date.

4.5.4 Reservoir Nodes

For the standard reservoir, the time series information required includes bottom, crest, spillway, top of dead storage, and minimum operation pool elevations; minimum and maximum valve releases; precipitation, seepage loss, and evaporation; and flood control and operational rules levels for any water users attached to the reservoir. Though not a time series, the height-volume-area relationship describing the reservoir bathymetry is additional input information required for the model. For the 2006 LRMBM, all the reservoirs had default time series data and the reservoirs do not store stream flow. These data can be replaced with real data at a later date.

4.6 Microsoft Excel Interface

To expedite the processing, formatting, and entering of data into the model, as well as the calibration and running of scenarios, DHI personnel developed a series of Microsoft Excel files and associated macros that interface with the LRMBM. These files and macros provided a more user-friendly platform and helped automate repetitive tasks, organize the data, and prevent errors in data handling. Important Microsoft Excel files include:

- *LRMBMInput.xls* – Organizes the input data for all the irrigation and catchment nodes. For the irrigation nodes, the workbook contains the daily values for the demand and return fraction. This workbook contains the return flow calculator and macros that automatically load the data into the proper LRMBM input files. Parameters needed for the return flow calculator include irrigated area, percent sprinkled, percent of each crop type that is flood and sprinkler irrigated, the sprinkler irrigation rate, and ditch loss. This workbook should be used when running scenarios where diversion schemes are altered and need to be loaded into the LRMBM. Macros automate the loading of the time series in the Microsoft Excel file into the appropriate MIKE BASIN time series files. The macro supports both daily and monthly time steps.

- *LRMBMCalib.xls* – Assists in model calibration. The files run repetitive MIKE BASIN simulations for calibration, load results from previous simulations for viewing, load the results into the comparative analysis with the 1999 Lemhi River and its tributaries seepage run, and calculate reach gains used in the first calibration effort for the LRMBM. Macros automate the loading of the time series in the Microsoft Excel file into the appropriate MIKE BASIN time series files.

5 COARSE DEMONSTRATION OF THE LRMBM

A course demonstration of the upper LRMBM was created for public demonstration purposes and to ensure the model was correctly constructed. At the completion of this development phase, the upper LRMBM is missing required times series data and remains uncalibrated. Except for conceptual demonstration, no results should be used from the model until the proper data has been input and the LRMBM calibrated. The course demonstration can be used to demonstrate the capabilities of the model and is a repository for the current data available. Furthermore, the model can be used to demonstrate the physical irrigation network of the upper Lemhi River Basin and can be a demonstrative tool for determining where water is diverted, applied, and returned to the river system.

6 LIMITATIONS WITH DEVELOPING THE UPPER LRMBM

In this project, the primary sources of uncertainty arise from a lack of data concerning the tributary diversion practices and the interaction of ground water and surface water. In addition, the inherent complexity of the irrigation network (e.g., commingled ditches and tributaries) makes it difficult to accurately track some diversions from their original offtake points to their ultimate return flow destinations. In this section limitations associated with modeling tributary diversions are discussed.

- *Lack of data describing diversion practices* - In meeting with water masters and landowners, it was evident that there is a great deal of uncertainty regarding diversion practices on certain tributaries. For instance, Little Eightmile Creek and Canyon Creek are currently inactive or are not currently managed by a water master. In order to better simulate irrigation diversions on tributary streams, it would be helpful to have daily records of water usage for each water user. Although such records are typically kept by water masters, inactive basins are unlikely have such data and even on managed streams, the data quality and temporal resolution of such records can vary widely.

- *Complexity of physical network* – The upper Lemhi River irrigation system consists of a complex network of Lemhi River ditches, tributary streams, and tributary ditches. Along the Lemhi River Valley floor, irrigation water is frequently re-used several times as return flows from one field are captured in ditches for use on downstream fields. This system results in commingling of irrigation waters which can be difficult to track. Examples of commingled irrigation waters occur when a ditch intercepts a tributary such as the L-58B Ditch which captures return flow from the L-58C and L-59 Ditches and Little Eightmile Creek. Commingling also occurs when a ditch intercepts another ditch, which happens frequently along the Lemhi River valley floor and results in very long return flow paths.

  According to Rick Sager (personal communication, 2006), it is also difficult to pinpoint the precise location where Little Springs Creek and Big Springs Creek emerge on the Lemhi River valley floor. The water table along the valley bottom is quite high relative to the ground elevation in this area, thus much of the bottomlands are a marshy area where the lower reaches of some tributaries seep into valley floor (e.g., the lower part of Mill Creek) and other tributaries emerge at indistinct locations (e.g., Big Springs Creek). Furthermore, it is also difficult to determine the flow paths of small streams and ditches because the valley floor contains numerous remnant floodplain and ditch features which intersect one another.

  Ground water plays an important role in the Lemhi River irrigation system because much of the water from flood irrigation seeps into the shallow subsurface, flows downslope and re-appears in the marshy areas along the Lemhi River Valley floor. Although a ground water model was developed for Big Springs and Little Springs Creeks, this model does not currently account for smaller scale exchanges between ground water and surface water. For example, many of the streams in the upper Lemhi Basin run dry along their lower reaches. This occurs due to low flows or when upstream water users divert all available flow. In such places, any remaining stream flow will seep into the cobbly gravel bed and the creek will run dry for a short distance before the water re-emerges from the ground and creates surface flow. In some places, the creek runs almost totally dry and any stream flow presumably re-surfaces in springs along the valley margins. In other areas (e.g., Mill Creek), the creek alternates between dry and slightly wet sections before entering Little Springs Creek.

Table 3. Summary of the diversions in the upper LRMBM. Associated with each diversion is the irrigation type, crop type used in the irrigated area, the total diversion amount as specified by the water rights, and the total irrigated area. Data gaps are denoted with a question mark. Note the data is incomplete and reflects May 2006 conditions in therefore it should be used with caution.

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Big Eightmile Creek Diversions				
BigEight-1 Ellsworth	Flood	Alfalfa	5.46	269
BigEight-2 Tyler	Sprinkler	Alfalfa	2.92	118
BigEight-3 Hermans' Ditch	Sprinkler	Alfalfa	18.92 (25.92)	897
BigEight-4	Flood	Grass	1.43	72
BigEight-5a Peterson	Flood	Pasture	2	16
BigEight-5b Ruggles	Sprinkler	Alfalfa, Grass	24.92 (66.21)	763
BigEight-6	Sprinkler	Alfalfa	4	219
BigEight-7 All Hands Highwater Ditch	Sprinkler	Alfalfa	4	398
BigEight-8	Sprinkler	Alfalfa, Grass	4.5	201
BigEight-9 All Hands Ditch	Sprinkler	Alfalfa, Grass	9.2	398
BigEight-10	Flood	Grass	9.3 (13.98)	438
BigEight-11a Cartright Ditch	Flood	Alfalfa	4.7	371.3
BigEight-11b Hill Ditch	Flood	Grass	2.4 (7.08)	91
BigEight-12	Flood	Pasture	4.5	201
BigEight-13 Getchrup Ditch	Flood	Pasture	0.6 (2.76)	18
BigEight-14 Devils Canyon	Flood	Pasture	1.8	73
Big Springs Creek Diversions				
Big Springs-1a	Pivot	Alfalfa	1.70	118.00
Big Springs-1b	Flood	Pasture	6.74	338.00
Big Springs-2	Flood	Grass	1.18	40.00
Big Springs-3	Flood	Pasture	1.36	?
Big Springs-4	Flood	Pasture	0.85	27.00
Big Springs-5a	Flood	Pasture	0.65	?
Big Springs-5	Flood/Sprinkler	Alfalfa, Grass	3.40	113.00
Big Springs-6	Flood	Pasture	5.57	185.00
Big Timber Creek Diversions				
Big Timber-1	Flood	Pasture	0.02	0.5
Big Timber-2	Flood	Pasture	0.5	25
Big Timber-3	Flood/Sprinkler	Alfalfa	5.88 (26.88)	626.8
Big Timber-4	Flood	Pasture	?	?

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Big Timber-5	Flood	Pasture	2	?
Big Timber-6	Flood	Alfalfa	4.2	?
Big Timber-7	Flood	Alfalfa	4.78	?
Big Timber-8	Flood	Alfalfa	6.24 (21.39)	?
Big Timber-9	Flood	Pasture	10.8	?
Big Timber-10	Sprinkler	Grass	8.78	?
Big Timber-11	Flood	Grass	27.8	?
Big Timber-11a	?	?	?	?
Big Timber-12	Sprinkler	Alfalfa	6.96	?
Big Timber-13	Flood	Pasture	2 (3)	?
Camyon Creek Diversions				
Canyon Ck-1	Sprinkler	Alfalfa	5.5	?
Canyon Ck-2	Sprinkler	Alfalfa	1.24	?
Canyon Ck-2a			1.54	?
Canyon Ck-3			5.24	?
Eighteenmile Creek Diversions				
Eighteenmile-1	?	?	2.3	?
Eighteenmile-2	?	?	1.8	?
Eighteenmile-3	?	?	1.2	?
Eighteenmile-4	?	?	1.56	?
Eighteenmile-5	?	?	1.2	?
Eighteenmile-6	?	?	1.2	?
Eighteenmile-7	?	?	1.2	?
Eighteenmile-8	?	?	1.2	?
Eighteenmile-9	?	?	1.2	?
Eighteenmile-10	?	?	6.47	?
Eighteenmile-11	?	?	3.1	?
Eighteenmile-12	?	?	0.98	?
Divide Ck-1	?	?	0.7	22
Eighteenmile-13	?	?	1.61	170
Eighteenmile-14	?	?	1.36	93
Eighteenmile-15	?	?	1.2	55
Eighteenmile-16	?	?	4.5	
Eighteenmile-17	?	?	5.73	287

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Eighteenmile-18	?	?	1.2	55
Eighteenmile-19	?	?	1.76	71
Hawley Creek Diversions				
Hawley-1	Sprinkler	Alfalfa	5.5 (6.78)	445
Hawley-2	Flood	Pasture	6.5 (19.5)	581
Hawley-3	Sprinkler	Hay	15.7	719.4
Hawley-4	Flood	Pasture	2	40.4
Lee Creek Diversions				
Lee Ck-1 McConnell	Flood	Pasture	0.04	1
Lee Ck-2 McConnell	Flood	Pasture	0.24	12
EversonStroud-1 Whittaker	Sprinkler	Alfalfa, Grass	3.2	291
EversonStroud-2 Harry's Ditch	Sprinkler	Alfalfa	4.4	377
EversonStroud-3a	Flood/Sprinkler	Alfalfa	4	186
EversonStroud-3b McConnell	Flood	Pasture	?	?
EversonStroud-4	Flood	Pasture	3.4	65
Lemhi River Mainstem Diversions				
L-46A	Flood	Pasture	?	?
L-47	Flood	Grass, Pasture	?	?
L-48			?	?
L-49	Flood	Alfalfa, Pasture	?	?
L-50	Flood	Alfalfa, Pasture	?	?
L-51	Flood	Pasture	?	?
L-52a	Flood	Pasture	?	?
L-52	Flood	Pasture	?	?
L-54	Flood	Pasture	?	?
L-57	Flood	Pasture	?	?
L-58	Flood	Pasture	?	?
L-58a	Flood	Alfalfa, Pasture	?	?
L-58b	Flood	Alfalfa, Pasture	?	?
L-58c	Flood	Alfalfa, Grass	?	?
L-59	Flood	Alfalfa	?	?
L-60	Flood	Pasture	?	?
L-61	Flood	Pasture	?	?
L-62	Flood	Pasture	?	?

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
L-63	Flood/Sprinkler	Pasture	?	?
Little Eightmile Creek Diversions				
Little Eightmile-1	Sprinkler	Alfalfa	2.72 (48.64)	133
Little Eightmile-2	Flood	Grass	1.01	38
Little Eightmile-3	Flood	Grass	.85 (10.75)	19
Little Springs Creek Diversion				
Little Springs-1	Flood	Hay	4.03	123
Little Timer Creek Diversions				
Little Timber-1	Sprinkler	Alfalfa	9.3 (14.1)	?
Little Timber-2	Sprinkler	Alfalfa	13.22 (35.63)	?
Little Timber-3	*Sprinkler*	Alfalfa	3.84	?
Little Timber-4	*Flood*	Pasture	14.1 (16.5)	?
Little Timber-5	*Flood*	Grass, Pasture	6.2	?
Mill Creek Diversions				
Mill Ck-1 Amonson	Sprinkler	Alfalfa	3.22	89.9
Mill Ck-2 Morphey	Flood	Grass	0.4	20
Mill Ck-3 Tyler Rockpile	Grass	Grass	0.9 (8.32)	45
Mill Ck-4 Snyder	Flood	Grass	1.2	46
Mill Ck-5a Tyler	Flood	Grass	2.5	93
Mill Ck-5b Amonson	Flood	Grass	6.36	72
Mill Ck-6	Sprinkler	Alfalfa	24.84 (38.9)	862
Mill Ck-7 McFarland Livestock Co.	Flood	Pasture	2.2	114
Mill Ck-8 DC Weirs	Flood	Grass	19.93	1093
Texas Creek Diversions				
Texas Ck-1	Flood	Pasture	2.91 (4.91)	?
Texas Ck-2	Sprinkler	Alfalfa	13.4 (16.4)	?
Texas Ck-3	Flood	Pasture	2.83	?
Texas Ck-4	Flood	Pasture	7.2	?
Texas Ck-5	Flood	Pasture	4.23	?
Texas Ck-6	Flood	Pasture	6.6	?
Texas Ck-7	Flood	Pasture	4.72	?
Texas Ck-8	Flood	Pasture	6.6	?
Texas Ck-9	Flood	Pasture	1.68	?
Texas Ck-10	Flood	Pasture	1.3	?

MIKE BASIN Offtake Nodes (Diversions)	*Irrigation Type**	*Crop Type*	*Total Diversion (cfs)***	*Total Irrigated Acres*
Texas Ck-11	Flood	Pasture	1.48	?
Texas Ck-12	Flood	Pasture	3.53	?
Texas Ck-13	Flood	Pasture	2.14	?
Texas Ck-14	Flood	Pasture	1.18	?
Negro Green-1	Flood	Pasture	9.01	?
Deer Ck-1	Flood	Pasture	4.59 (19.19)	?
Sourdough-1	Flood	Pasture	1.42	?

* Irrigation types found in the Lemhi River Basin are flood, sprinkled, or pivot. If it states 70% flood, the other 30% is assumed to be sprinkled.
** The values in parentheses are the high flow water rights in cfs.

7 RECOMMENDATIONS FOR FURTHER DEVELOPMENT OF THE LRMBM

Though IDWR and DHI personnel completed the initial phase of extending the LRMBM to include the upper Lemhi River Basin, additional analysis and data collection are required to develop a calibrated model. These recommendations do not reflect any additional data and analysis that may be required to address specific questions posed to the model in the future. However, implementing these recommendations will provide greater insight into water movement in the Lemhi River and its tributaries, and thus can provide a greater foundation for the LRMBM.

7.1 Data Collection

The quantity and location of data collection will be a function of time, budget, and the questions users would like to address using the LRMBM. As the limiting element in the calibration of the LRMBM is the stream flow and diversion discharge time series information, these are of utmost importance for development of the model. Specific data needs are:

- *Daily diversion discharge* – Operation of the diversions significantly influences flow in the modeled tributaries. Because the total natural discharge to these streams is typically minimal, the diversions typically cause the tributaries to go dry during much of the irrigation season. In order to more accurately model the tributary diversions, daily measurements of discharge should be measured for each diversion. The discharge can be measured directly using a structural measuring device, such as a weir or flume, or indirectly by measuring water level from a staff gauge or measured with a pressure transducer. If the water level is obtained, a stage-discharge rating curve is necessary to convert the stage records to discharge. Ideally, stream flow gages would be installed on each modeled tributary upstream of any diversion. This gage would provide measurements of actual inflows to the tributary and thus could be used to calibrate the rainfall-runoff model or StreamStats analysis.

If permanent gages cannot be established on all the tributaries, a method must be devised that combines stream gaging on select tributaries with statistical means of extrapolating the record to other basins. For example, a statistical relationship could be developed between observed flows on gaged basins and StreamStats estimates for the same basin. This relationship could then be applied to other similar, ungaged basins in order to 'adjust' the Streamstats estimate to better account for local hydrologic conditions.

- *Stream gaging upstream and downstream of sensitive areas on tributaries* – The original LRMBM accounted for contributions to the Lemhi River from precipitation, ground water gains/losses, and tributary inflow by modeling reach gains/losses. This same approach has not been applied to the tributaries due to lack of discharge data for the tributaries. However, it would be highly instructive to have gages installed below sensitive reaches where flow is a limiting factor to fish habitat. Such reaches could be identified by IDWR and other agencies and the data could be used to model reach gains and losses do to natural and anthropogenic impacts.
- *Daily diversion discharge* – Operation of the diversions significantly influences flow in the modeled tributaries. Because the total natural discharge to these streams is typically minimal, the diversions typically cause the tributaries to go dry during much of the irrigation season. In order to more accurately model the tributary diversions, daily measurements of discharge should be measured for each diversion. The discharge can be measured directly using a structural measuring device, such as a weir or flume, or indirectly by measuring water level from a staff gage or measured with a pressure transducer. If the water level is obtained, a stage-discharge rating curve is necessary to convert the stage records to discharge.
- *Use of METRIC data in the return flow calculation* – To determine the consumption rate in the LRMBM, the ET rate is based on the reference ET data from Corvallis, Montana. IDWR currently calculates the actual ET rate throughout the Lemhi River Basin from satellite imagery. It is recommended that the calculated ET rate replace the reference ET rate to improve accuracy of the agriculture nodes.
- *Ground water data* – There is a close linkage between ground water and surface water resources in the upper Lemhi Basin. In order to better track the magnitude, rate and locations of ground water flow paths better ground water data must be obtained. Possible approaches for collecting this data include: conducting seepage runs along Little Springs and Big Springs Creeks in order to determine the amount of water gained along these streams and installing piezometers or shallow wells to monitor ground water levels in key areas (e.g., the Big Springs Aquifer). Tracer tests could also be conducted in order to track ground water flow paths. For example, conservative tracers could be used to determine whether the Mill Creek diversions are supplying ground water directly to Little Springs Creek or if these return flows are re-entering the Lemhi River further downstream.

7.2 Modeling

The primary modeling tasks that need to be completed involve populating the model with diversion data and calibrating the entire model. Calibration involves adjusting the reach gains/losses, lag times and *IGW* values to attempt to match the simulated and observed discharges. Calibration will also involve adjusting the lag time and storage characteristics of the LRMBM GW model. The Microsoft Excel file *LRMBMCalib.xls* has been developed to aid in this process.

At the conclusion of this phase, ground water is only modeled explicitly for Big Springs Creek and Little Springs Creek. Along the mainstem Lemhi River, ground water can be accounted for by adjusting lag times on return flow paths and by creating a third ground water model. The lag time method can be used to account for different return flow rates for overland and shallow subsurface flow whereas the ground water model can be used to represent larger-scale exchange between the aquifer, individual diversions and a discrete aquifer outlet location. In places where return flows follow subsurface flow paths, the lag times will be greater than for places where return flows return to the stream via overland flow paths. For the tributaries, lag times were not computed due to insufficient data. However, DHI and IDWR personnel did make notes indicating the estimated return flow times as recorded during meetings with water masters. Where available, such notes are included in the Lemhi River diversion Microsoft Excel worksheet.

The Mill Creek Reservoir and any other reservoirs in the upper Lemhi River Basin could be more accurately modeled if additional data were available. Currently the Mill Creek Reservoir is modeled using place-holder rules, but because this is a decreed and actively used reservoir, more accurate data should be available. Specific data that is needed to better model the reservoir includes: storage area characteristics and any guidelines or rule curves used to operate the reservoir.

There are currently no water users pumping ground water for irrigation in the LRMBM. However, these water users could easily be added to the model so long as sufficient data exists that details pumping rates and aquifer characteristics. If the ground water users are pumping from the two shallow aquifers already in the model (e.g., Little Springs and Big Springs aquifers), then the water user could be added just by specifying a pumping rate. If the ground water user is extracting from another aquifer, then that aquifer must be added to the model. Alternatively, one could assume that ground water abstraction is ‘unlimited’ meaning that the water user can pump at the desired rate with no limitations placed on the abstraction. If the latter method is chosen then the aquifer need not be defined.

The United Nations FAO 56 method for evaluating crop evapotranspiration and computing crop water requirements has been recently incorporated into MIKE BASIN. This methodology may provide IDWR a more simple yet also robust method for computing *ET*, as the calculations are performed entirely within MIKE BASIN, which eliminates the need for external Microsoft Excel macros which are currently used to calculate *ET* and return flows. The FAO 56 method could be incorporated into future upgrades of the LRMBM.

7.3 Additional Analysis

There are several analyses that while not crucial to development of a calibrated model, would increase the understanding of water movement in the basin.

- *Precipitation analysis* – Currently precipitation is not incorporated into the upper Lemhi River portion of the LRMBM. However, early in the irrigation season when large frontal storms enter the basin, stream flow may be influenced by precipitation. In the original

LRMBM, it was proposed that “local design storms” could be developed to account for the temporal and spatial distribution of these large storms. Here, we propose that the precipitation analyses be extended to the upper Lemhi River and its tributaries so that precipitation from large storms can be added to reach gains for each tributary.

- *Seepage runs on selected tributaries* - A concurrent seepage run and simulation on selected high-priority tributaries would provide greater foundation for calibrating and refining the LRMBM. Seepage runs are recommended at both the onset of the irrigation season when flow in the Lemhi River and its tributaries diminishes and late in the irrigation season during low flow.
- *Ground water* - Ground water levels and return periods are important in dictating the instream flows during the spring runoff period and late summer and early fall when the snowmelt contribution is negligible. In the LRMBM, the parameters most affected by the ground water-surface water interaction are the initial abstraction early in the irrigation season and IGW lag time later in the irrigation season. Further analysis of ground water well hydrographs, sensitivity of the initial abstraction duration and magnitude, and IGW lag time would improve the model representation of the natural system. Coupling ground water analyses with field studies, such as seepage runs or piezometer studies, could further improve the understanding of ground water behavior in both the Lemhi River and its tributaries.

8 CONCLUSIONS

From February 2006 through July 2006, IDWR and DHI personnel extended the original LRMBM to include the Lemhi River and 12 tributaries upstream of McFarland Campground. The surface water budget model is developed in MIKE BASIN, a river network model that is based on an ArcGIS platform. In general terms, MIKE BASIN is a mathematical representation of the river basin encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, and existing as well as potential major water use schemes and their various demands for water.

This phase of the project has resulted in the development of skeleton surface water budget model for the Lemhi River and 12 tributary basins upstream of McFarland Campground. DHI and IDWR have worked carefully to ensure that all diversions as well as tributary connections to the Lemhi River and key ditch systems are accurately represented in the model. As part of the model development, DHI and IDWR also created a water rights inventory for diversions in the upper Lemhi River Basin and prepared an extensive list of notes documenting water masters’ comments and additional unresolved issues for each diversion. This water rights inventory, along with the LRMBM, provides a comprehensive framework for better understanding the complex water management and hydrologic system of the basin.

To augment the time series input and calibration of the LRMBM, DHI developed a set of Microsoft Excel workbooks that will assist IDWR with future model efforts. These workbooks include a file that will automatically generate empty time-series files with the appropriate names, a file to calculate return flows and load data into the time-series files, and a file to assist with model calibration.

Model data required for this project includes stream gage records; daily discharge data for each diversion; and irrigated area, *ET* rates, crop type, and area serviced by sprinkler irrigation within each irrigated area. At the completion of this phase of model development, there were insufficient time series data to develop a calibrated model for the entire model area. Although the original LRMBM containing only the mainstem Lemhi River had been calibrated (DHI, 2003), the current model is much more complex and therefore requires a substantial amount of additional data in order to develop a defensible calibration. Upon calibration, the LRMBM will enable the user to evaluate operation plans by viewing the simulation results with a GIS background that can show the river, points of diversion and return flows, irrigation canals, and canal service areas superimposed on aerial photography of the area. An additional advantage to the Microsoft Excel interfaces is that users with little operational knowledge of MIKE BASIN can run scenarios directly from Microsoft Excel using MIKE BASIN as the computational kernel.

Developing the skeleton LRMBM involved building the river network and compiling, computing, formatting, and inputting the data. The river network and diversion locations primarily reflect water masters knowledge of the Lemhi River and its tributaries. The upper Lemhi River portion of the LRMBM encompasses the Lemhi River upstream of McFarland Campground. Selected tributaries are also included in the model including: Little Springs, Big Springs, Mill, Lee, Big Eightmile, Big Timber, Little Timber, Texas, Eighteenmile, Hawley, Canyon, and Little Eightmile Creeks.

As the groundwater component of stream flow is believed to be important for maintaining Lemhi River flow throughout the summer (Sager, personal communication, 2006), the MIKE Basin Ground Water Module was implemented on Big Springs Creek and Little Springs Creek as well as the surmised catchment areas feeding those springs (Appendix A). Return flows from diversions from Big Timber, Bi Eightmile, Lee, and Mill Creeks that potentially augment spring flow are included in the model. The preliminary model showed a positive response to irrigation practices.

In this phase of the project, catchment inflows for the tributaries in the upper Lemhi River Basin were estimated by developing Rainfall-Runoff models for each tributary basin (Appendix B). The preliminary model results indicate a positive correlation between simulation and observed stream flow.

Though IDWR and DHI personnel completed this third phase of the LRMBM development, additional analysis and data collection are needed to develop a fully calibrated model. Further data collection for stream and diversion flow is essential to accurately quantify water movement throughout the basin. Areas of concern where data is limited or poorly understood should receive additional stream flow measurements. Additional data and information describing the tributary connections to the Lemhi River and diversion practices would also be instructive.

The LRMBM is a dynamic model that can be refined and expanded as data becomes available and as new questions are identified. The LRMBM's first phase of development involved the construction of a calibrated MIKE BASIN model for the mainstem Lemhi River. In the second phase, the model was extended to include 14 tributary basins and key ditch systems downstream of McFarland Campground. In this third phase of model development, the model was extended to include the Upper Lemhi Basin and 12 tributaries upstream of McFarland Campground. The Lower Lemhi model was merged with the Upper Lemhi model to create a comprehensive model of the entire Lemhi River Basin. With additional data this extended model can be used to demonstrate how the irrigation diversions along the Lemhi River and its tributaries can be operated to meet stream flow targets.

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APPENDIX A:

DEVELOPMENT OF A LINEAR GROUND WATER MODEL FOR LITTLE SPRINGS & BIG SPRINGS CREEKS IN THE UPPER LEMHI RIVER BASIN

A-1 INTRODUCTION

This appendix describes the use of the MIKE BASIN Ground Water Module (GW) to support the Lemhi River MIKE BASIN Model (LRMBM). The MIKE BASIN GW is used to simulate the effect of irrigation on stream recharge; it is widely believed that flood irrigation promotes elevated ground water levels in the Lemhi River Basin and that this shallow ground water slowly percolates back to the main valley floor where it supports stream flows during the dry season. The ground water model described herein is a skeleton model that is intended to provide a preliminary framework for modeling ground water surface water interaction in the Lemhi River Basin. The ground water model constructed in the LRMBM was to evaluate the recharge to the Little Springs and Big Springs Creeks from irrigation diversion along Mill, Lee, Big Timber, and Big Eightmile Creeks. This document provides background on the MIKE BASIN GW, describes how the it was constructed, the data used to populate the model, summarizes model performance, provides results from a demonstration simulation, and provides suggestions for improving the model and data needed to model ground water in the study area.

A-2 MODEL USED: MIKE BASIN GROUND WATER MODULE

The Ground Water Module (GW) within MIKE BASIN uses a linear reservoir model where ground water discharge through to the stream is proportional with water level. The GW dynamic calculates the water balance in the ground water reservoir at each time step, accounting for the exchange between the surface water and ground water. The ground water aquifer interacts with the surface water system through several fluxes:

- Stream seepage - stream loses water to the aquifer
- Ground water recharge - catchment contributes discharge to the aquifer
- Ground water discharge - aquifer discharges to the stream
- Ground water pumping – water user can pump water to or from the aquifer

Ground water abstractions can be modeled in several ways. Pumping demands can be either specified as an absolute time series (e.g., water user pumps 3 gpm each day for a month), or as a fraction of the overall demand. The model can also be used to simulate ground water recharge by assigning negative pumping rates to water users.

The MIKE BASIN GW uses a linear reservoir model that assumes the catchment area is constant and that ground water discharge is also proportional with storage. The coupled differential equations solved in the linear ground water model are:

$$\frac{\partial h_1}{\partial t} = (-k_1 - k_i)(h_1 - L_1) + q_{recharge} + Q_{stream\_seepage} \qquad \text{(Equation A.1)}$$

$$\frac{\partial h_2}{\partial t} = k_1(h_1 - L_i) - k_2(h_2 - L_2) - q_{pumping} \qquad \text{(Equation A.2)}$$

The variables in Equations A.1 and A.2 are depicted in Figure A1 where the dimensions of L and h are length and k is a rate (L/t). In the simplest ground water model, (e.g., no inflows are specified) the storage in the aquifer will exponentially decay over time. The time constant t determines the speed of the exponential decay and is set for k_1 and k_2. In a simple ground water model with no inflows, after time, only 36.8% of the original storage will remain.

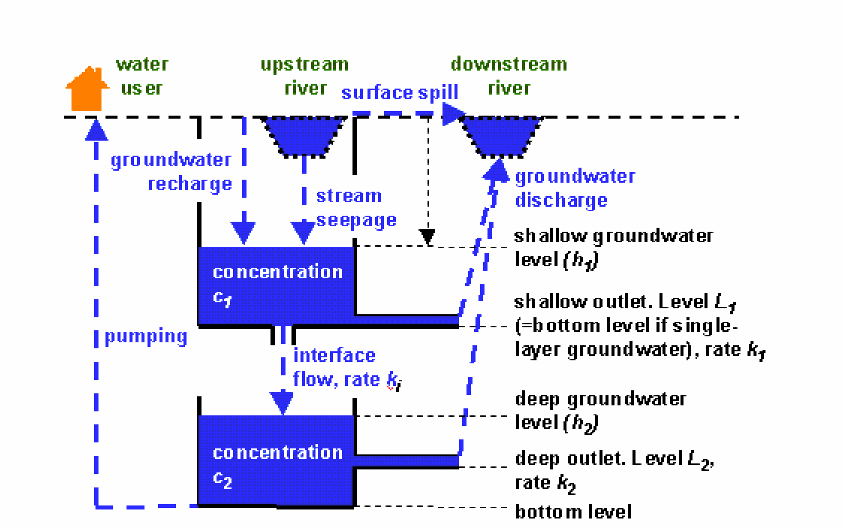

Figure A1. Conceptual model of the linear ground water model in MIKE BASIN. Reservoirs including the rivers and ground water layers are denoted in blue polygons. Water fluxes are denoted blue dashed lines with arrows. The parameters in Equations A.1 and A.2 are expressed in the descriptions.

Calibration of a linear ground water model involves tuning both the aquifer characteristics and the water user properties until the model is providing realistic results and performing in a manner consistent with observed data. For example, once the model is populated with the best available data, parameters such as the time constant and storage thickness can be varied. Storage thickness is defined by specifying the depth to the outlet of the aquifer and the depth to the initial water table. Because the ground water model is based on the linear reservoir model, MIKE BASIN does not account for porosity, thus the storage thickness must account for the actual volume of water stored in the aquifer—not just the volume of the water-bearing geological formation. As it can be difficult to quantify the precise volume of stored water, the storage thickness characteristics are best determined through calibration. Additionally, the time series defining catchment runoff and inflows may also require calibration, or at least validation, because it can be difficult to constrain such parameters using observed data. A good starting point for the calibration exercise is developing a water balance for the catchment as this can provide many of the parameters needed for the model (Figure A1).

A-3 Model Construction

IDWR and DHI constructed a simplified MIKE BASIN GW for Little Springs Creek and Big Springs Creek in the upper Lemhi River Basin. The ground water model was constructed in the following manner:

1. The contributing aquifers to Little Springs and Big Springs Creeks were digitized in ArcGIS. It was assumed that the contributing area of this aquifer roughly followed the local topography (Figure A2). The Little Springs Creek aquifer was bounded by Mill Creek on the west, Lee Creek on the east, and Little Springs Creek to the north. The Big Springs Creek aquifer was bounded by big Eightmile Creek on the west, Big Timber Creek on the east, and Big Springs Creek to the north. The southern (upstream) boundaries of the aquifers were defined on the basis of topography because it was assumed that the alluvial deposits that compose the aquifer thin southward as the land elevation rises (Crosthwaite et al., 1965).

2. The contributing aquifers were defined as catchments in MIKE BASIN. The catchment outlets are located just above the confluence of Little Springs and Big Springs Creeks with the Lemhi River. The catchments were assigned the following properties:
    a. Depth to initial water table = 4 ft
    b. Depth to outlet = 5 ft
    c. Time constant = 180 days

    Note that the shallow thickness (aquifer is 1 ft deep) was used in order to better simulate the actual storage volume of the aquifer. In MIKE BASIN, ground water is treated as a reservoir and porosity or storativity of the aquifer is not explicitly stated. Thus, the groundwater reservoirs must scale the thickness in order to not overestimate the actual volume of water stored in the aquifer.

3. Each tributary water user that irrigates within an aquifer catchment area was assigned diversion demands based on their adjudicated water diversion amount as determined from the IDWR Water Rights database. Each water user located within the boundaries either the Big Springs and Little Springs aquifers was associated with the corresponding aquifer by specifying the ground water parameters for that water user (Figure A2).

4. Recharge from a specific water user to a ground water aquifer due to seepage from irrigation practices cannot be set within MIKE BASIN directly. Therefore, a macro written in Visual Basic for Applications was developed to account for this flux to the ground water aquifer. The Ground Water Macro (GW Macro) determines the total amount of water withdrawn for every water user in the GW at every time step (e.g., the diversion amount) and then delivers that quantity as a negative pumping rate to the aquifer. The user-specified portion that is delivered to the aquifer is:

    $$Seepage = S_f(\text{ diversion amount} - \text{surface return flow amount}) \qquad \text{(Equation A.3)}$$

    The default value for the seepage fraction (S_f) is 5% indicating that 5% of the total withdrawal amount not consumed by *ET* or used in return flow at each time step is 'pumped' back into the aquifer. The macro performs this calculation for each diversion in every time step.

A-4 TIME SERIES DATA

The time series data used in the demonstration model was selected in order that LRMBM GW simulations will highlight the interaction between flood irrigators from the tributaries and stream flow in Little Springs and Big Springs Creeks. Because the main purpose of the LRMBM GW was to investigate the impact of irrigation on stream flow, catchment runoff and aquifer recharge were set to null values. Catchment runoff was set to zero so that all water discharged from the aquifer was discharged as ground water, rather than a combination of direct runoff and ground water. This representation concurs with anecdotal evidence that suggests there is very little surface water runoff yielded from the alluvial terraces that form the aquifers (John Amonson, personal communication 2006, Rick Snyder, personal communication 2006). In addition, aquifer recharge was also set to zero in order to ensure that all recharge to the aquifer was due solely to seepage from irrigators. In reality, the alluvial aquifers likely receive inflows from upper areas of the watershed, however there is currently very little data describing the magnitude and timing of aquifer recharge (e.g., Crosthwaite et al., 1965, Spinazola, 1998, Donato et al., 1998). If data describing aquifer inflows and catchment runoff were available, these time series can be updated to include the additional data.

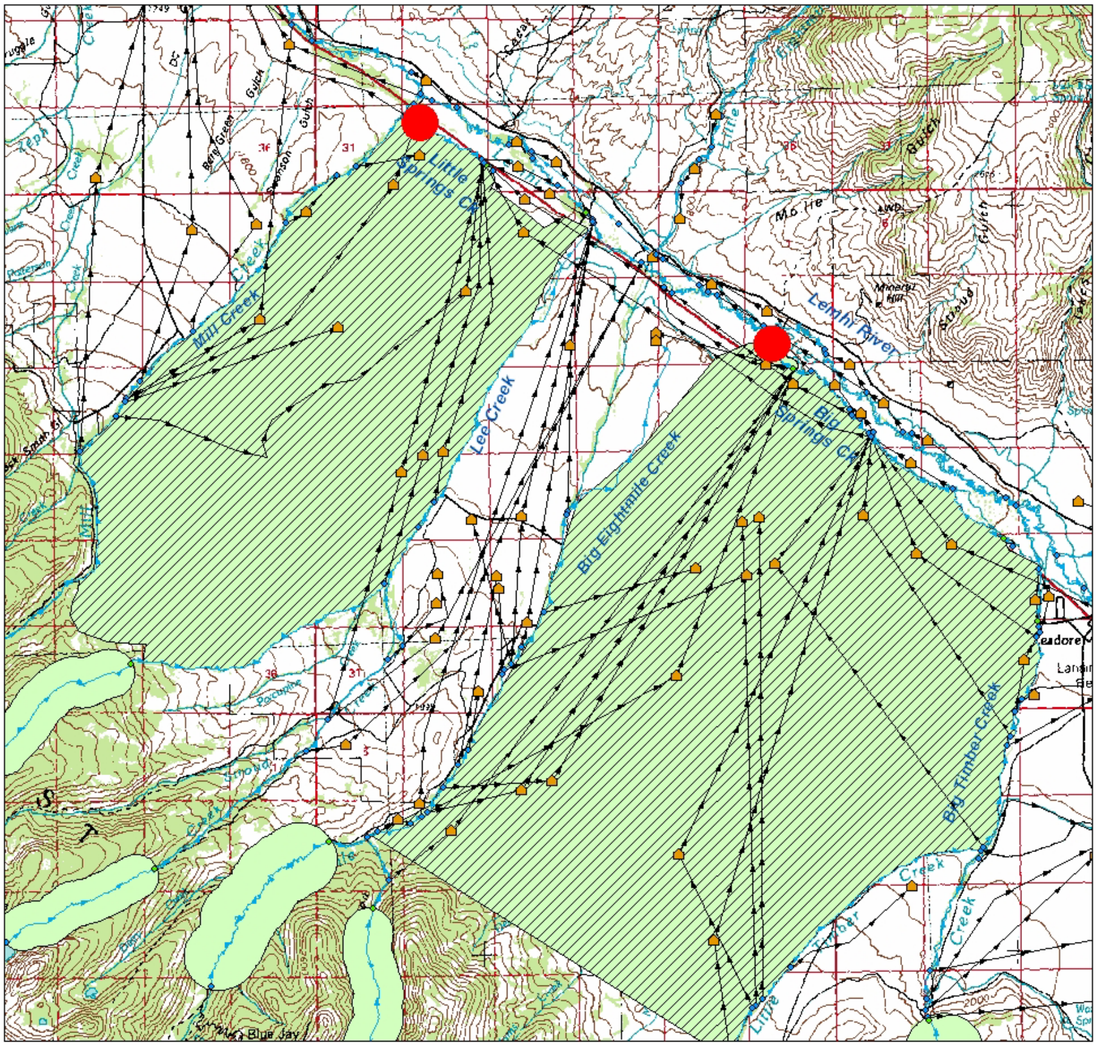

Figure A2. Schematic of the Little Springs and Big Springs ground water mode domain. The hatched green polygons represent the contributing aquifers for Big Springs Creek and Little Springs Creek. The red circles represent the outlet for each catchment that is located near each streams' confluence with the Lemhi River. The blue and black lines, unhatched green polygons, stream branch points, and orange pentagons are features in the MIKE BASIN network that represent the stream network, catchments, stream nodes, and irrigation nodes, respectively.

A-5 PRELIMINARY RESULTS

The LRMBM with the ground water component was model was ran for one irrigation season (April 1-September 30). This preliminary model trial showed that ground water discharge declined over time while ground water recharge from water users varied seasonally (Figures A3). Ground water recharge from water users initially rises with the commencement of the irrigation season, then declines as withdrawals are curtailed due to diminishing stream flows. The shape of the decline in ground water discharge is dictated by the storage characteristics of the aquifer and the time constant used to define the length of time necessary for a third of the original storage volume to remain.

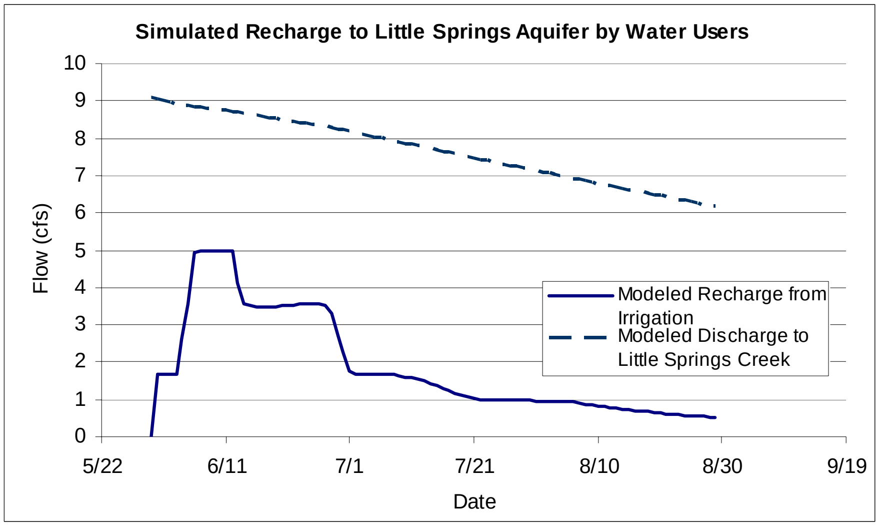

Figure A3. Preliminary model results from Little Springs Aquifer. Ground water discharge from the aquifer to Little Springs Creek is shown on the black dashed line while ground water recharge is shown in blue solid line.

The ground water - surface water interaction and irrigators in the Lemhi River Basin is complex. Because the linear groundwater model in MIKE BASIN is a lumped conceptual linear reservoir model, several limitations were necessarily in representing the physical system. The limitations listed below should therefore serve as opportunities for future data collection and model development.

- At this phase of the LRMBM GW development, the data used to populate the irrigation demand and catchment inflow is placeholder data from the water rights data set and uncalibrated rainfall-runoff analyses, respectively. Using these data, the aquifer characteristics were selected after running a series of simulations, where the shallow thickness of the aquifer (1 ft) and time constant (180 days) seemed to provide results that were within the realm of possible behavior for this type alluvial aquifer. In order to develop more accurate values for the aquifer thickness and time constants of the Big Springs and Little Springs Creeks' aquifers, stream flow and diversion data are needed.

- The aquifer boundaries were largely drawn on the basis of surface topography. However, the aquifer boundaries may not precisely follow ground topography and may be influenced by irrigators or streams outside of the current aquifer delineations. Additional data is needed to better define the subsurface flow paths in the upper Lemhi River Basin. Once such data is available, the aquifers can be defined more accurately.

- Currently, the GW Macro used to 'pump' excess irrigation water into the aquifer assumes that the portion of water entering the aquifers is constant for all water users. However, the actual fraction of water seeping into the subsurface is likely to vary across the landscape depending on the local hydrogeologic characteristics, antecedent soil moisture, or other factors. It would be beneficial to update the GW Macro so that the constant seepage rate can be temporally and quantitatively modified for each water user associated with an aquifer.

- Currently only flood irrigators are associated with the GW because it is assumed that sprinkler irrigation does not contribute significant volumes water after accounting for evapotranspiration. However, it may be beneficial to link areas irrigated by sprinklers with the GW if it is determined that sprinkler irrigation does contribute to ground water levels.

- The GW does not currently account for ground water contributions from ditch seepage or seepage through stream channels. However, there is substantial anecdotal evidence to suggest that seepage through streambeds and ditches can be quite high (Rick Sager, personal communication 2006; Croswthwaite et al., 1965). Computation of the ditch loss to the groundwater system would help to further quantify groundwater recharge associated with the irrigation diversions.

A-6 RECOMMENDATIONS

Additional data is needed to better understand the complex interaction of ground water-surface water and irrigation in the Lemhi River Basin. Currently, very little is known about subsurface flow paths, both with respect to the physical route that water may follow in the aquifer and the rate at which ground water travels. We propose developing a 'water budget' for selected areas within the upper Lemhi River Basin in order to better quantify both subsurface and surface water resources.

- It would be beneficial to quantify the total inflows to the alluvial aquifers feeding the Lemhi River system. Such an endeavor would involve quantifying inflows due to natural processes (e.g., ground water flow from upper areas of the catchment and local infiltration due to precipitation) as well as inflows contributed by irrigators.
- Currently, stream gages area located on Big Springs Creek and on the Lemhi River near its confluence with Big Springs Creek, but Little Springs Creek is ungaged. Because the MIKE BASIN linear ground water model is an empirical model, it requires calibration of the aquifer parameters in order to produce realistic results. It is recommended that discharge data be obtained for Little Springs Creek as well as discharge estimates of other large springs along the Lemhi River Valley floodplain. Estimates of ground water inputs can be gained from previous studies (Donato et al., 1998), but specific data quantifying ground water contributions at key locations in the upper Lemhi River Basin would greatly improve future modeling efforts.
- Tracer and isotopic studies could be used to establish subsurface flow paths and to determine the travel time for various paths. For example, a conservative tracer could be injected at various diversions or monitoring wells and used to determine where the irrigation water resurfaces and the length of time it takes to travel in the subsurface. Isotopic studies provide insight on the origin of water (shallow versus deep) that emanates from the springs.
- Monitoring wells or piezometers could be established in order to track temporal variability in ground water levels. For example, piezometers at key locations along the alluvial terraces could be used to track the elevation of the water table over time, which could be linked with discharge data for springs and diversion records in order to establish relationships between irrigation and ground water discharge.
- Implement a physically based groundwater model. Physically based ground water models more accurately calculate flow paths, groundwater tables, effects of recharge, and effects of pumping. However, these models need more data including aquifer geology, groundwater levels, pumping locations, irrigation locations, precipitation distribution and timing, *ET* rates, and land use cover. MIE SHE, a physically based integrated surface water – ground water is such a tool to evaluate the aquifer to this level of complexity.

A-7 CONCLUSIONS

DHI implemented the MIKE BASIN GW to investigate the interaction between irrigation, ground water, and surface water resources along Big Springs and Little Springs Creeks in the upper Lemhi River Basin. The MIKE BASIN GW is a lumped conceptual linear ground water model. The LRMBM GW was used to determine the fate of excess irrigation water that seeps into shallow aquifers and returns to the stream network. The recharge associated with excess irrigation water is discharged back into the stream network near the mouth of each creek. To facilitate this calculation, a customized Ground Water Macro was developed to calculate the amount of water that seeps into the subsurface during each time step.

Limitations in data have restricted the level of calibration and the extent of the modeling domain. As calibration of the GW parameters require data, additional stream flow data is required to fully calibrate the current LRMBM GW. In addition, the LRMBM GW domain can be expanded as the ground water component of other areas is to be studied. For example, Lee Creek (a tributary to the Lemhi River) and its water users could easily be added to the existing model because the Little Springs Aquifer and its physical properties are already defined. The LRMBM GW requires testing and calibration to ensure that aquifer volume and fluxes are realistic. However, such analyses are currently incumbent upon the availability of data describing diversion amounts, ground water fluxes, ground water flow paths, and other data.

Once additional data is available calibration would involve altering the aquifer parameters to get best match between simulated flows and observed data. The parameters that require calibration are the depth to initial water table, depth to outlet, and the time constant. Calibration of MIKE BASIN models is generally performed by simply running the model while varying the parameters sets (within a reasonable range). This process could be performed manually or automated by adaping existing Microsoft Excel sheets which have been created by DHI to automate the calibration of other MIKE BASIN parameters.

The LRMBM GW provides a practical framework for modeling ground water along the Big Springs and Little Springs Creeks. The LRMBM GW quantifies the portion of the irrigation water that recharges the local ground water system and predicts the timing of return. Though not fully calibrated, the LRMBM GW provides insight into the surface water irrigation – ground water recharge interaction that ultimately influences spring flows. As additional stream flow data is recorded, the model can be updated to refine our understanding. With the LRMBM GW, the influence of flood irrigation on summer flows can be evaluated to assist in managing water in the Lemhi River Basin.

A-8 REFERENCES

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APPENDIX B:

DEVELOPMENT OF RAINFALL-RUNOFF MODELS FOR THE UPPER LEMHI RIVER BASIN

B-1 INTRODUCTION

IDWR and DHI have developed a MIKE BASIN model of the upper Lemhi River Basin to evaluate water distribution associated with irrigation practices within the basin. The Lemhi River MIKE BASIN Model (LRMBM) requires inflow boundary conditions for all simulated tributary streams. As of June 2006, the majority of the tributary streams in the model are ungaged and tributary stream flows are not well understood by water managers. Therefore, a method was needed for developing stream flow time series for the inflow boundaries of the ungaged tributaries.

There are several methods that could be used in developing stream flow time series in the ungaged tributary streams to support the Lemhi River MIKE BASIN Model (LRMBM). These methods include installation of new stream gages, transfer of flow records from nearby catchments with similar characteristics, utilization of regional hydrologic curves or equations to predict statistical flows, and the development of rainfall-runoff models to simulate a catchments processing of precipitation into stream flow. The latter method was chosen for this study because rainfall-runoff models predict runoff given catchment attributes as well as changing precipitation rates. The MIKE BASIN Rainfall-Runoff Module (RR) was used in this study. For a more detailed discussion of the various alternatives and their advantages and disadvantages see *Rainfall-Runoff Modeling report for the Stanley and East Fork Salmon River Basins* (DHI, 2006).

B-2 MODEL USED: NEDBØR-AFRSTRØMNINGS-MODEL (NAM)

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

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

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

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

B-3 MODEL CONSTRUCTION

IDWR and DHI constructed a NAM model to predict daily stream flow for each tributary in the upper LRMBM. Catchment boundaries were delineated from a USGS 30 m NED digital elevation model (USGS, 2006). The catchments areas were delineated upstream of each catchment node in the upper LMBM which were located just upstream of the upstream-most active water diversion in the model. The resulting catchments were compared to watershed GIS coverages provided by IDWR to ensure reasonable catchment delineation.

The NAM model for the LRMBM consists of 16 catchments each of which were subdivided into two or three subcatchments in order to accurately account for variations in precipitation and temperature within the basin. The NAM catchments include Canyon Creek, Deer Creek, Devils Canyon, Sourdough Creek, Texas Creek, Little Timber Creek, Big Timber Creek, Negro Green Creek, Divide Creek, Eighteenmile Creek, Stroud Creek, Hawley Creek, Lee Creek, Mill Creek, Big Eightmile Creek, and Little Eightmile Creek (Figure B1, Table B1).

B-4 TIME SERIES DATA

Time series data required for the NAM models include concurrent precipitation, temperature, ET, and stream flow data. A summary of the available time series data and the methodology used to apply the data in the NAM model is provided below.

Climatic Data – The Lemhi River Basin is located near the eastern edge of the Northwestern maritime climate zone and climate is characterized by wet winters and dry summers. Most of the precipitation falls as snow during winter, with local convective storms occurring periodically during the summer months. Due to its mountainous nature, the precipitation and temperature measurements around the basin vary greatly depending on aspect and elevation of the meteorological gages. Precipitation and temperature data were available from seven NRCS SNOTEL sites located in or near the basin (NRCS, 2006). These sites include Schwartz Lake, Meadow Lake, and Moonshine in Idaho and Darkhorse Lake, Bloody Dick, Lemhi Ridge, and Beagel Springs in Montana (Figure B1). Additionally, precipitation, temperature, and ET data were available from Oregon State University's AgriMet site in Corvallis, Montana (USBR, 2006). In addition to these station data, spatially continuous monthly and annual precipitation and temperature data is available for the U.S. at a resolution of 2.5 arc-minutes from the PRISM dataset (PRISM, 2006).

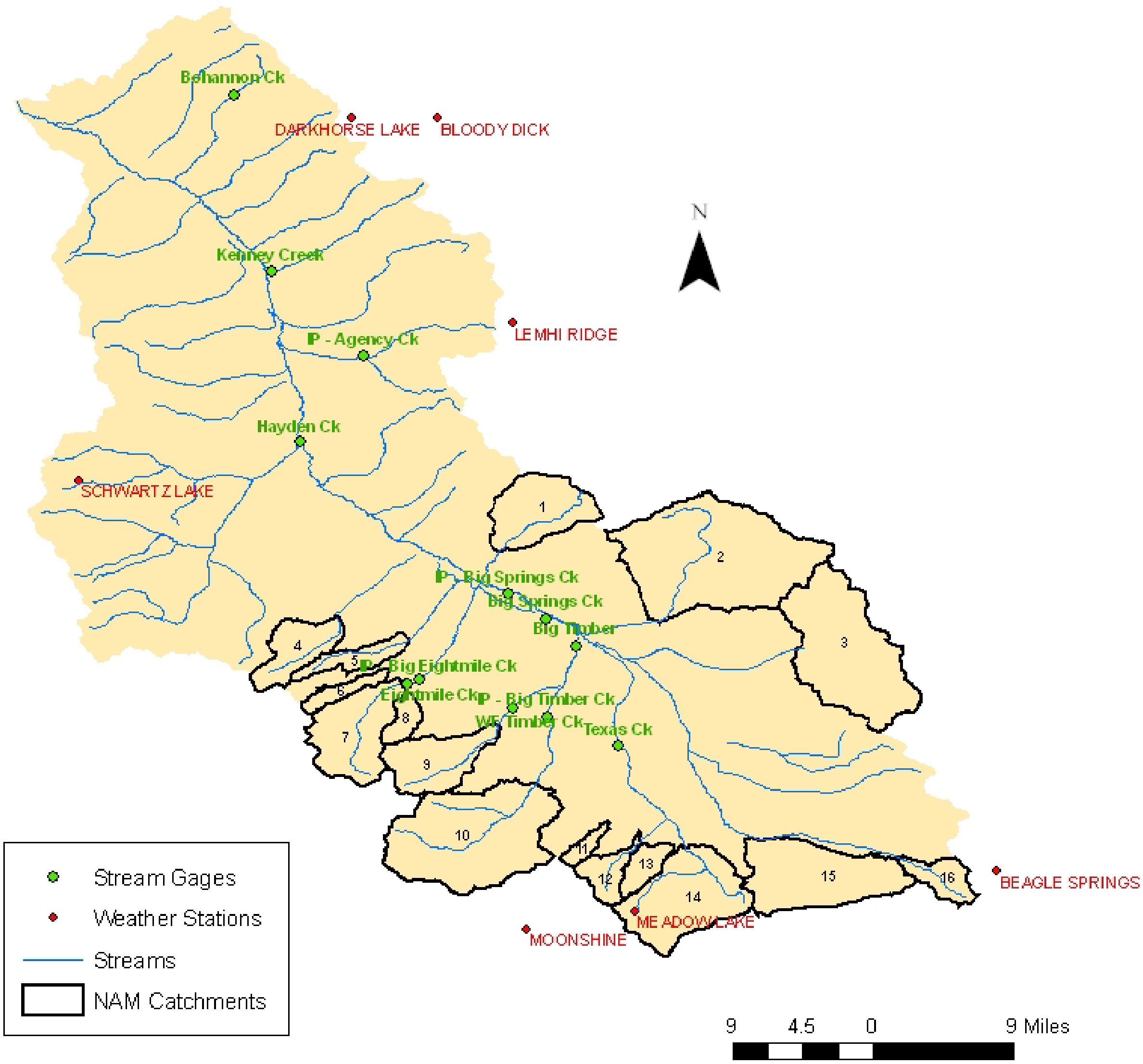

Figure B1. Locations of the catchments (basin numbers keyed to Table B1) and weather stations used in the NAM modeling of the Lemhi Basin. The Corvallis Station (not shown) is located approximately 80 miles to the Northeast of the Lemhi River Basin.

An examination of the PRISM data indicates that precipitation varies widely within the Lemhi River Basin from approximately 9 to 53 inches/year largely as a function of elevation. Rain shadow effects are also an important factor in controlling the variation of precipitation within the basin. The SNOTEL sites are located at elevations ranging from 7,440 to 9,150 feet above mean sea level (asl) and are more representative of the middle and upper elevation portions of the NAM catchments. The Corvallis AgriMet site is located at an elevation of 3,600 feet asl and is more representative of the lower elevation portions of the NAM catchments.

In order to obtain a precipitation distribution for the NAM model, the PRISM mean annual precipitation data from 1971 – 2000 was simplified into four precipitation zones. The zones are designated from lowest to highest precipitation as zones 1 through 4 (Figure B2A). The long-term average annual precipitation associated with each of the precipitation gage stations was estimated by taking the PRISM value at each station location. These values indicated that one station (Corvallis) had a value comparable to the zone 1 value, four stations (Beagel Springs, Lemhi Ridge, Schwartz Lake, and Moonshine) had values comparable to the zone 2 value, two stations (Bloody Dick and Meadow Lake) had values comparable to the zone 3 value, and one station (Darkhorse Lake) had a value comparable to the zone 4 value. A Thiessen Polygon method was used to determine polygons for the four gage sites comparable to zone 2 and the two gage sites comparable to zone 3 (Figure B2B, Figure B2C). The two Thiessen Polygon datasets were then merged with the simplified PRISM precipitation zones to produce a series of polygons with each polygon being associated with one of the eight precipitation gage sites (Figure B3).

Table B1. Catchments used in the NAM model showing drainage areas and climate station gages used.

Catchment	*ID #*	*Drainage Area (mi.^{2})*	*Gages Used*
Little Eightmile Creek	1	23.38	Corvallis, Lemhi
Canyon Creek	2	30.15	Corvallis, Beagel, Lemhi, Meadow
Hawley Creek	3	52.34	Corvallis, Beagel, Lemhi, Meadow
Mill Creek	4	14.72	Corvallis, Schwartz, Meadow
Lee Creek	5	8.33	Corvallis, Schwartz, Meadow
Stroud Creek	6	4.95	Corvallis, Schwartz, Moonshine, Meadow
Big Eightmile Creek	7	26.64	Corvallis, Moonshine, Meadow
Devils Canyon Creek	8	4.97	Corvallis, Moonshine, Meadow
Little Timber Creek	9	19.70	Corvallis, Moonshine, Meadow
Big Timber Creek	10	57.23	Corvallis, Moonshine, Meadow
Negro Green Creek	11	3.26	Corvallis, Moonshine, Meadow
Deer Creek	12	8.12	Corvallis, Moonshine, Meadow
Sourdough Creek	13	6.44	Corvallis, Moonshine, Meadow
Texas Creek	14	35.34	Corvallis, Moonshine, Meadow
Divide Creek	15	36.34	Corvallis, Beagel, Meadow
Eighteenmile Creek	16	8.37	Corvallis, Beagel, Meadow

In order to more accurately distribute the precipitation within the resulting precipitation polygons, it was necessary to scale the local gage site data to match the associated long-term average PRISM value. The long-term average PRISM value was first tabulated by taking an area-weighted average of the precipitation values within each of the precipitation polygons. The values were then compared to the gage site values determined from the PRISM data and a scaling factor was determined for each gage site used in the model (Table B2). The scaling factors were applied evenly throughout the period of record at each gage site to determine final time series of precipitation for each of the precipitation polygons.

The same polygons used to distribute the precipitation data were used to distribute the temperature data. No scaling was performed except for at the Corvallis gage site where long-term (1971-2000) PRISM minimum temperature data indicated a significant difference between the minimum temperatures at the Corvallis gage site and the minimum temperatures within the lowest temperature zone. Thus, the temperature record at the Corvallis site was scaled accordingly. Comparison of the PRISM temperature data with the other gage site data indicated relatively minor differences in temperatures between the zones and the associated gages, thus no scaling was performed initially at the other gage sites. During the calibration process, however, it was noted that snow accumulations were significantly lower than indicated by the SNOTEL data, thus a temperature reduction was applied to all of the temperature data in order to get the simulated snow accumulations to better match the observed accumulations. ET data was available at only one location, thus the daily ET data from the AgriMet site at Corvallis was applied throughout the model area.

Table B2. Scaling factors applied to the precipitation time series used in the model showing long-term annual average PRISM values in each polygon and the value of the gage associated with each polygon.

Gage	Polygon Value	Gage Value	Scaling Factor
Schwartz Lake	21.8	27.0	0.81
Meadow Lake	28.9	33.0	0.88
Corvallis AgriMet	13.0	13.0	1.00
Beagle Springs	21.9	25.0	0.88
Lemhi Ridge	21.4	25.0	0.86
Moonshine	22.3	23.0	0.97

Stream Discharge - Stream gage data along tributaries within the Lemhi Basin consists of sites along Kenney Creek, Bohannon Creek, Agency Creek, Hayden Creek, Big Springs Creek, Big Timber Creek, WF Timber Creek, Big Eightmile Creek, and Texas Creek. Unfortunately, only one of these locations, Big Eightmile Creek, has a recent record and is located above all known water rights and water diversions (Figure 1). Data from the other sites was considered for use in model calibration, however because of the uncertainty associated with actual diversion rates it would be difficult to compare simulated discharges with observed discharges at these sites. Thus the model was calibrated using only the Big Eightmile Creek gage and parameter values determined through this calibration were applied throughout the other catchments. The calibration period corresponded to the period of record at the gage which was from June 29, 2005 to May 2, 2006.

B-5 RESULTS AND DISCUSSION

For the Big Eightmile Creek gage calibration, the objective was to produce a simulation with an overall good fit to the observed data and with a strong emphasis on summer-time base flows to target flow regimes that are of highest concern to fish populations. The calibrated model produces a good visual fit to the observed discharges (Figure A.4), with simulated discharges providing a reasonable match to observed discharges including the timing of the spring and summer snowmelt recession, the magnitude of baseflows, and the timing of the rising limbs. The shorter duration runoff events occurring throughout the fall and winter are not captured in the simulated discharges because these storm events are presumably local events and are not reflected in the precipitation gage records used in the model.

It is difficult to evaluate the model predictions of peak flows because the gage data begins part way into the summer snowmelt recession and does not capture the peak flow. Comparison of the gage record with other gages in the basin indicated that peak discharges generally occur between early May and late June. Additionally, a gage located farther downstream along Big Eightmile Creek indicates a maximum flow of 96 cfs on June 6, 2005. These observations suggest that the flow occurring at the beginning of the gage

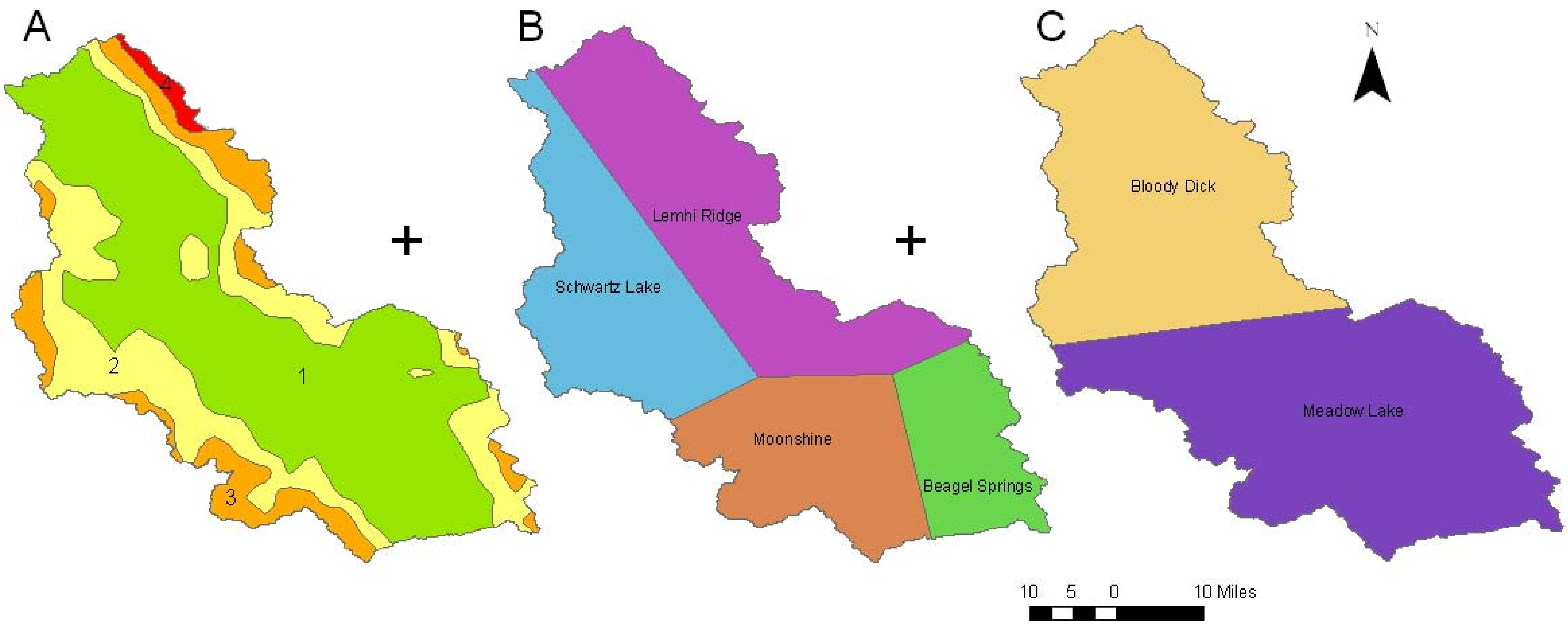

Figure B2. Process and data sources used to distribute climate data in the NAM model; A) Lumped PRISM data with zones 1-4 as described in the text, B) Thiessen Polygons for zone 2 showing station names, and 3) Thiessen Polygons for zone 3 showing station names. The final intersected polygons are shown in Figure B3.

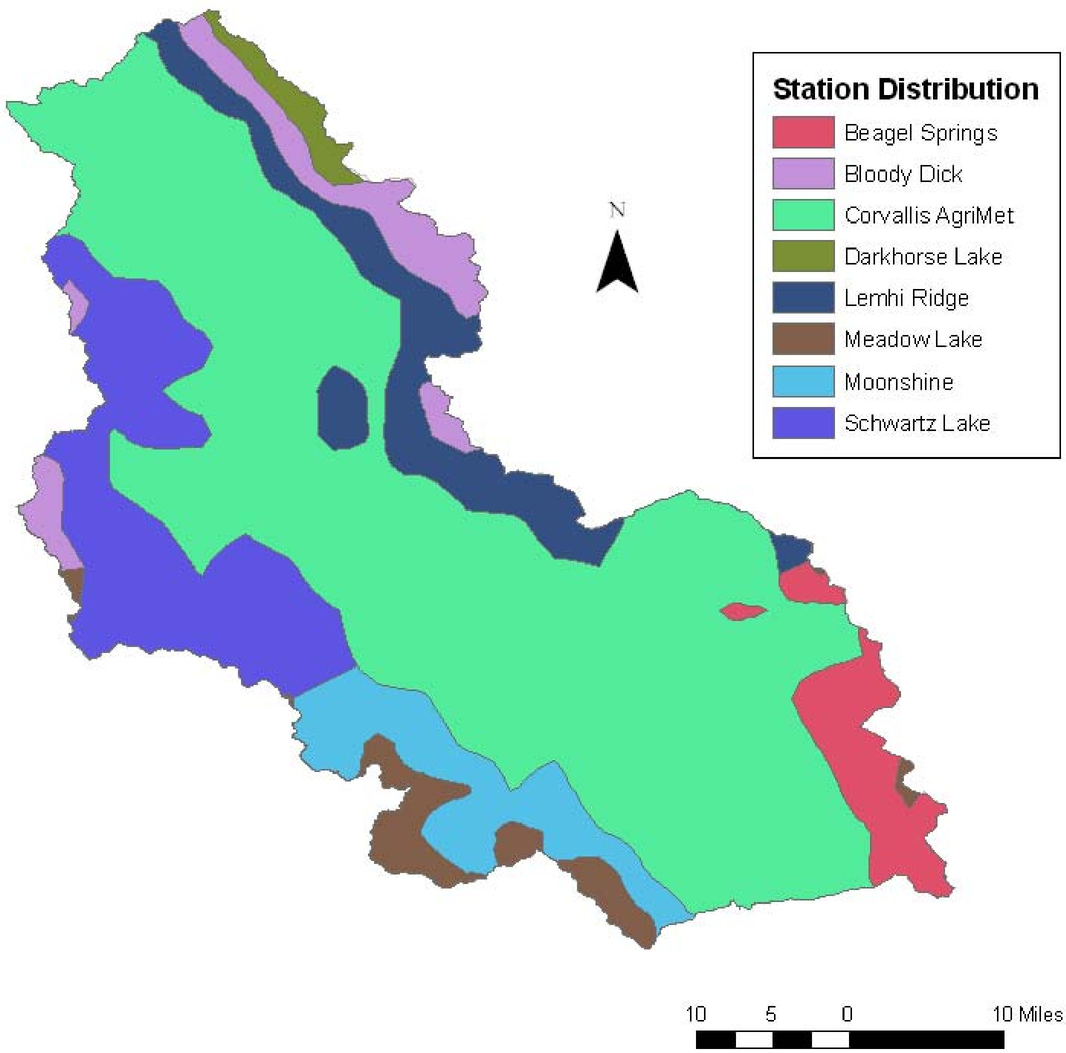

Figure B3. Final distribution of polygons used to distribute the temperature and precipitation station data in the NAM model.

record is close to the peak flow. Thus the simulated hydrograph showing a maximum flow of 103 cfs on June 8, 2005 appears to be reasonable. Quantitatively, the calibration has a mean residual value (ABS(simulated value – observed value)) of 1.5 cfs and a total volume error of -5.9% over the calibration period (June 29, 2005 to May 2, 2006) making it a very good calibration.

Input data used to calibrate the NAM parameters for the model include: daily accumulated precipitation and average daily temperature recorded at the Corvallis, Moonshine, and Meadow Lake climate stations; daily stream discharge data from the Big Eightmile Creek gage; daily ET data from the Corvallis climate station; and catchment area. Calibrated NAM parameters for the model are presented in Table A.3. These parameters determined through calibration in the Big Eightmile catchment were applied to the other catchments in the model. An example of the resulting simulated discharges for one of the catchments in the NAM model, Deer Creek, is shown in Figure A.5 for the period from January 2002 through December 2005, and mean monthly simulated discharges for all 16 catchments are shown in Table A.4.

Table B3. NAM parameters determined during calibration of Big Eightmile Creek catchment and applied to other catchments in the model.

Parameter	*Description*	*Value*
U_{max}	Maximum water content in surface storage	0.787 in
L_{max}	Maximum water content in root zone storage	11 in
CGOF	Overland flow runoff coefficient	0.25
CKIF	Time contstant for routing interflow	480 hrs
CK1,2	Time constant for routing overland flow	45.6 hrs
TOF	Root zone threshold value for overland flow	0.1
TIF	Root zone threshold value for interflow	0.5
Tg	Root zone threshold value for GW recharge	0.3
CKBF	Time constant for routing baseflow	600 hrs
C_{area}	Ratio of GW-area to catchment area	0.8
C_{snow}	Constant degree-day coefficient	0.0383 in/°F/Day
T_0	Base temperature (snow/rain)	32°F

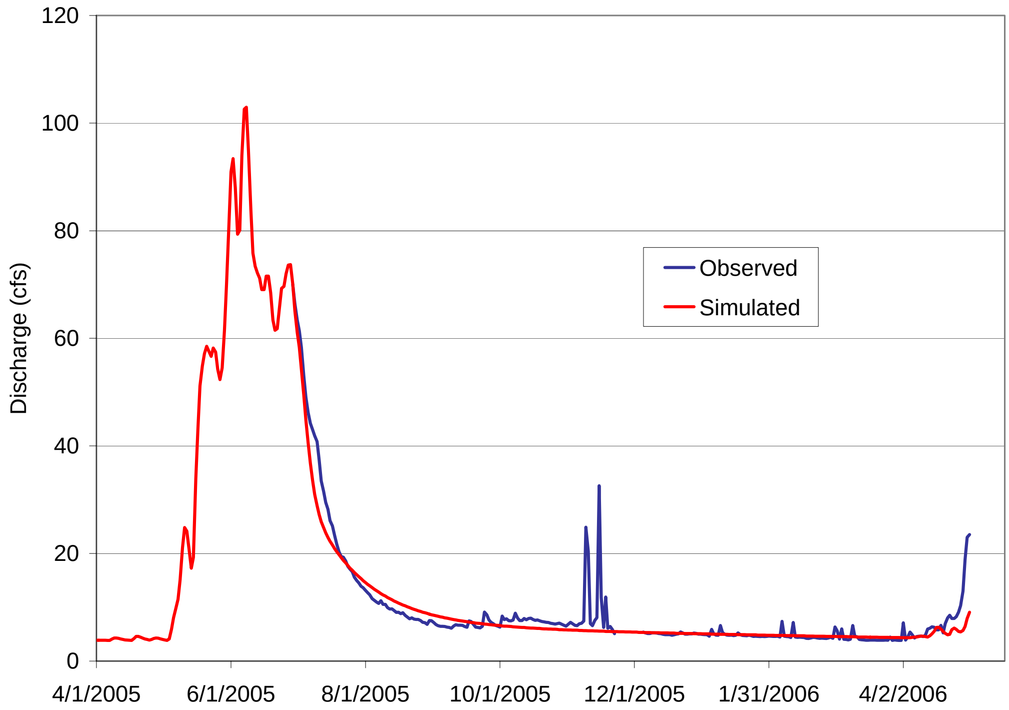

Figure B4. Comparison plot showing the observed discharge and the model simulated discharge for the Big Eightmile Creek catchment.

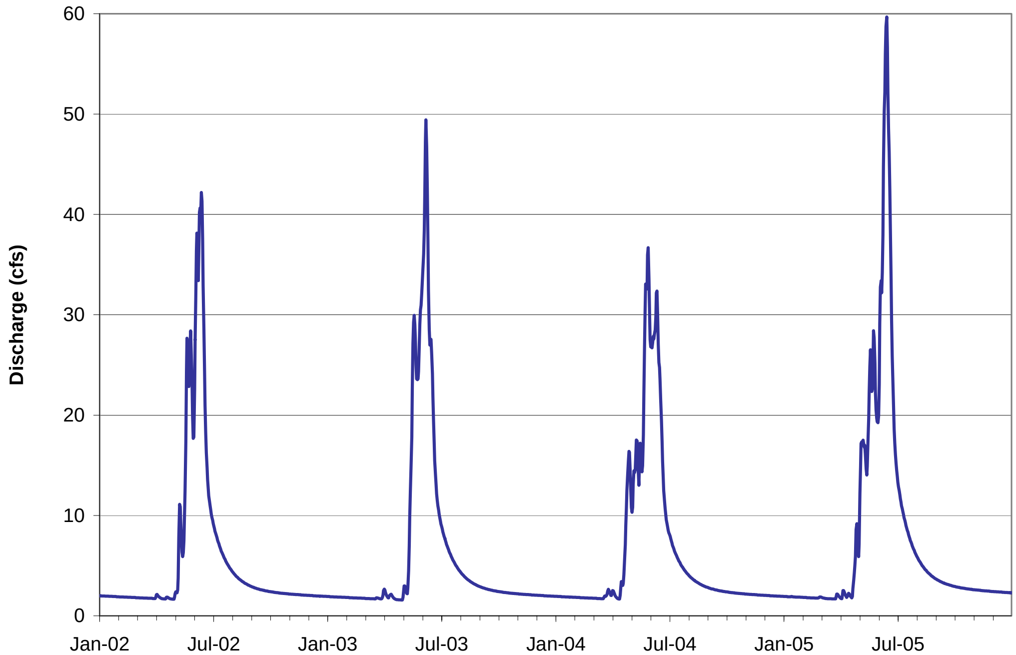

Figure B5. Simulated discharge for Deer Creek from January 2002 through December 2005.

B-6 LIMITATIONS

Several factors represent sources of uncertainty between the model simulated discharges and the actual discharges occurring in the basin, including:

- *Climate Data* – Although there are several weather stations in and around the basin, most of these are located at similar elevations in the upper elevation portions of the basin. There are relatively few weather stations available which represent conditions in the middle and lower elevation portions of the basin, and the Corvallis station used to represent the low-lying areas is located approximately 80 miles away in another basin and thus may not be representative of the area for which it was applied. Additionally, the use of only one gage location to represent ET in the entire basin does not capture the expected degree of variation in ET within the basin. Distributing precipitation, temperature, and ET using numerous gage locations would be particularly desirable in this basin where there is a very large degree of variation in topography, temperature, precipitation, and presumably ET.

- *Stream Gage Data* – Only one stream gage with recent data was available for calibration because of the uncertainty associated with the gage records at other gages located downstream of known water rights and stream diversions. Thus the model was calibrated at only one location resulting in a high degree of uncertainty about the accurateness of the simulated flows in the other catchments. Additionally, the gage used for calibration only has a little less than 1 year of data and does not capture the peak discharge. This is not ideal, and it would be preferable to have multiple gage locations with multiple years of data with which to calibrate to.

Table B4. Simulated mean monthly discharges (1997 – 2005 average) for the 16 catchments in the NAM model.

	Big Eightmile Ck	Big Timber Ck	Deer Ck	Devils Canyon	Little Timber Ck	Negro Green Ck
January	5.62	15.34	2.32	1.04	4.57	0.80
February	5.33	14.55	2.20	0.98	4.34	0.76
March	5.08	13.89	2.10	0.94	4.14	0.72
April	5.39	15.31	2.34	0.99	4.54	0.79
May	26.52	62.31	8.99	5.00	19.26	3.46
June	77.23	193.84	28.52	14.47	58.31	10.48
July	36.43	123.06	19.67	6.45	35.50	5.92
August	13.55	41.34	6.44	2.45	12.10	2.06
September	8.76	25.29	3.89	1.60	7.46	1.29
October	7.17	20.19	3.08	1.32	5.98	1.04
November	6.49	18.17	2.77	1.19	5.39	0.94
December	6.02	16.67	2.53	1.11	4.95	0.86

	Sourdough Ck	Texas Ck	Divide Ck	Eighteenmile Ck	Everson Stroud Ck	Hawley Ck
January	1.14	4.63	0.64	1.52	0.93	3.89
February	1.08	4.40	0.60	1.44	0.88	3.70
March	1.03	4.19	0.58	1.38	0.84	3.55
April	1.12	4.63	0.78	1.70	0.91	4.78
May	5.26	21.73	7.72	8.08	4.91	29.33
June	14.99	58.14	5.57	19.83	12.36	51.21
July	8.04	34.47	1.84	9.94	5.67	16.53
August	2.86	11.94	1.04	3.73	2.17	7.93
September	1.81	7.45	0.79	2.38	1.42	5.54
October	1.47	5.99	0.69	1.94	1.17	4.70
November	1.33	5.41	0.64	1.76	1.06	4.33
December	1.23	4.98	0.60	1.63	0.99	4.03

	Lee Ck	Little Eightmile	Mill	Canyon
January	0.78	2.67	2.68	1.79
February	0.74	2.54	2.55	1.70
March	0.72	2.45	2.47	1.64
April	1.16	3.72	3.61	2.42
May	5.65	22.49	15.61	20.33
June	8.04	32.24	29.75	16.64
July	3.03	8.35	14.90	4.78
August	1.42	4.65	5.82	2.83
September	1.02	3.51	3.87	2.22
October	0.88	3.07	3.22	1.95
November	0.81	2.84	2.95	1.82
December	0.75	2.67	2.72	1.71

- *Influence of Irrigation* – Any diversions of stream flow for irrigation upstream of the NAM catchment areas would likely influence discharges within the catchment, particularly during the lower summertime baseflows that are a primary concern of the calibration. Catchment areas were delineated so as to include only those portions of the basin located above all known water rights and diversions, however this does not necessarily mean that no diversions occur above the model catchment outflow locations. Additionally, any water applied for irrigation purposes within the catchments was not included in the model and may have an influence on flows.

- *Variable Basin Characteristics* – The various basins have differing characteristics of elevation, geology, vegetation, soils, snow accumulation and melt, runoff, etc. Although effort was taken to distribute precipitation and temperature in as much detail as possible, the parameters developed for Big Eightmile Creek may not be representative of the parameters in the other basins. More calibration data is thus needed in order to refine the model and confirm the applicability of the model parameters to the other basins in the model.

- *Antecedent Conditions* – If the antecedent conditions are unknown, it is preferred to have several years of data to calibrate the model. From the short period of record for the stream gage, the antecedent conditions were assumed for the calibration. Thus, as further steam data is collected, the model can be run to "equilibrate" to know conditions and the model calibration will improve.

B-7 FUTURE EFFORTS

DHI and IDWR constructed the NAM model using the best available data; however more data would lead to a lower degree of uncertainty associated with the results. To improve and augment the NAM model, further data collection and analysis are recommended. Specific recommendations include:

- *Stream flow gaging* – The lack of current stream gage data at locations above known water rights and diversions hindered the ability to establish calibrated NAM models for ungaged tributaries. It is recommended that more stream gages be placed above diversions in representative tributaries for the entire year and that several years worth of data are collected. It is recommended that the stream gages be placed in tributaries representing the eastern and southern and southern catchments.

- *Calibration expansion* – As additional stream flow data are collected and new stream gages come on-line, the NAM model should be re-calibrated using the new data.

- *Climatic variations* – As new temperature, precipitation, and ET data become available the distribution of climate data used in the model should be revised. Obtaining climate data at the lower and middle elevations in the basin is of particular interest.

- *Evaluate the influences of irrigation* – If irrigation practices are determined to be important in the portions of the basin simulated with the model, the timing and magnitude of water applied for irrigation should be quantified and included in the NAM model.

B-8 CONCLUSIONS

The NAM model developed to simulate runoff in the upper LMBM was calibrated based on stream discharge from the USGS Big Eightmile Creek gage along with precipitation and temperature data from the Corvallis, Moonshine, and Meadow Lake weather stations, and ET data from the Corvallis weather station. The calibration resulted in a good visual fit and a quantitatively good fit between the simulated and observed discharges. Parameters developed for Big Eightmile Creek were applied to numerous other drainages in order to simulate discharge in ungaged catchments that will be used as upstream boundary conditions in a MIKE BASIN model of the Lemhi Basin. For these additional basins, additional precipitation and temperature data was used from the Schwartz Lake, Lemhi Ridge, and Beagel Springs weather stations. It is unknown how well the model performs for the ungaged catchments as there are no observed data with which to compare the simulated results. In order to decrease the uncertainty associated with the model results, additional climate station data should be used to better represent the spatial variability of climate across the basin if possible, and further calibration of the model using additional gaging locations with longer periods of record should be performed.

B-9 REFERENCES

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