EVALUATION OF DIVERSION OPERATION PLANS TO MEET NEGOTIATED FLOW TARGETS FOR SALMON AND STEELHEAD IN THE LEMHI RIVER BASIN USING THE MIKE BASIN MODEL

Prepared for the

Bureau of Reclamation

and the

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by

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1 INTRODUCTION

This report describes the initiative by the Idaho Department of Water Resources (IDWR) and the Bureau of Reclamation (Reclamation) to develop a surface water budget model for the Lemhi River basin, Idaho. The purpose for developing the Lemhi River MIKE BASIN Model (LRMBM) is to quantify and collectively represent sources and uses of streamflow throughout the entire mainstem of the Lemhi River system from McFarland Campground to the Salmon River.

Currently, irrigation operations can dewater the Lemhi River's mainstem when several irrigators simultaneously begin filling their canals during spring runoff. As the canals are filling, return flows are not yet available to help meet instream flow requirements downstream from the L6 diversion. The LRMBM has been constructed to illustrate how irrigators can sequentially manage their irrigation diversions to maintain adequate streamflow downstream from the L6 diversion during spring runoff. This model also can be used to evaluate operation plans that provide enough water to meet irrigation needs and to meet in-stream needs for fish at other times of the year when streamflow is in short supply.

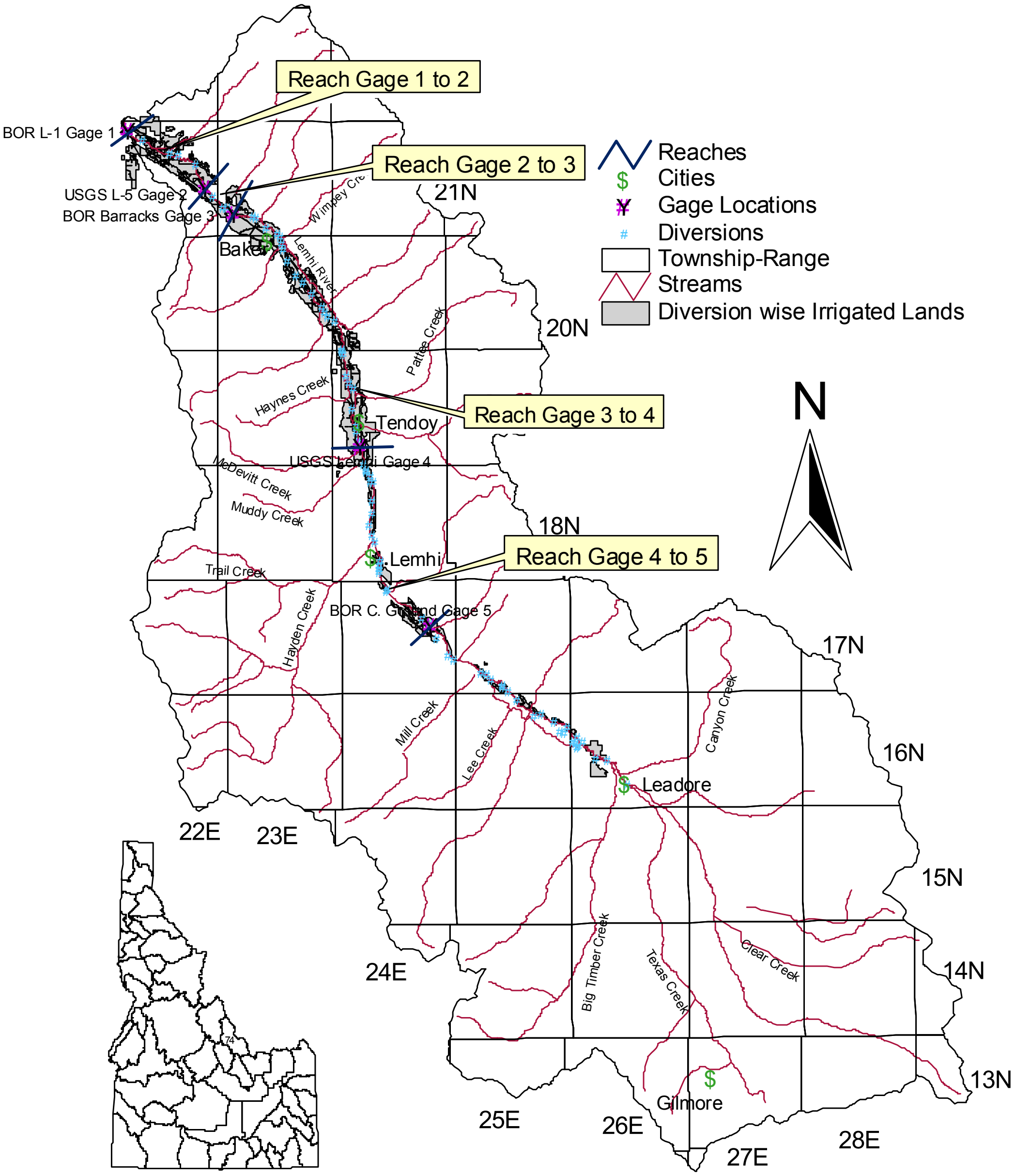
The model construction occurred from September 16, 2002, to January 31, 2003. During this period, IDWR, Reclamation, and DHI, Inc. personnel worked quickly to build the river network, compile and populate the model with data, and calibrate the model. The calibrated model can be used to evaluate operation scenarios for the spring runoff period. However, additional analysis and data may be needed to improve the model's accuracy and to better address user needs. This report also includes:

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

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 Lemhi-area landowners and water users to employ that would conserve and restore fish species listed under the Endangered Species Act. Some of these measures focus on improving streamflow 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 spring runoff and during the irrigation season in a short reach of the river at the L-6 Diversion. Figure 1 illustrates the study area, including the reaches of concern.



Lemhi River Basin # 74 Map

Figure 1. Lemhi River Basin #74 Map of the study area in east-central Idaho. The study reach extends from McFarland Campground to the confluence of the Lemhi and Salmon Rivers.

During high flows in the spring runoff period, irrigators open their diversions to charge their canals and soak their fields. This builds up storage in the ground water under the fields adjacent to the river. This shallow ground water storage is believed to be slowly released back to sustain streamflows in the river later in the irrigation season.

However, when irrigators simultaneously open diversions in the spring, the river can become dry at the L-6 diversion for one to two weeks until canals are charged and return flows are able to restore water to the river. In spring 2002, the Lemhi River watermaster devised a plan to open diversions sequentially. This successfully avoided dewatering the Lemhi River downstream from the L-6 Diversion.

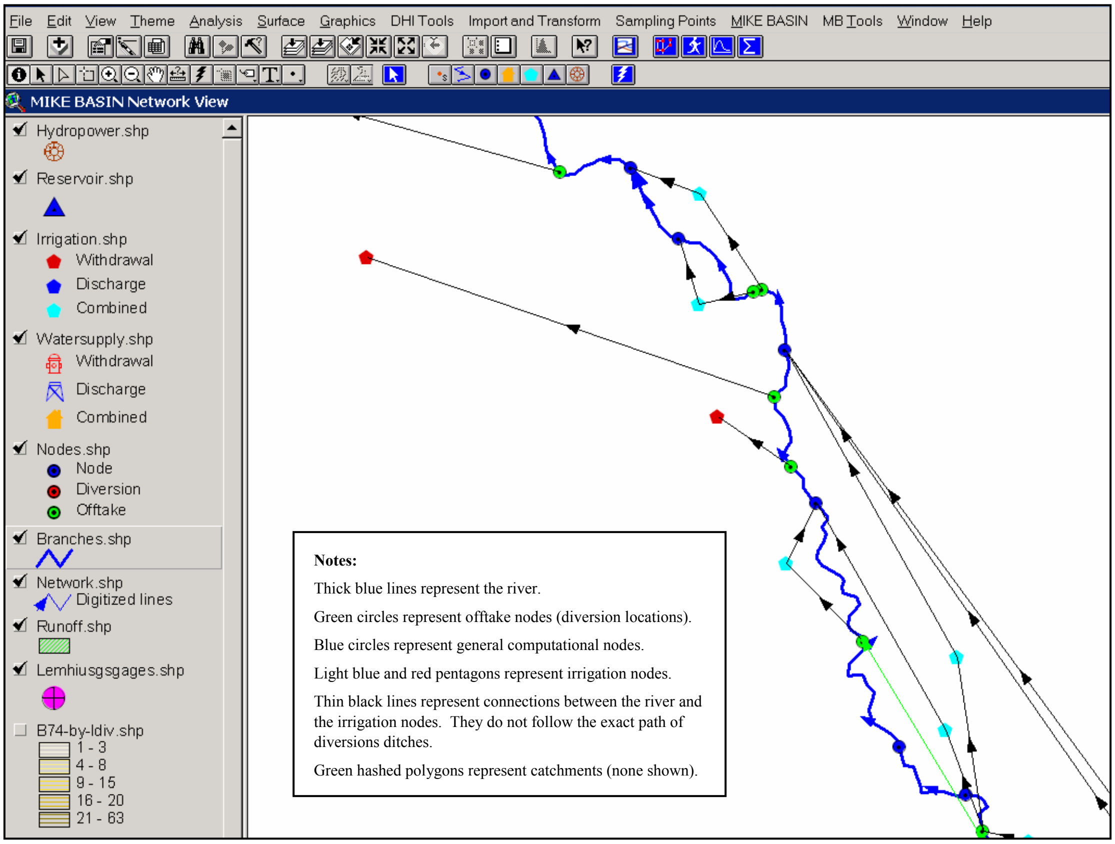
In part of an addendum to the Conservation Agreement, the agreement's signatories requested that Reclamation develop a surface water budget model of the mainstem of the Lemhi River. Reclamation is cooperating with IDWR and DHI to develop this model. The Lemhi River watermaster and several area water users also are providing assistance. The model is intended to represent the availability and use of water for irrigation along the mainstem of the Lemhi River.

In the short term, the model was configured to represent different approaches that the watermaster could use to deliver water to fields and to keep the river from dewatering at the L-6 diversion in the spring. This report describes the model and how it evaluates the spring runoff situation. If the model is shown to demonstrate a successful solution to the spring runoff situation, it then could be configured to evaluate water management alternatives intended to both meet irrigation demands and provide enough streamflow for migrating salmon and steelhead during other times of the irrigation season.

3 MODELING METHOD

3.1 Model Used

MIKE BASIN is an integrated water resource management and planning computer model that integrates a Geographic Information System (GIS) with water resource modeling (DHI 2002). 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.



Notes:

Thick blue lines represent the river.

Green circles represent offtake nodes (diversion locations).

Blue circles represent general computational nodes.

Light blue and red pentagons represent irrigation nodes.

Thin black lines represent connections between the river and the irrigation nodes. They do not follow the exact path of diversions ditches.

Green hashed polygons represent catchments (none shown).

Figure 2. Example of the model's interface and the MIKE BASIN setup.

MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. Figure 2 illustrates the network model interface. The branches (lines with arrows) represent individual stream sections while the nodes (blue, red, or green filled circles) represent confluences, diversions, locations where certain water activities may occur, 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 ArcView 3.2 (a GIS software package). All information regarding the configuration of the flow simulation network, location of water users, reservoirs and intakes, and outlets of return flow are also defined by on-screen editing.

Four types of on-river and four off-river nodes are available in MIKE BASIN:

The on-river nodes are:

Simple – locations on the river network that have neither offtakes nor diversions.

Catchment – simple nodes that have a catchment outlet, permitting the user to introduce water into the model.

Offtake – locations on the river where water is withdrawn for irrigation or water supply.

Diversion – junctions on the river where the water's path splits into two downstream river branches.

The off-river nodes are:

Water supply – water usages where a simple relationship exists between temporal variations in water extraction (from the river and ground water) and return discharge, given as time-series to and from river nodes. Examples include municipal and industrial water supplies.

Irrigation – a water supply node that may include a time-delayed return discharge. This time delay is provided to the model as time-series based on a linear-reservoir routing delay function.

Reservoir – simulate reservoir operations either as standard or as allocation pool-type reservoirs.

Hydropower – nodes that can be associated with a reservoir node to calculate and optimize power generation from a reservoir.

Constructing a MIKE BASIN model includes building the river network (the plumbing system); compiling, processing, and inputting the simulation data; and calibrating the model. Building the river network involves digitizing the river branches and nodes from GIS coverages. In MIKE BASIN, digital elevation modeling (DEM) is also available to generate the river branches.

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 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.

Once the water usage has been defined, the model simulates the performance of the overall system by applying a water mass balance method in every branch and 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 ArcView 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 water users; apply priorities to water distribution; simulate ground water use; and simulate transport and degradation of substances affecting water quality in rivers and reservoirs. Water quality substances that MIKE BASIN simulates include ammonia/ammonium, nitrate, oxygen, total phosphorus, and organic matter. Organic matter is represented in terms of biological oxygen demand and chemical oxygen demand. A more complete description of the capabilities and applications of MIKE BASIN can be found at http://www.dhisoftware.com/mikebasin/.

MIKE BASIN was created to easily allow expansion to address complex systems if additional analyses are required or to incorporate additional data as it becomes available.

3.2 Lemhi River MIKE BASIN Modeling Methods

Developing the LRMBM involved building the river network; compiling, computing, formatting, and inputting the data; and calibrating the model. This section describes the LRMBM methods and assumptions.

3.2.1 Network Setup

Information contained in the river network was compiled from GIS coverages, aerial photographs, IDWR GIS coverage for diversion locations, USGS gaging station locations, and custom irrigated area maps created by IDWR. Figure 3 shows an example of this compiled data. Rick Sager, Lemhi River watermaster, was instrumental in helping verify that this information represented actual field conditions.

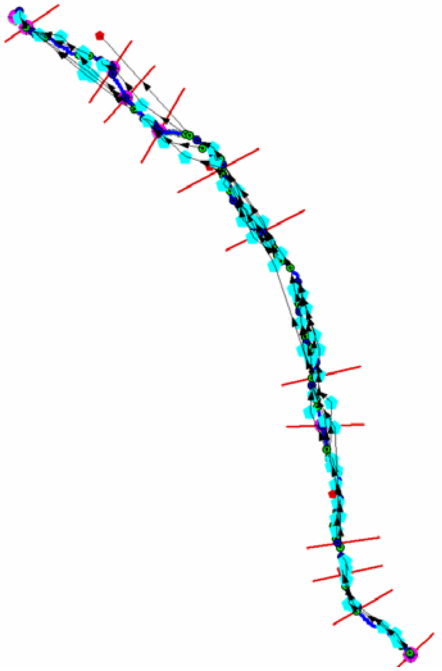


Figure 3. Data compiled to create Lemhi River modeled reaches.

The mainstem course of the Lemhi River was digitized using aerial photographs, and offtake nodes (diversions) were digitized from IDWR's diversion coverage. After confirming the initial digitized river course and offtake node locations, Mr. Sager supplied information about irrigated fields and return flow locations for each irrigation node.

For most offtake nodes (diversions), multiple irrigators share the diverted water throughout the irrigation season. In the LRMBM, all irrigators using water from an offtake node are represented by a single irrigation node because the water is being applied to fields in the same general area; further, the authors are unaware of any records identifying location and timing of flood irrigation application within an irrigation area during the study period (Sager 2002).

For five offtake nodes that represent a relatively large area (diversions L-06, L-21, L-30, L-31, and L-42), water is applied in several distinct locations. Water allocation to those separate fields served by each diversion was determined, and multiple irrigation nodes were associated with respective offtake nodes. If future analysis requires refinement of water allocation within these or other irrigation areas, then the LRMBM can easily be reconfigured to incorporate additional data and improved knowledge about the system.

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 were associated with respective irrigation nodes and were located at a downstream point along the Lemhi River where the majority of the return flow was considered to return. 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 simulation model.

3.2.2 Time Series Input Data

In MIKE BASIN, the movement of water into and out from the river system is specified with time series data. In the LRMBM, time series input information from streamflow gaging station records was specified for six catchment nodes to define the catchment specific runoff. Time series input information also was specified for 58 irrigation nodes 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), and lag time (the linear routing of return flow from the irrigated fields back to the river). The temporal availability of each data type is presented in Figure 4 and Table 1.

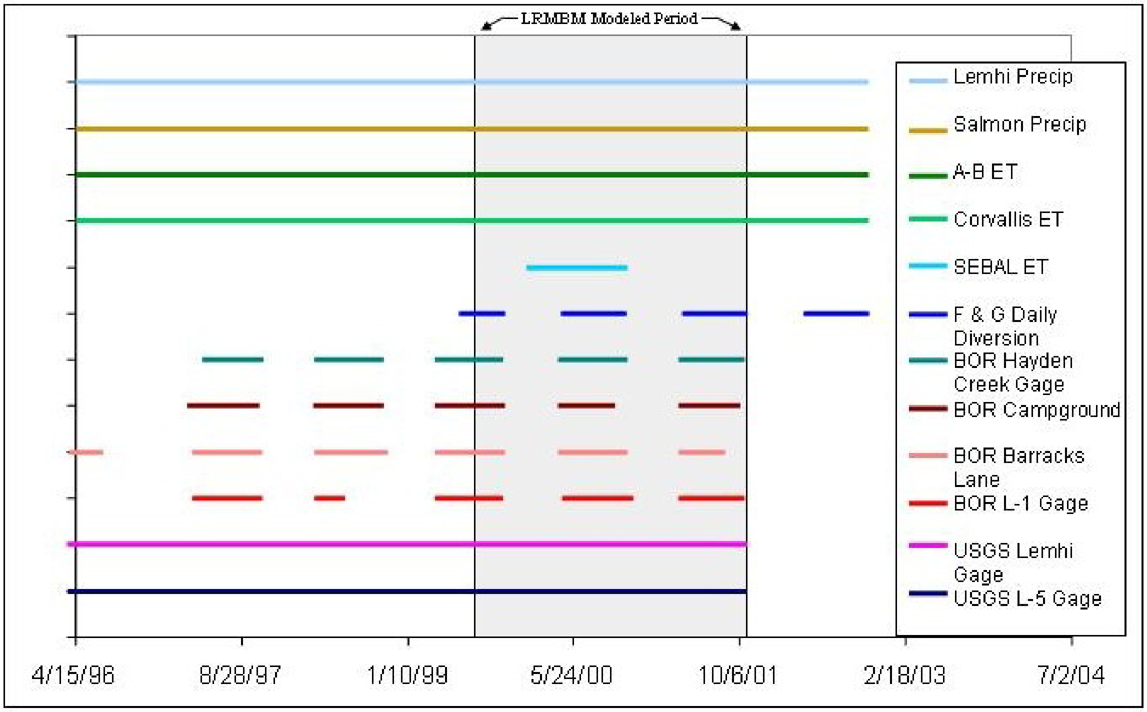


Figure 4. Timeline showing availability of the time series data for the LRMBM.

Table 1. Specific dates of the time series data for the LRMBM.

Reclamation Stream Gages	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
BLM McFarland Campground	3/27-10/31	4/1-10/29	4/2-10/31	4/7-9/25	4/5-10/9	na*
Hayden Creek	4/3-10/31	4/2-10/28	4/2-10/25	4/7-10/31	4/5-10/21	na*
Barracks Lane	3/27-10/31	4/1-10/29	4/2-10/31	4/7-9/25	4/5-10/9	na
L-3A	na*	na*	na*	na*	na*	na*
L-1	4/1-10/30	4/2-7/5	4/2-10/24	4/19-11/20	4/4-10/20	na*
USGS Stream Gages						
Lemhi	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	na*
L-5	1/1-12/31	1/1-12/31	1/1-12/31	6/1-12/31	1/1-12/31	na*
Diversion Stage Records						
Daily Diversion Stage	na	na	6/15-10/30	4/15-10/30	5/1-10/31	4/15-10/30
Evapotranspiration Rates						
Allen and Brockway	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31
Corvallis, MT Gauge	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31
SEBAL	na	na	na	na	4/1-10/31	na
Precipitation						
Salmon Gage	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31
Lemhi Gage	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31	1/1-12/31

*Recorded by Reclamation or USGS, but not incorporated by the modelers at the completion of phase 1.

The time series data for all the catchment and irrigation nodes was gathered, computed, formatted, and entered into the LRMBM. Microsoft Excel interfaces with MIKE BASIN were created for data loading, formatting, and computing. This software also allows water users and stakeholders to test operation plans using a calibrated LRMBM within an easy-to-use interface. The data for each time series were compiled according to these procedures:

Determining Catchment Specific Runoff

For the LRMBM, streamflow gaging station records define catchment specific runoff locations. Catchment specific runoff represents surface inflow at the upstream model boundary; it also was used with reach gains/losses to calibrate the model. Five gages are available along the study reach: Reclamation McFarland gage, USGS Lemhi River gage, Reclamation gage at Barracks Lane, USGS L-5 gage, and Reclamation gage at L-1. The Reclamation gages only cover the irrigation season (as shown in Table 1). An additional gage (Reclamation gage on Hayden Creek) near the confluence of Hayden Creek and Lemhi River provided inflows for the creek.

The Reclamation McFarland gage was the upstream boundary inflow for the model. The Hayden Creek gage was also used as an inflow boundary at its confluence with the Lemhi River. The other gages were used to determine the reach gains/losses that reflect other contributions to the system beyond the surface water model, including precipitation, ground water gains/losses, and ungaged tributary inflow.

Determining Irrigation Demand

Irrigation demand is the quantity of water that crops require for healthy growth without significant reduction in yield. For calibration of the model, demand was assumed to be the historic, daily-diverted flows. For potential scenarios, input from the local community was used to demonstrate the applicability of the LRMBM. For future development, a demand calculator could be created in Microsoft Excel for each diversion that incorporates crop type, irrigated lands, percentage under sprinkler, and ditch loss.

To determine the historic, daily-diverted flows for each offtake node, contemporaneous stage/discharge measurements were analyzed to develop stage-discharge rating curves. These curves were applied to daily stage measurements collected by IDFG fish screen personnel. IDFG personnel collected daily stage levels in all diversions from June 14, 1999, to October 30, 2002, during irrigation seasons. Stage levels were linearly interpolated for data gaps. If a data gap had a positive value and a zero on either side, the stage for the missing days was assumed to be zero. This assumption helped avoid over-allocation of water when the diversion was potentially off; it also prevented computing diverted flows that were below those measured during the contemporaneous stage/discharge measurements.

Screen tender records indicating only “stockwater” was assumed to represent zero discharge to the diversion for that day. Computed discharges greater than the maximum measured discharge were truncated to equal the maximum measured discharge. Rick Sager, Lemhi River watermaster, verified these truncated maximum discharge values.

In this phase, precipitation was assumed to be included in the reach gains. For the majority of the irrigation season, the convective storms that generate precipitation during the summer months are spatially and temporally variable throughout the lower valley. Figure 5 illustrates the spatial and temporal variability of the precipitation for two gaging stations (Leadore and Salmon) between 1999 and 2001. However, according to Bob Loucks, a local landowner in the basin, large frontal events that occur in April through mid-June and deliver greater than one inch of precipitation are spatially distributed over the entire study reach and influence the Lemhi River flow. In the next phase of the LRMBM development, precipitation will be examined to determine the influence of storm events in determining river discharges early in the irrigation season.

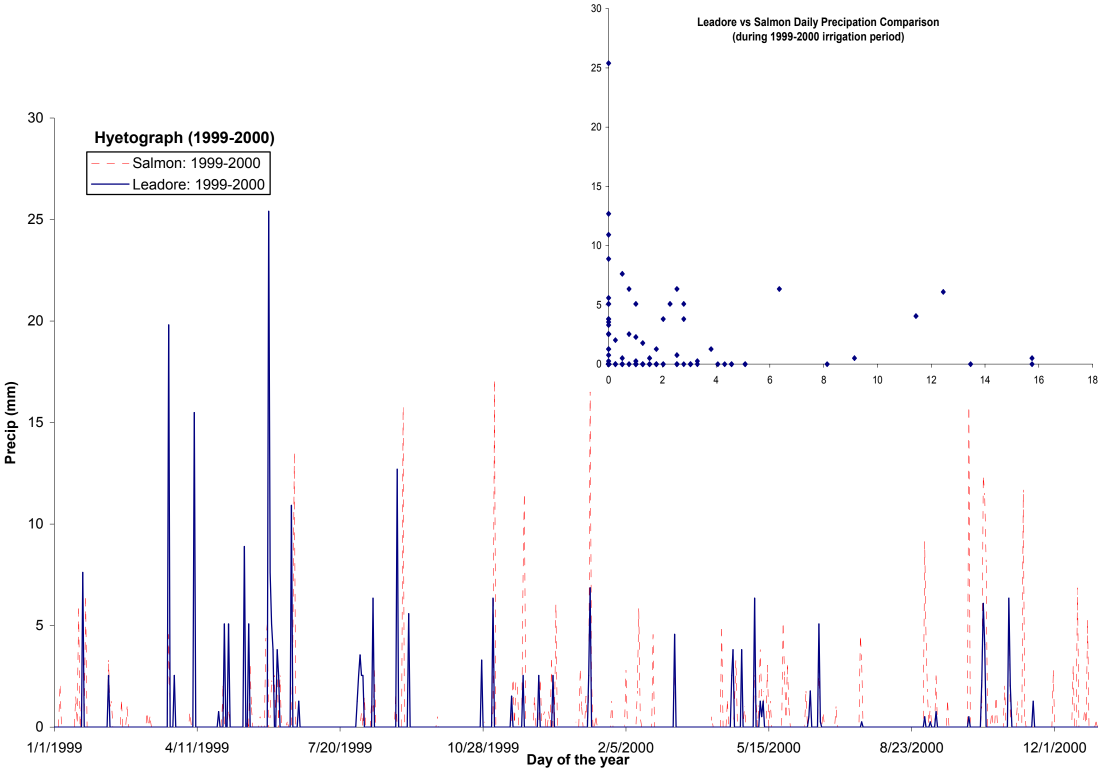


Figure 5. Hyetographs for the rain gages at Salmon and Leadore, Idaho, during the 1999, 2000, and 2001 irrigations season.

Determining the 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.

Determining the 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, in this particular model, until the next downstream gaging station node.

Figure 6 illustrates how water flows through an irrigation node. Part of the diverted water is lost from the system as evapotranspiration (ET), part becomes return flows (RF) that enter the river as either surface or subsurface flows by the downstream node, and part enters the intermediate ground water (IGW) system. IGW is returned to the river as a reach gain at the next downstream node that coincides with an actual gaging station after

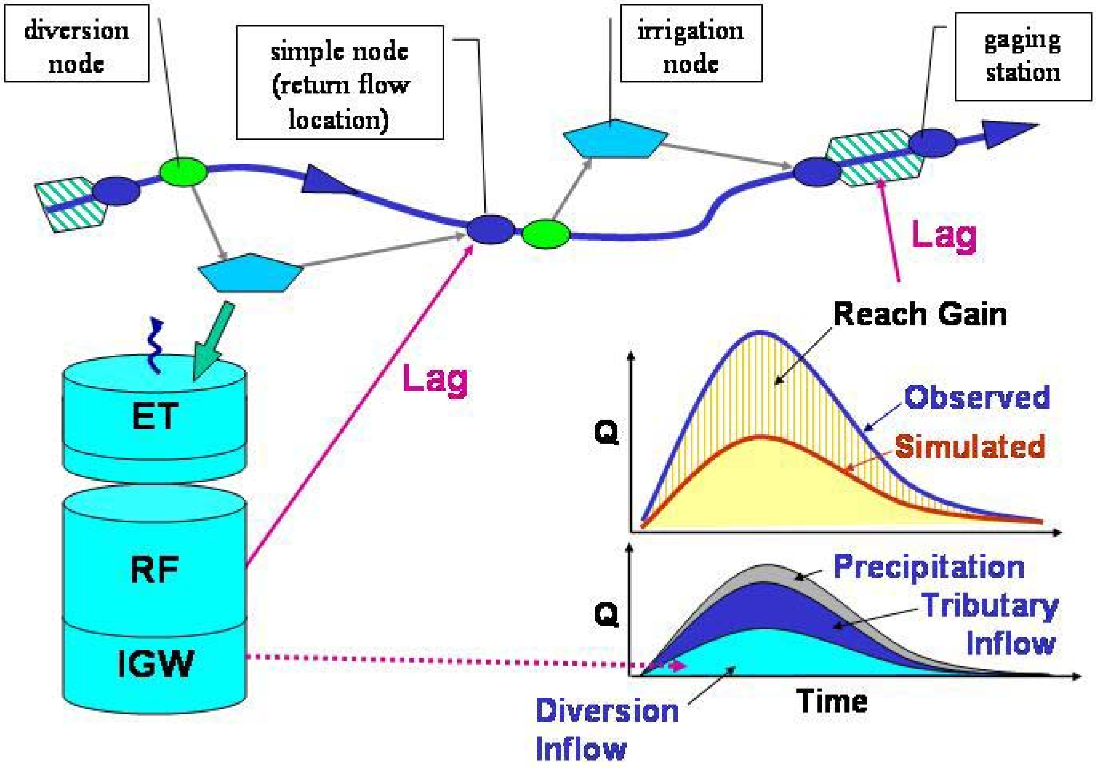


Figure 6. Schematic of the water flow through an irrigation node.

a specified lag period. Reach gains represent precipitation, tributary underflow, and other components that are not explicitly included in the model and were assumed to represent residual between simulated and observed streamflow measurements at a gaging station.

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 diversion coverage provided by IDWR. The crop type and the percentage of area associated with a crop were provided by Rick Sager. For fields irrigated with sprinklers, sprinkler rates were assumed to be .75 inches per day per acre in demand calculations (Sager 2003).

Determining Irrigated Lands Associated with Diversions

To determine the irrigated areas (A_{CT}) associated with each diversion, IDWR personnel collected and tagged each point of diversion in the Lemhi River basin; scanned and registered the Lemhi Decree maps, aerial photos, and points of diversion in ArcView; and digitized the aerial extent of each place-of-use areas for each of the water rights according the decree maps, registered aerial photos, and the claims file. Assignment of the place-of-use areas of each water right to a point of diversion (e.g. L-1) was done using information collected by the IDWR Lemhi River watermaster's office.

Most individual points of diversion serve several places of use. For modeling purposes, multiple places of use associated with an individual point of diversion were aggregated. Precipitation, evapotranspiration, amount of water applied, losses to ground water, etc., 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.

Determining Evapotranspiration (ET) Rates

Three methods for estimating ET rates were investigated for this study: the Surface Energy Balance Algorithm for Land (SEBAL) technique, the Corvallis, Montana, AgriMet station ET data, and the Allen-Brockway (A-B) ET using the Salmon weather station. The Corvallis, Montana, AgriMet station ET data was selected for this study because it was available over the period of record and was relevant to the irrigated areas in the Lemhi River basin. ET rates derived from the Allen-Brockway (A-B) ET, which were determined using Salmon weather station data, are higher due to higher temperature associated with the urban setting. The Corvallis, Montana, station is located in an agricultural field and is more representative of the Lemhi agricultural area.

SEBAL was used to determine ET rates for the Lemhi River basin for the 2001 irrigation season. ET data were captured for the instant the satellite traveled over the area and extrapolated (using AgriMet data) into 24-hour or monthly ET data, and sometimes into seasonal ET data. The extrapolation includes temporal and topographical variability.

IDWR's Technical Service Bureau created and supplied the places of use shapefiles for each point of diversion. The University of Idaho Kimberly Research and Extension Center used the SEBAL technique to create monthly ET images from March to October using Landsat image data. The IDWR Geospatial Technology Section determined ET for the places of use for each point of diversion by processing monthly SEBAL ET images in ERDAS image processing software, ARC/INFO, and ARCVIEW GIS software. The final ET values were linked to the places of use shapefiles.

Time constraints prevented the incorporation of this SEBAL ET into MIKE BASIN; however, it may be useful for future studies in the Lemhi River basin.

Determining Conveyance Ditch Losses

Conveyance loss is the loss of water during transport from the point of diversion (at the source) to the on-farm places of use. 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. Though these losses can be controlled, the cost is often prohibitive.

Seepage losses through the soil vary with soil texture in the channel bed; however, other factors can influence the seepage rate. Since seepage losses are the primary losses that are the least practical to control, they must be quantified to determine the necessity of any additional water that may be required to overcome those losses for irrigation purposes.

IDWR most commonly uses the Worstell method seepage loss estimation procedure from the *Guidelines for the Evaluation of Irrigation Diversion Rates* (Hubble 1991). 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:

$$S = 0.0667 \times i \times W$$

S is seepage loss in cfs per mile
i is seepage rate in feet per day
W is top width of water surface in feet
0.0667 is the factor to estimate the wetted perimeter as a function of W and to convert units.

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.

Determining Intermediate Ground Water Quantities

The aquifer underlying the Lemhi River is relatively shallow throughout most of the study reach. The 1997 Lemhi River seepage run demonstrated that the Lemhi River, through the study reach, is primarily a gaining river and that only 4 percent of the outflow from the basin departs as ground water (Donato 1998). In the LRMBM, all water entering the IGW will return to the river in the next downstream reach gain/loss. This assumption is based on the ground water boundary conditions in the study reach.

At the Narrows, just downstream from the Lemhi River and Hayden Creek confluence, bedrock comes within 16 feet of the surface, forcing underflow moving down the valley towards the surface and dividing the Lemhi River basin into two zones. For the lower boundary, Donato (1998) reports that only 4 percent of the water leaves the basin as underflow; therefore, the balance leaves as surface flow. Because underflow is low compared to surface flow at these boundaries, the ground water system can be considered closed and therefore supporting the validity of the 100 percent IGW return flow estimate.

In the LRMBM, IGW water is added to the reach gain/loss gage with the exception of the USGS L-5 gage reach gain/loss. Comparing the gage data between Reclamation's Barracks Lane gage and the USGS L-5 gage indicates a streamflow loss within the reach. Whether this loss is an artifact of the data accuracy is beyond the scope of this project. In the LRMBM, return flow from L-10 and L-13 is realized in the L-1 gage reach gains.

This study identifies the volume of water required to initially fill the ground water aquifer before return flow is initiated at the start of each irrigation season as "initial abstraction." In the LRMBM, this volume of water is assumed to be needed to represent the aquifer filling in the spring. Therefore, this initial volume is not returned to the Lemhi River during simulations that address the dewatering of the mainstem of the during the spring irrigation season. Thus, at the onset of irrigation, the return fraction will be adjusted to account for this water loss to build up storage in the ground water aquifer.

Determining Lag Time

Timing of return flows from irrigated lands to the Lemhi River depends on the irrigated field's location in relation to the Lemhi River, the degree of channel surface flow returns, and ground water flow direction and rate. In MIKE BASIN, delayed return flow is described using the following equation:

$$q_0 = \left(1 - \frac{x}{(dt/T)}\right) * q_i + x * S$$

and

$$x = 1 - \exp\left(-dt/T\right)$$

q_i is the inflow from the irrigation node
q_o is the outflow from the irrigation node
dt is the time step length
T is the lag time
S is the subsurface storage (accordingly, $\Delta S = q_i - q_o$)

The MIKE BASIN user can specify the lag time to control the timing of the return fraction. As Figure 7 illustrates, longer lag times slow the return flow rate. In the LRMBM, lag times vary for each irrigation node and were used to calibrate the model.

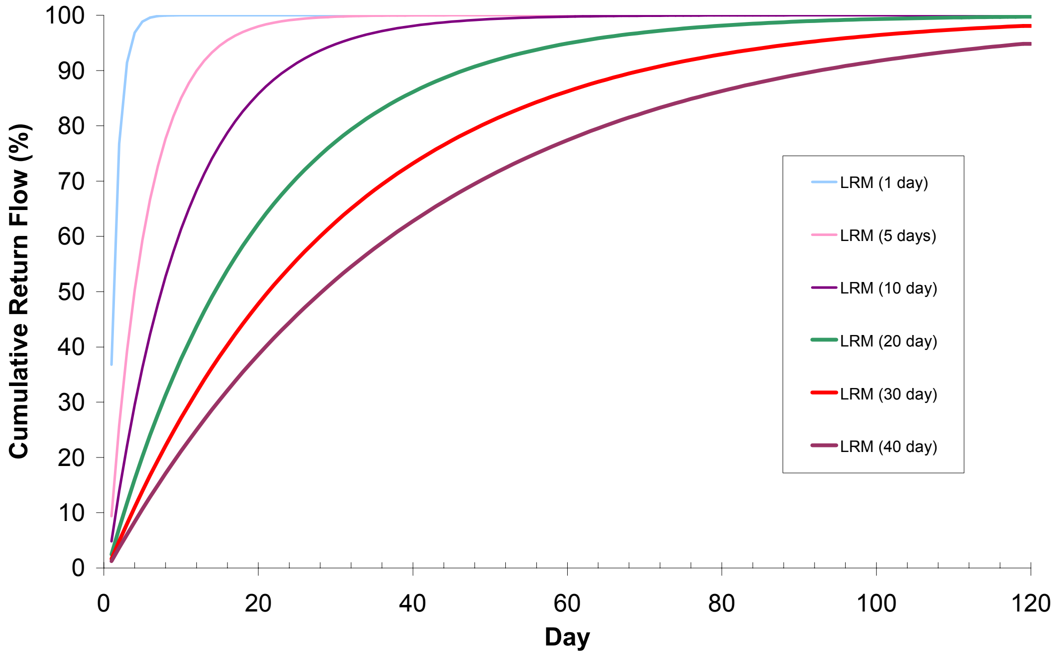


Figure 7. Cumulative return flow fraction by varying the lag time parameter.

3.3 LRMBM Calibration

Calibrating the LRMBM was accomplished by varying parameters in an attempt to match simulated and observed flow at the USGS and Reclamation stream gages and the 1997 Lemhi River seepage run results (Donato 1998). It also required developing reach gains to account for the difference between the simulated and measured stream flow discharges at the gaging stations. Parameters in the model calibration included the lag time and the IGW component of the return fraction. Both of these variables are difficult to quantify directly from the data currently available.

Calibration methods included visually inspecting the observed and simulated hydrographs at a given gage, and optimizing by trial-and-error the root mean square difference between observed and simulated daily flows, and the slope and R^2 value from the linear regression of the observed and simulated daily flow values.

For each subreach delineated in the seepage run, the calibration process followed these steps:

1. Entered suggested lag times provided by local landowners to provide baseline results for comparison.
2. Ran between 50 and 150 simulations, randomly varying the lag time between 25 and 300 percent of suggested lag times for each run, then compared the observed and simulated discharge records at the next downstream gage to determine the best lag time configuration.
3. Refined the best lag time configuration by varying lag times for individual irrigation nodes and comparing simulated to observed gage records at the next downstream gage.
4. Adjusted the IGW parameters by comparing the observed and simulated gage records at the next downstream gage.
5. Checked the flow of water in the network by comparing the relative amount of water diverted and returned to the Lemhi River for August 4 through August 8 and October 27 through October 31 of each irrigation season in the simulations to the results in same time period of the 1997 Lemhi River seepage study.
6. Adjusted the lag time and IGW to account for any discrepancies in the gage comparison and seepage run comparison.

The simulated discharges and the 1997 Lemhi River seepage run were compared to refine the water movement in the long stretches of river that contain several offtakes and return flow nodes with no gaging stations for accurately representing reach gains/losses.

Donato's seepage run study measured inflow and outflow from the Lemhi River during August 4 through August 8, 1997, and October 27 through October 31, 1997. From these measurements, Donato created reach gains/losses from 14 reaches between Leadore, Idaho, and Salmon, Idaho. The ratio of Donato's reach gains to the measured river flow was used as a relative benchmark for confirming the parameter configuration between gages.

Donato's seepage run did not occur during the LRMBM simulation period; therefore, the precipitation, tributary inflow, and irrigation operation are most likely different. However, the relative contributions to and operations of the system were assumed to be similar. Therefore, if LRMBM simulation and Donato's reported reach gain - river flow ratio were within 10 percent, the parameter configuration was assumed to be sufficiently accurate.

Reach gains/losses account for contributions to the Lemhi River from precipitation, ground water gains/losses, and 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. The authors are not aware of any data that provide information related to these contributions in the same temporal and spatial resolution of the LRMBM. At the completion of this phase, adjustments in the reach gains/losses from a change in the IGW had been established but remained uncalibrated.

3.3.1 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. Some important Microsoft Excel files include:

- **LemhiDailyDiv.xls** – Calculates the demand for each diversion. This file loads the daily stage data into the worksheet representing the accompanying diversion, calculates the daily diversion rate from stage and the stage-discharge rating curve, and loads the data into LemhiDivInput.xls.
- **LemhiDivInput.xls** – Organizes the input data for all the irrigation nodes. It contains the daily values for the parameters required by irrigation nodes: demand, ground water fraction, return fraction, and lag time. This workbook contains the return flow calculator and macros that automatically load the data into the proper LRMBM input files. This workbook should be used when running scenarios where diversion schemes are altered and need to be loaded into the LRMBM. A summary table of all the parameters for each diversion can be generated using a macro.
- **LemhiCalib.xls** – Helps calibrate the model. 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

seepage run, and calculate reach gains used in the first calibration effort for the LRMBM. Macros drive all the tasks except for the reach gain calculations. Note that one base MIKE BASIN simulation must be run from the ArcView GUI before additional simulations can be run directly from within Microsoft Excel.

- **LemhiRGAdjust.xls** – Calculates the influence of the IGW component of the return fraction on the reach gains. This file calculates the lag time and quantity of the return fraction to the next downstream gage in the system and loads the altered reach gain file into the appropriate MIKE BASIN time series file. This file is still being constructed.

All the Microsoft Excel files will help users input data, develop future capabilities, and run scenarios in the LRMBM.

4 MODEL RESULTS

4.1 Input Data Summary

4.1.1 Gage Data

Discharge records from the USGS Lemhi gage indicate that 2000 and 2001 recorded below historical discharges while 1999 was above average, as shown in Figure 8. Water year 1997 was above average through the peak period but fell below average later in the irrigation season. For comparison between the simulated run and the USGS 1997 Lemhi River seepage run (Donato 1998), this may imply that the irrigation operations may be similar, but the contribution from inflowing tributaries and intermediate ground water may have been greater.

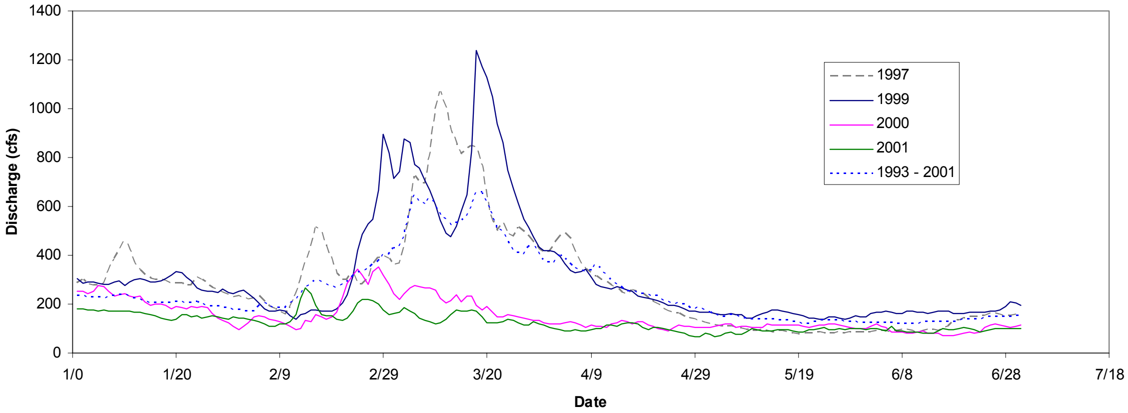


Figure 8. Irrigation season hydrographs at the USGS gage at Lemhi, Idaho, for water years 1997, 1999, 2000, 2001, and the average irrigation season hydrograph from 1993 to 2001.

4.1.2 Diversion Data

Most stage-discharge rating curves exhibited a power relationship with an exponent value greater than one. For diversions with insufficient data or poor relationships between stage and discharge measurements, a linear relationship or single value was adopted. Diversions with a linear relationship were L-01, L-02, L-12, L-15, L-21 (2001 irrigation season only), L-32, L-43B (2000 and 2001 irrigation seasons only), and L-45B. Diversions with a single value were L-03B, L-10, L-29, L030A (2001 irrigation season only), and L-34.

Poor correlation between stage and discharge measurements may be due to maintenance, operation, or algae growth in the diversion channel, thus influencing the conveyance of the channel and consequently the stage. In some cases, a few outliers were disregarded to develop curves that were more representative of the population of data. Also, if no relationship between stage and discharge in a given year was apparent, then multiple curves based on stage were examined as an alternative. For example, diversion L-44 has two curves depending on the diverted water's stage, reflecting if water is channeled to the right or left diversion ditch just downstream of the diversion entrance.

4.1.3 Irrigation Node Parameters

In the LRMBM calibration, the demand parameter for each irrigation node is synonymous with the quantity of daily diverted water calculated for each diversion. Table 2 shows the average demands, return fractions, and lag times for the Lemhi River diversions. The average demand in the study period varies from 0.5 (L-14) to 43.3 cfs (L-14 and L-06), with an average value of 9.8 cfs for all diversions. Maximum diverted water during the study period averaged 19.0 cfs for all the diversions, with a maximum of 72.1 cfs (L-06).

Return fractions averaged 0.67 for all the irrigation nodes throughout the study period. The maximum reached 1.00 for irrigation nodes where the IGW_{FL} was assumed to be 1 (note: for the IGW parameter in the return fraction calculator, a "0.0" or "1.0" indicates that all infiltrated water is going to the IGW or return fraction, respectively). In general, from Reclamation's McFarland gage to the USGS Lemhi gage, the return fraction values are greater because it was found that the IGW ratio best fit the observed data with a value of 1. This may be due to the ground water inflow to the Lemhi River as ground water is forced to the surface in the Narrows. Also, return fractions drop just downstream of the Narrows because the IGW component becomes greater. Low return fractions for L-03, L-06y, and L-07 represent loss to the system from irrigated water leaving the system without returning to the Lemhi River. For L-06 and L-07, this represents the portion of the water sent to irrigate fields along the Salmon River.

Ditch loss was only accounted for in six irrigation nodes: L-03, L-06y, L-07, L-09, L-42y, and L-45D. Rick Sager, Lemhi River watermaster, supplied these ditch loss fractions. Future development of the model and future studies of other ditches in the area will use the Worstell calculation method (Hubble 1991; IDWR 1999).

Table 3 presents the return fraction calculator parameters. IGW_{FL} for the study reach above the Narrows averaged 1.0, while it averaged 0.85 below the Narrows. IGW_{sp} values were between 0.4 and 0.5. For both the IGW_{FL} and IGW_{sp}, lower values represented fields that were located farther away from the Lemhi River.

For each irrigation node in the LRMBM, lag times varied between 1 and 25 days, with an average of 8.5 days. Table 2 shows that lag times for the L-37, L38, and L-39 diversions are noticeably larger (20 days) in comparison to lag times from other irrigated areas in the study reach. The discrepancy in lag times may be influenced by the underflow from Hayden Creek that flows into the Lemhi River just upstream of these diversions. The LRMBM does not account for this underflow that was observed during the 1997 Lemhi River Seepage run. Underflow contributions would be expected to be delayed from the peak flow in the river, and therefore, they may be increasing the lag times for those diversions in the LRMBM.

4.2 Model Results

4.2.1 Overview of the LRMBM

The LRMBM encompasses approximately 34 miles of the mainstem Lemhi River from the BLM McFarland Campground to the confluence of the Lemhi and Salmon Rivers (as shown on Figure 1). Initially, the model was intended to extend upstream to the Reclamation gage at Leadore, Idaho, but inaccuracies in the data from the Leadore gage prevented that area's inclusion. The model network has the following criteria:

- Model simulations are run on a daily time step from 53 offtake nodes (representing diversions L-1 through L-45D along the Lemhi River) and 58 irrigation nodes (representing the irrigated area associated with the offtake nodes).
- Multiple irrigation nodes are used on several diversions (L-06, L-21, L-30, L-31, and L-42) 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.
- Catchment nodes at the Reclamation McFarland gage and Hayden Creek and Lemhi River confluence represent direct flow input into the model.
- Catchment nodes at the USGS Lemhi, Reclamation Barracks Lane, and USGS L-5 gages represent points where reach gains/losses were incorporated.

Table 2. Average demands, return fractions, and lag times for Lemhi River diversions.

	Demand (cfs)		Return Fraction		Lag time (days)
Diversion	Average Discharge	Maximum Discharge	Average	Maximum	
L-01	1.8	2.2	0.79	0.90	2
L-02	4.7	7.6	0.85	0.90	1
L-03	17.9	34.1	0.49	0.50	3
L-03A	11.0	23.3	0.82	0.90	3
L-03AO	1.4	25.0	0.55	0.88	1
L-06x	22.0	37.5	0.56	0.75	6
L-06y	21.3	34.6	0.26	0.45	9
L-07	28.2	50.0	0.26	0.45	9
L-08	2.0	2.0	0.75	0.80	2
L-08A	27.0	50.7	0.67	0.90	7
L-09	17.8	30.4	0.00	0.00	0
L-10	16.9	22.2		0.00	5
L-11	4.9	10.0	0.68	0.90	3
L-12	2.8	5.3	0.64	0.90	3
L-13	18.6	33.3	0.04	0.06	10
L-14	0.5	0.9	0.00	0.00	0
L-15	6.2	8.8	0.74	0.90	3
L-17	5.8	31.0	0.62	0.90	8
L-18	0.8	2.0	0.70	0.90	3
L-19	4.5	13.5	0.87	0.90	3
L-20	21.0	45.1	0.77	0.90	8
L-21x	5.2	10.8	0.76	0.90	8
L-21y	5.2	10.8	0.68	0.80	10
L-22	19.6	43.8	0.54	0.75	14
L-23	17.7	40.0	0.80	0.90	14
L-24	2.9	16.0	0.80	0.90	3
L-25	6.1	15.0	0.71	0.90	5
L-26	4.0	10.8	0.76	0.90	5
L-27	5.0	10.0	0.76	0.88	5
L-28	9.8	13.5	0.55	0.69	7
L-29	18.4	30.9	0.79	0.90	14
L-30x	0.6	1.2	0.56	0.90	5
L-30y	5.0	5.0	0.65	0.90	10
L-30z	7.1	17.2	0.52	0.90	20
L-30A	2.2	6.2	0.78	0.90	3
L-31y	3.3	4.0		0.68	14
L-31x	13.2	16.0	0.72	0.80	10
L-31A	14.5	24.2	0.52	0.60	8
L-32	11.5	14.1	0.49	0.70	14
L-33	21.0	35.0	0.26	0.40	20
L-34	1.6	1.6	1.00	1.00	3
L-35	2.4	3.5	0.81	1.00	8
L-35A	2.8	5.3	0.95	1.00	2
L-37	4.1	8.8	0.96	1.00	20
L-38	2.7	5.3	0.98	1.00	20
L-39	2.7	5.4	0.90	1.00	20
L-40	7.8	12.2	0.93	1.00	10
L-42x	6.9	11.2	0.90	1.00	12
L-42y	16.2	26.0	0.55	0.60	25
L-43	3.2	10.1	0.94	1.00	5
L-43A	3.5	8.7	0.79	1.00	5
L-43B	1.8	6.6	0.95	0.99	2
L-43C	4.6	20.8	0.00	0.00	0
L-44	7.6	11.3	0.92	1.00	6
L-45	6.8	8.8	0.95	1.00	6
L-45A	6.7	10.5	0.94	1.00	14
L-45B	1.8	3.1	0.96	1.00	3
L-45D	16.7	34.8	0.54	0.68	14

Irrigation node parameters that include demand, groundwater fraction, return fraction, and lag time parameters. Groundwater fraction is 0 for all diversions in the study reach so it has been excluded from the table. The suffixes “x”, ‘y”, and “z” following a diversion name represent multiple irrigation nodes representing one diversion and progresses from upstream to downstream, respectively.

Table 3. Return fraction calculator parameters.

Diversion	Area (acres)	Percent sprinkled	Ditch Loss	Crop Type (percent)			IGW_{DL}	IGW_{FL}	IGW_{SP}
				Alfalfa Hay	Grass Hay	Pasture			
L-01	40.7	0	0	0	0	100	0.85	0.85	1.00
L-02	40.1	0	0	0	0	100	0.85	0.85	1.00
L-03	837.5	50	0.5	50	20	30	0.00	0.85	0.50
L-03A	121.0	0	0	30	40	30	0.85	0.85	1.00
L-03AO	64.6	50	0	0	40	60	0.85	0.85	0.50
L-06x	791.8	45.6	0	45	45	10	0.00	0.85	0.40
L-06y	730.8	0	0.5	40	50	10	0.00	0.85	0.40
L-07	924.7	0	0.5	25	75	0	0.00	0.85	0.50
L-08	24.6	0	0	0	0	100	0.85	0.80	1.00
L-08A	948.4	0	0	30	50	20	0.85	0.85	1.00
L-09	708.1	50	0.3	25	75	0	0.90	0.85	0.50
L-10	895.6	90	0	90	0	10	0.85	0.85	0.00
L-11	164.4	0	0	0	50	50	0.85	0.85	1.00
L-12	121.3	0	0	0	0	100	0.85	0.85	1.00
L-13	493.7	80	0	80	20	0	0.85	0.10	0.00
L-14	52.4	0	0	0	0	100	0.85	0.85	1.00
L-15	167.4	0	0	0	80	20	0.85	0.85	1.00
L-17	299.9	0	0	0	70	30	0.85	0.85	1.00
L-18	20.1	0	0	0	0	100	0.85	0.85	1.00
L-19	23.0	0	0	0	0	100	0.85	0.85	1.00
L-20	358.0	0	0	0	80	20	0.85	0.85	1.00
L-21x	107.8	0	0	0	100	0	0.85	0.85	1.00
L-21y	107.8	0	0	0	80	20	0.85	0.85	1.00
L-22	928.3	20	0	20	70	10	0.85	0.85	0.50
L-23	306.8	0	0	0	0	100	0.85	0.85	1.00
L-24	36.8	0	0	0	0	100	0.85	0.85	1.00
L-25	140.9	0	0	0	50	50	0.85	0.85	1.00
L-26	70.0	0	0	0	0	100	0.85	0.85	1.00
L-27	75.7	0	0	0	80	20	0.85	0.85	1.00
L-28	517.6	40	0	0	50	50	0.85	0.85	0.50
L-29	306.0	0	0	0	75	25	0.85	0.85	1.00
L-30x	84.0	0	0	0	100	0	0.85	0.85	1.00
L-30y	210.0	0	0	0	100	0	0.85	0.85	1.00
L-30z	546.0	0	0	40	60	0	0.85	0.85	1.00
L-30A	23.9	0	0	0	100	0	0.85	0.85	1.00
L-31y	253.7	60	0	60	40	0	0.85	0.80	0.50

Diversion	Area (acres)	Percent sprinkled	Ditch Loss	Crop Type (percent)			IGW_{DL}	IGW_{FL}	IGW_{SP}
				Alfalfa Hay	Grass Hay	Pasture			
L-31x	190.3	0	0	50	50	0	0.85	0.80	1.00
L-31A	237.5	0	0	70	0	30	0.85	0.60	1.00
L-32	476.7	0	0	75	0	25	0.85	0.70	1.00
L-33	1077.4	0	0	5	70	25	0.85	0.40	1.00
L-34	80.1	80	0	80	0	20	1.00	1.00	1.00
L-35	59.2	0	0	0	100	0	1.00	1.00	1.00
L-35A	19.9	0	0	0	100	0	1.00	1.00	1.00
L-37	17.8	0	0	0	75	25	1.00	1.00	1.00
L-38	4.5	0	0	0	0	100	1.00	1.00	1.00
L-39	30.3	0	0	0	100	0	1.00	1.00	1.00
L-40	55.3	0	0	0	100	0	1.00	1.00	1.00
L-42x	115.4	0	0	0	0	100	1.00	1.00	1.00
L-42y	269.2	0	0.5	100	0	0	0.80	0.40	1.00
L-43	24.6	0	0	0	100	0	1.00	1.00	1.00
L-43A	68.4	0	0	0	100	0	1.00	1.00	1.00
L-43B	9.7	0	0	0	100	0	1.00	1.00	1.00
L-43C	64.9	0	0	0	100	0	1.00	1.00	1.00
L-44	38.1	0	0	0	100	0	1.00	1.00	1.00
L-45	42.5	0	0	0	100	0	1.00	1.00	1.00
L-45A	59.1	0	0	0	0	100	1.00	1.00	1.00
L-45B	7.3	0	0	100	0	0	1.00	1.00	1.00
L-45D	304.0	50	0.5	50	25	25	0.70	0.90	0.10

The suffixes “x”, ‘y”, and “z” following a diversion name represent multiple irrigation nodes representing one diversion and progresses from upstream to downstream, respectively.

Because contemporaneous data are limited, the model was constructed to reflect the operations from June 15, 1999, to the September 30, 2001 (the period of record for the diversions). The model is run on a daily time step from the June 15, 1999, to September 30, 2001, but it is only currently valid for periods when the daily diversion stage was recorded: June 15 to October 30, 1999; April 15 to October 30, 2000; and May 1 to October 31, 2001 (as shown on Table 1). Due to a lack of stage records at the Reclamation McFarland gage, validity of the model from the gage to the USGS Lemhi gage is restricted to June 15 to October 30, 1999; April 15 to September 9, 2000; and May 1 to October 9, 2001. In addition, discharge records from the USGS L-5 gage are missing from January 1 to June 18, 2001. The simulation is unable to compare proposed scenario simulation with observed data during these time periods. Though 2002 irrigation season data is available, it needs to be formatted and input into the model.

4.2.2 Comparison of Hydrographs

Overall, correlation between observed and simulated stream flow hydrographs indicates that the LRMBM provides a reasonably good representation of the Lemhi River system, as shown in Figure 9. Discrepancies between the simulated and measured discharge values stem from uncertainties and assumptions incorporated into the model to account for contributions from tributary inflow, precipitation, and regional ground water inflow. In the LRMBM, these factors are incorporated in the reach gains. The greater the contribution from these factors between gages, the less accurate the inflow to the downstream gage becomes. For example, the LRMBM results better represent the USGS Lemhi gage records than the Reclamation Barracks Lane gage records because fewer contributions are made due to tributary inflow. The same relationship applies to the USGS L-5 gage and the Reclamation L-1 gage.

Lack of accounting for reach gains along the river is particularly significant for the Reclamation Barracks Lane gage, where the LRMBM simulated no discharge in August and September during the 2000 and 2001. No discharge was simulated in the river segments between the L-09 and the Reclamation Barracks Lane gage. During this time period, stream records show that stream discharge was observed in the Lemhi River. To address this discrepancy between actual and simulated streamflow, it is recommended that an additional gage be placed on the Lemhi River between the Lemhi and Barracks Lane gages and that tributary inflow from Agency Creek, Sandy Slough, and Withington Creek be monitored.

While no formal sensitivity analysis was performed, during the calibration period it was observed that longer lag times shifted peaks to the right, lowered the magnitude, and lengthened the durations. It is inferred that this simulates attenuation associated with ground water recharge from return flow to the Lemhi River. Decreasing IGW values lowered the overall stream discharge. A full sensitivity analysis to quantify the LRMBM's response to these parameters is recommended in future analysis.

4.2.3 Comparison between the USGS 1997 Lemhi River Seepage Run and the LRMBM results.

The relative percentage change in the inflow and outflow water balances for reaches 5, 8, 9, 10, 11, 12, and 13 for water years 1999, 2000, and 2001 are within 12 percent, with an average of 6 percent, when comparing the seepage run and simulated results. Table 4 shows the percentage results of this comparison. Given the inaccuracies in the flow measurements, daily diversion input calculations for the model, and the difference in operational and existing conditions prevalent between the years, this agreement indicates the LRMBM is simulating the general water movement trends within the natural system.

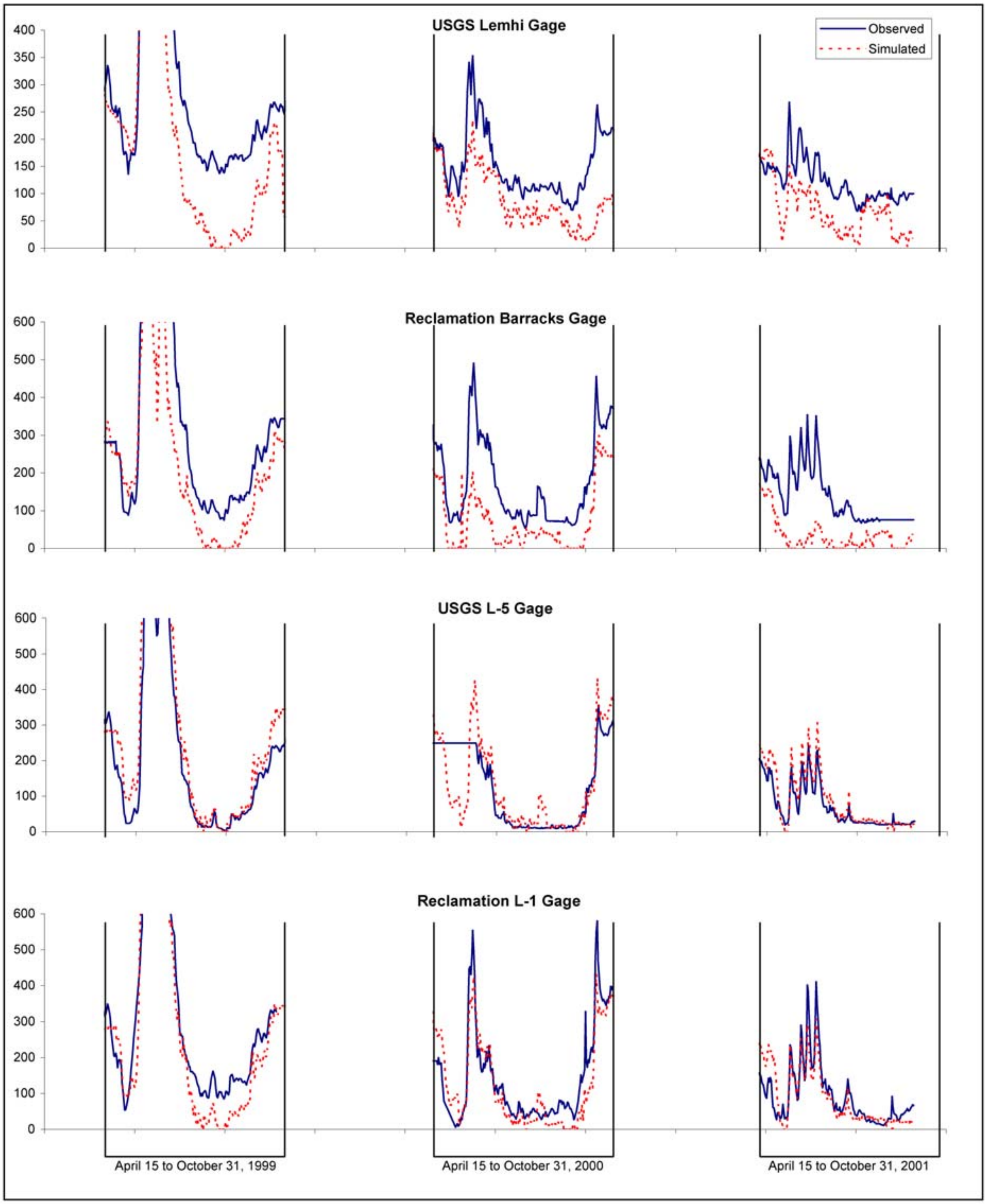


Figure 9. Comparison of observed discharge records and LRMBM results without reach gains

Table 4. Comparison of the relative percentage change in the inflow and outflow water balances for the USGS 1997 Lemhi River seepage run and LRMBM results for the 1999, 2000, and 2001 time periods.

USGS 1997 Seepage Run	August 4-8 Results (percent)				October 27-31 Results (percent)		
	1997	1999	2000	2001	1997	1999	2000
Reach 4 - Reclamation gaging station at BLM McFarland Campground to highway bridge upstream from L-44 diversion	9.6	55.3	6.1	17.9	-5.0	-1.0	7.0
Reach 5 - Highway bridge upstream from L-44 to Lemhi.	-4.7	-4.9	-7.1	-16.7	-10.0	-3.0	-11.0
Reach 6 - Lemhi to 0.1 mile downstream from Hayden Creek Road.	4.3	4.7	21.9	16.9	-3.0	0.0	0.0
Reach 7 - 0.1 mile downstream from Hayden Creek Road to USGS gaging station 13305000.	-43.8	-10.3	-17.4	-2.2	-19.0	-9.0	-44.0
Reach 8 - USGS Gaging Station 13305000 to highway downstream from L-30 diversion.	9.6	4.0	3.0	-0.5	-3.0	-5.0	-5.0
Reach 9 - Downstream from L-30 diversion to highway bridge 0.15 miles upstream from L-19 diversion.	15.7	24.7	14.5	9.3	-2.0	-2.0	-2.0
Reach 10 - 0.15 miles upstream from L-19 diversion to highway bridge 0.7 miles upstream from Baker intersection.	10.5	3.1	5.2	3.7	-1.0	0.0	0.0
Reach 11 - 0.7 miles upstream from Baker intersection to Reclamation gaging station at Barracks Lane.	19.0	20.7	17.3	30.4	-6.0	-3.0	-5.0
Reach 12 - Reclamation gaging station at Barracks Lane to USGS gaging station 13305310.	23.7	27.9	31.1	28.0	-5.0	0.0	0.0
Reach 13 - USGS gaging station 13305310 to Reclamation gaging station at L-3A diversion.	2.9	9.3	6.0	8.4	0.0	0.0	0.0
Reach 14 - Reclamation gaging station at L-3A diversion to Reclamation gaging station at L-1 diversion.	8.4	-25.3	-16.7	-23.1	-8.0	-10.0	-5.0

Reaches 4, 6, 7, and 14 had greater discrepancies, but these can be accounted for by the following factors:

- **Reach 4** – The incoming hydrograph for the Reclamation McFarland gage does not record underflow. The 1997 seepage run indicated this was a gaining reach in August and October 1997. Return flow from the L-45D and L-45B irrigation nodes are well below the larger quantity measured in the seepage run. This discrepancy is most likely from underflow contributions.
- **Reach 6** – In the seepage run, there is a 20 percent increase from Hayden Creek seepage. The model does not account for this. If the Hayden Creek seepage inflow is subtracted from the observed flow, the net gain to the reach is within 11 percent of the simulated values.

- **Reach 7** – During the seepage run, Hayden Creek inflow was 77 percent of the inflow from the top of the reach. The corresponding contribution in the simulation was 51 percent, 39 percent, and 28 percent for the water years 1999, 2000, and 2001, respectively. If the Hayden Creek flow is reduced to 40 percent of the incoming flow, then the net balance for the reach is 11 percent, and then within 9 percent of the simulated net balances.
- **Reach 14** – In the 1997 Lemhi River seepage run, inflow from irrigation water was not measured in this reach. All gains were observed as reach gains at the Reclamation L-1 gage. In the LRMBM, irrigation nodes representing diversions L-8, L-8A, L-7, L-6, L-3AO, L-3A, L-3, and L-2 have return flows for the Lemhi River. The discrepancy between the observed and simulated net balance can be attributed to the return flow within this reach.

4.2.4 Areas of Variable Accuracy

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 channel 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.

5 SCENARIOS

Between May 8 and May 14, 2001, the discharge at the USGS L-5 gage dropped severely. Two scenarios were modeled using the calibrated LRMBM to investigate potential diversion operation alternatives to address this drop. This period is intended to represent potential operations during a low water year in the basin.

The first scenario was introduced to demonstrate to the local community the applicability of the LRMBM to represent how the watermaster could stagger diversion timing to meet a negotiated flow target in the spring of 2001. The scenario modeled the effects of suspending diverted water in diversions L-24, L-25, L-26, L-27, and L-28 from May 7 to May 12, 2001. The second scenario was developed by local landowners during a community presentation in January 2003. The local landowners proposed lowering the discharge in L-9 by 4.5 cfs, L-8A by 14 cfs, and L-6 by 11 cfs from May 1 to May 20, 2001. Figure 10 shows the hydrographs for these two scenarios. Both scenarios provide additional flows at the USGS L-5 gage during a low water year and demonstrate that the model can be used to evaluate these scenarios.

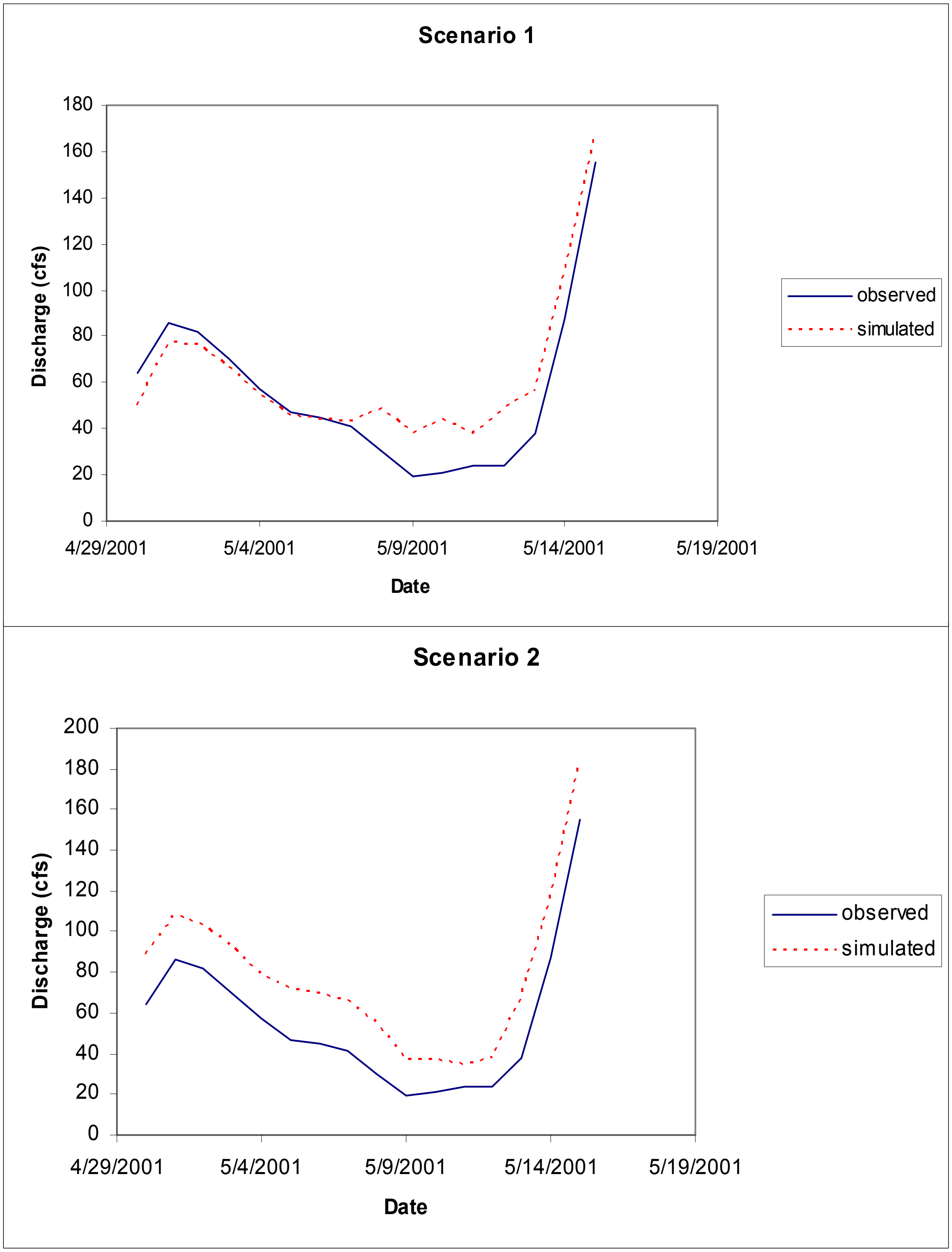


Figure 10. Modeled hydrographs at the USGS L-5 gage for scenarios 1 and 2.

6 PUBLIC REVIEW AND COMMENT

Throughout the development of the LRMBM, Reclamation, IDWR, and DHI sought public review and comment from a group of informed local agency staff and water users. Comments by the attendees provided valuable information. Meetings held in Salmon included:

- June 2002, October 2002, and January 2003 to review and comment on the model configuration, model assumptions, and preliminary simulation results.
- January 2003 to provide a final review of the model.

Public comments helped the developers alter and recalibrate the LRMBM. A simulation was developed to demonstrate the LRMBM streamflow management alternatives that would illustrate how the initial diversions to irrigation canals could be operated sequentially to deliver streamflow to charge those irrigation canals and to maintain streamflow downstream from the L6 diversion during the spring runoff period. In addition, during the final presentation, the LRMBM was used to determine an operational plan put forth by the local agency staff and water users attending the meeting to address the same scenario.

Though no quantifiable data is available, DHI personnel feel that the understanding by the local agency staff and water users of the Lemhi River basin and LRMBM increased dramatically. This assertion is based on the change in focus of the questions, comments, and suggestions concerning the model over the series of presentations.

Initially, the comments addressed general understanding of how models work and their applicability in addressing questions of concern. By the final presentation, the comments were directed towards specific capabilities in the model, questions they would like to see addressed, and suggestions on how to refine the knowledge of the Lemhi River basin or collect data for further improvement of the LRMBM.

A few of these specific questions, comments, and suggestions include (Loucks 2003; Olsen 2003; Sager 2003; Smith 2003):

1. Examination of the early storms with greater than one inch precipitation on the hydrograph at Salmon.
2. Suggestions for lag times for various irrigated areas in the basin and methods for quantifying the results.
3. Operational plans to address the streamflow at L-6 during the spring runoff.
4. How changing areas of the basin from flood to sprinkler irrigation would affect flow in the Lemhi River throughout the irrigation season.
5. General questions concerning operation of the LRMBM and the accompanying Microsoft Excel interfaces.

7 LRMBM LIMITATIONS

Limitations of the LRMBM arise from the inherent limitations of network models, the lack of detailed input and calibration data, and inaccuracies associated with simulating the return flow lag time.

7.1 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.

7.2 Data Availability

The accuracy of model results depends on the quantity and quality of the input data. Data limitations for this LRMBM analysis include:

- Only 2.75 irrigation seasons of contemporaneous data available with which to calibrate the model.
- Lack of plentiful gage data along the Lemhi River.
- Poor resolution of the mixing of tributary-diversion water.
- Multiple water diversions within several irrigated areas.
- Uncertainty associated with the ground water-surface water interaction.

- Missing data in the daily stage records for diversions.
- Poor stage-discharge rating curves for some diversions.

As a general rule, longer periods of record better reflect climatic conditions as they range from extremely wet to dry seasons. Therefore, the parameter configuration in a river model becomes more accurate as a fuller range of natural climatic variability is incorporated in the input data sets used for model calibration. The minimum number of years of data depends on the climatic variability. The parameter configuration for the LRMBM is built on only 2.75 irrigation seasons of data: one average runoff year and two drought years. Consequently, the LRMBM is expected to represent dry year conditions better than wet year conditions. As data is collected in the future, MIKE BASIN can easily accept the new data and the parameter configuration can be updated.

Too few stream gages prevent the model from accurately determining the influence of multiple diversions and return flows that occur between gages. It also clouds the model's ability to incorporate reach gains that occur along the system. In the LRMBM, each irrigation node has parameters for the intermediate ground water portion of the return fraction and its lag time. These data were used to calibrate the model. With multiple irrigation nodes between gages, multiple sets of parameter values could produce the same result. While comparison to the seepage run provides a guide for calibrating the parameters, the seepage run occurred in 1997. Its precipitation, tributary inflow, and irrigation operation were likely different for the same time period in 1999, 2000, and 2001. Thus, the seepage run is only a guide for calibrating parameters. Additional stream gages at key locations would provide the reference points needed to better represent estimates for return fraction and lag time.

The 1997 seepage run also indicated that the Lemhi River gained along all but one subreaches during the irrigation season. In the LRMBM, gains and losses are calculated and accounted for at the USGS Lemhi Gage, Reclamation's Barracks Lane gage, the USGS L-5 gage, and the Reclamation L-1 gage. Therefore, model reaches far downstream of a gage may indicate less instream flow than most likely exists in the river because the model currently does not distribute gains to subreaches between gaging stations. This could be problematic if the model simulates a shortage to a diversion that relies on the stream gains that actually occur in a subreach but are not currently represented in the LRMBM. Gains could be linearly pro-rated and added incrementally to simulated streamflow between gaging stations as a rough approximation to account for gains between gaging stations, but in sections where confidence in the instream flows is deemed important, additional gaging station would need to be added.

In irrigated areas where diverted water is reused or mixes with tributary inflow, the demand and return flow lag time become more complicated to represent. For demand, the reuse of water in irrigated areas along Agency Creek, Sandy Slough, Withington Creek, Bohanon Creek, and the L-7 and L-6 diversions makes computing lag time and return fraction very difficult. Thus, when scenarios need to be evaluated for specific allocations in these irrigated areas, more detail about how the system operates will need to be incorporated into the model configuration.

Ground water plays a significant role in the Lemhi River flows throughout the irrigation season. Evidence of this includes the reach gains measured during the 1997 Lemhi River seepage run and the effects of the initial abstraction at the onset of the irrigation season. Currently, local experience and a sensitivity analysis provide the justification for the lag time and the intermediate ground water portion of the return fraction. Additional investigation and analysis are needed to further understand these parameters.

Accuracy of the historic daily diverted water computed for each diversion is a function of the quality of the diversion stage records and the stage-discharge rating curves. Uncertainty in the stage records arises from data gaps in the records and the approach used to interpolate the record to create the time series input data described above. Stage is recorded once daily and therefore assumed to be constant for the day. Also, stage may be influenced by in-ditch conditions such as ditch maintenance and algae growth. This uncertainty can lead to erroneous estimates for the quantities of water diverted from the river and thus add error during the calibration of the parameters.

The stage-discharge rating curves, used to convert diversion stage to a discharge, can vary in accuracy depending on quality and variability in the contemporaneous stage-discharge measurements upon which the relationships are built. Factors that influence the water conveyance of the channel and thus the stage include maintenance, operation, or algae growth in the diversion channel. Water discharge measurements also have inherent error in the measurement.

7.3 Modeling Limitations

In the LRMBM, lag time of the return flow is simulated by a linear-reservoir routing delay. While this accurately represents either surface or subsurface return flow, it does not simulate a system where part of return flow occurs rapidly as a pulse of surface flow and another part is lagged over some time period as subsurface flow. For portions of the flood irrigated land along the Lemhi River, a mixture of surface and subsurface return is observed. In these cases, the simulated conditions would have a more steady return flow than is observed and thus may not represent peaks and valleys as accurately.

Return flow nodes are associated with irrigation nodes and are located at a downstream point along the Lemhi River where the majority of the return flow is considered to return. While placing the return location at the downstream-most point is adequate for the majority of the system, this simplification could become problematic if model simulations indicate that the stream becomes sufficiently depleted downstream of an intermediate diversion that occurs between the original point of diversion and its associated return location. If the model indicated a shortage at the intermediate diversion, it would be advisable to quantify the amount of any return flow that may occur between the upstream and intermediate diversions. If this problem with the model occurs and the appropriate data is collected to remedy that problem, the LRMBM can be altered to reflect multiple locations of return flow.

Generally, as one proceeds downstream in the study reach, the reuse of water and the influence of tributary input and mixing of water become more prevalent. The reuse of diverted water increases the complexity of computing return fractions and lag times for calibration. Four systems that have significant reuse of diverted water or tributary inflow include:

- Agency Creek: L-42 ⇒ L-32 ⇒ L-31A ⇒ L-31 ⇒ Agency Creek ⇒ Lemhi River
- Withington Creek: L-30 ⇒ L-22 ⇒ L-21 ⇒ L-15 ⇒ Withington Creek ⇒ Lemhi River (some water may be diverted to L-14 and L-13 from Withington Creek)
- Sandy Slough: L-23 ⇒ L-22 ⇒ Sandy Creek ⇒ L-21 ⇒ L-15 ⇒ Sandy Slough ⇒ Lemhi River
- Bohannon Creek: L-23 ⇒ L-22 ⇒ L-21 ⇒ L-15 ⇒ Lemhi River.

Currently, return fractions and lag times for each irrigation node have been individually computed to approximate how long the water may take to re-enter the Lemhi River from that irrigation node. Thus, when scenarios need to be evaluated for the specific allocation in these irrigated areas, more detail about how the system operates will need to be incorporated into the model configuration.

Water enters the diversion ditches through headgates located at the points of diversion along the Lemhi River. Quantity of water passing through the headgates is a function of the gate opening and the river stage. Increases in the river stage results in an increase in the quantity of water diverted. Therefore, when evaluating scenarios, it is anticipated that discharge in the Lemhi River will change, thus changing the quantity of water diverted. Currently, there is no corresponding adjustment between the river stage and the diversion rate. Therefore, evaluation of scenarios that implement changes to diversion rates far upstream from the point of interest may not accurately represent the total quantity of water in the river at the point of interest. Future efforts in diversion gate automation will aid in simulating the effects of altering upstream diversion practices.

Although the IGW component of the reach gains in the LRMBM has not been fully implemented or calibrated, the proposed diversion operation alterations for augmenting flows early in the irrigation season should not be sensitive to this component. The IGW component simulates the deeper ground water contribution to the stream. Travel times for the ground water are from weeks to months. This expansive time is too long to affect the relatively quick response necessary for early irrigation season flow augmentation.

Implementing the IGW component will be more necessary to evaluate alternatives later in the irrigation season.

8 RECOMMENDATIONS FOR OVERCOMING LRMBM LIMITATIONS

Though IDWR, Reclamation, and DHI personnel worked to complete the initial phase of the LRMBM, additional analysis and data collection may further improve the model. These recommendations do not reflect any additional data and analysis that may be required to address specific question posed to the model in the future. However, implementing these recommendations will provide greater insight into water movement in the Lemhi River basin, and thus can provide a greater foundation for the LRMBM.

8.1 Data Collection and Analysis

The quantity and location of additional data collection will be a function of time, budget, and the questions users would like to address using the LRMBM. The following is a list of data collection needs, organized by importance.

8.1.1 Install Additional Stream Gages

The river stretch between the USGS Lemhi and L-5 gages is long and experiences significant gains. Recommended installation locations are near diversions L-30 and L-12. Site observations for 15 days before and after irrigation season can help determine base conditions. Adding stream gages at these locations would allow the model to introduce reach gains along the stream and to quantify the instream flow in the Lemhi River at and downstream from the gage. In addition, the model can be extended to include the Leadore to McFarland Campground reach if an accurate stream gage is placed at Leadore.

8.1.2 Monitor Tributary Inflows from Sandy Slough, Withington Creek, and Agency Creek

The Sandy Slough, Withington Creek, and Agency Creek tributaries are major return points for water diversions. They have water returning from multiple uses in the irrigated areas. The same monitoring process used for diversions (install a staff gage, measure stage-discharge contemporaneously throughout the irrigation season, and record the daily stage) could be applied to these streams. This data could be useful in modeling scenarios associated with channel reconnection and TMDL issues.

8.1.3 Install V-notch Weirs or Other Flow Measuring Structures on Selected Diversions

Installing v-notch weirs or other flow measuring structures on diversions L-3A, L-9, L-10, L-15, L-29, L-32, L-42, L-43, L-43B, L-43C, L-44, L-45, and L-45A would provide greater accuracy in the quantifying the amount of water diverted. These diversions were selected because they divert greater than 5 cfs and have poor stage-discharge rating curves (r^2 values of less than 0.7). Installing these devices can lay the foundation for diversion automation in the future. As the accuracy, quantity, and automation of input data increases, the MIKE BASIN model can be expanded to include daily system operations. The model could be automatically updated with daily measurements. This would create a real-time tool to evaluate potential operational scenarios to meet irrigation and in-stream targets.

8.1.4 Calibrate and Refine LRMBM Seepage Runs

A concurrent seepage run and simulation would provide greater foundation for calibrating and refining the LRMBM. Seepage runs are recommended at the onset of the irrigation season when the Lemhi River becomes reduced and again late in the irrigation season. If resources are limited, reducing the length of the study reach to include only the section of the river downstream of the USGS Lemhi gage is advisable.

8.1.5 Ground Water-Surface Water Interaction

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.

The modelers performed a cursory examination of ground water well hydrograph data, performed a sensitivity analysis of initial abstraction by staggering quantity and timing of return fraction rates, and computed travel times using Darcy's Law for IGW lag times. However, fully exploring these variables was deemed too time consuming for completion of the initial phase of the model's development. 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 these analyses with field study, such as seepage runs or piezometer studies, could further improve the understanding of ground water behavior in the Lemhi River basin.

Installing piezometers or thermisters can help determine gains or loses throughout the system. This information would provide information on ground water-surface water interaction along the stream and supply information useful for addressing initial abstraction.

8.2 Modeling

8.2.1 Incorporate 2002 Gage Data

Though Reclamation and USGS have collected gage data for the 2002 irrigation season, this information has not been incorporated into the model. Incorporating the information requires appending the two upstream boundary hydrographs (the Reclamation McFarland gage and the Hayden Creek gage), and calculating the reach gains at the USGS L-5 and L-1 gages. Reclamation's Barracks Lane gage was not operational during the 2002 irrigation season and was, therefore, unavailable for this analysis. Daily stage reading have already been converted into daily stages and need to be loaded into the LemhiDivInpt.xls, a spreadsheet that automatically loads irrigation node information into the appropriate MIKE BASIN time series files. Including this information would provide another season of data to further calibrate the LRMBM.

8.2.2 Implement Quality Assurance and Quality Control Analysis

The results from this phase of development primarily reflect the efforts from DHI personnel to calculate, format, input, and calibrate the LRMBM. While great care was taken to ensure the data was correctly calculated and input into the LRMBM, time constraints prevents the calibration from being externally reviewed; however, this can be done in the next phase of the project.

8.2.3 Refine the Reach Gain Calculator

Currently, the IGW lag times entered into the reach gain calculator are approximated from the expected time of travel based on Darcy's Law. These should be calibrated and fully incorporated into the reach gain calculator.

8.2.4 Apply SEBAL Data

At the conclusion of the initial phase of developing the LRMBM, evapotranspiration (ET) rates were determined by extrapolating the ET rates from the meteorological station at Corvallis, Montana, and adjusting the rate for the crop type. During the development, IDWR acquired and processed ET rates based on SEBAL (a method of calculating ET rates using digital images from Landsat and other remote-sensing satellites that measure visible, near-visible, and infrared light (Morse et al. 2000)). Unfortunately, these data were not able to be included in the model development. Since the data are collected to represent local ET rates, it is suggested that this information be incorporated into the model for the 2001 irrigation season.

8.2.5 Refine Initial Abstraction Rates

At the onset of the irrigation season, ground water levels rise, wax before the irrigation season ends, and wane after irrigation season ends. The term "initial abstraction" refers to the quantity of diverted water that is used to saturate the ground prior to return flow back to Lemhi River in an irrigated area. Preliminary investigations indicate that ground water wells in the irrigated area show a water level increase of approximately 15 to 20 feet during this period (Donato 1998). Additional ground water level analysis could help quantify the filling of the shallow ground water system and the sustained release of this source of water to the Lemhi River later in the summer. Unfortunately, there was not enough time to conduct this analysis.

In addition, DHI personnel considered staggering the return fraction over several days at the onset of the irrigation season to simulate the initial abstraction for diversions L-40 through L-44. Of the five alternatives, the best alternative was to stagger the return flow over five days using the following return fractions: 0.0, 0.1, 0.3, 0.5, and 0.7. This was based on an assertion from Don Olsen (2003), a local landowner, that he sees response in the Lemhi River after 5 days of flood irrigating his land. The sequence should be further refined to reflect the actual local conditions

8.2.6 Sensitivity Analysis

While the modelers performed preliminary sensitivity during calibration, a rigorous analysis for return fraction lag time, IGW, and IGW lag time has not been conducted. Conducting a sensitivity analysis would provide further understanding of the importance of these parameters within the model.

8.3 Further Analyses

8.3.1 Precipitation

Precipitation in the current LRMBM is treated as a component of reach gains stemming from precipitation distributed spatially and temporally during the summer months in the lower valley (see Figure 5). When incorporating these storms into the model, the temporal and spatial distribution localized storms must be considered. Current hydrological work that uses the meteorological data from local weather stations to create "local design storms" may be useful.

In addition, Bob Loucks (2003), a local landowner in the basin, indicated that large frontal events, occurring in April through mid-June, deliver greater than one inch of precipitation, and that they tend to be spatially distributed over the entire study reach. Rainfall events greater than 1 inch between April and mid-June can be correlated to streamflow at the gages. If this shows a positive correlation, then the LRMBM could be altered to account for these climatic influences to help refine irrigation operation plans during the onset of the irrigation season.

8.3.2 Extension of the LRMBM Upstream to Leadore, Idaho

Extending the model upstream to Leadore, Idaho, would allow for scenarios that include diversion operations upstream from Reclamation's McFarland gage. This was planned to be the initial extent of the model, but lack of quality gage data at Leadore prevented this extension. In the short term, the upstream hydrograph could be supplemented with rainfall-runoff models. However, for long-term use of the LRMBM, the installation of a gage at the upstream boundary is warranted and strongly recommended.

9 CONCLUSIONS

From October 1, 2002, until January 31, 2003, IDWR, Reclamation, and DHI personnel completed the first phase in the surface water budget model development for the Lemhi River, Idaho. The surface water budget model is developed in MIKE BASIN, a river network model that is based on an ArcView 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.

The completed first phase in the LRMBM development has resulted in a surface water budget model and Microsoft Excel interface that allows the Reclamation, IDWR, local stakeholders, and other interested parties to have a working MIKE BASIN surface water budget model for the mainstem Lemhi River. This tool enables them 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. Several Microsoft Excel interfaces have been developed to facilitate input and output operations to the LRMBM. These interfaces also allow users, having little operational knowledge of MIKE BASIN, to run scenarios from Microsoft Excel interfaces and to use MIKE BASIN as the computational kernel instead of having to interact directly with MIKE BASIN.

Developing the LRMBM involved building the river network; compiling, computing, formatting, and inputting the data; and calibrating the model. The river network configuration primarily reflects Rick Sager's knowledge of the Lemhi River system. The model covers 34 miles of the lower Lemhi River and incorporates 53 diversions that flow to 58 irrigation nodes. The model is run on a daily time step from June 18, 1999, to September 30, 2001. The simulation time period is restricted by the lack of contemporaneous data.

Model data include stream gage records; daily stage reading, contemporaneous stage-discharge data, and irrigated areas for each diversion; and ET rates, crop type, and area serviced by sprinkler irrigation within each irrigated area. Daily diversion rates were generated by applying stage-discharge rating curves, developed from the contemporaneous state-discharge data, to the daily stage readings at each diversion. To calculate the quantity of return flow to the Lemhi River, a calculator was developed in Microsoft Excel to determine the daily return rate based on ET rate, irrigated area, crop type, ditch loss, sprinkled area, and loss to the intermediate ground water system. Microsoft Excel sheets were developed to augment data processing, data population into the time series files that support MIKE BASIN, calibration of the LRMBM, and analysis of alternatives.

Comparing observed and simulated hydrographs and relative water budget with the USGS 1997 Lemhi River seepage run, the LRMBM demonstrated that the model can simulate water movement in the study area. The LRMBM was sensitive to changes in lag time and IGW parameters during model calibration and the demand parameter during development of scenarios.

Two scenarios were simulated to demonstrate the applicability of the LRMBM for addressing the depression that develops below the L-6 diversion at the onset of irrigation in a dry water year. The first scenario showed that diversion timing can be altered to increase the flows below the L-6 diversion. The second scenario had a similar outcome; it showed that flow can be increased at several diversions to reach the same instream result.

Public involvement throughout the project augmented the development of the LRMBM and increased local awareness. Through a series of meetings, DHI, IDWR, and Reclamation personnel gained insight into how water moves through the Lemhi River basin; this knowledge helped them better develop the LRMBM using this data and the accompanying local understanding of the system. Through the GIS interface and time series graphs, local agency staff and water users also gained insight into water movement through the basin. Therefore, it is anticipated that the LRMBM will provide an excellent platform for future discussions on water operation plans in the Lemhi River basin.

Limitations of the LRMBM arise from the inherent limitations of network models, the lack of detailed input and calibration data, and inaccuracies associated with simulating the return flow lag time. The primary limitation is the absence of quality data. Time series data with the same time period only overlaps for 2.75 years

Though IDWR, Reclamation, and DHI personnel worked quickly to complete the first phase in the LRMBM development, additional analysis and data collection are needed to further improve the model. Further data collection is recommended to quantify water movement in areas where data is limited or poorly understood. Specific recommendations include installing one or two stream gages on the Lemhi River, monitoring tributary inflow from larger tributaries, and improving monitoring of discharge on diversions with poor stage-discharge rating curves.

The brief time frame under which this model was constructed prevented full development of all the model capabilities and analysis to better understand the system. Suggested model improvements include incorporating 2002 gage and 2000 SEBAL data; quality checking the model and data; and refining the reach gain calculator to account for irrigated water that enters the intermediate ground water system. Additional recommended analyses include investigating the ground water-surface water interaction, investigating the influence of frontal storms on Lemhi River hydrographs early in the irrigation season, investigating the sensitivity analysis to determining the influence of parameters on model outcome, and extending the LRMBM study area to Leadore, Idaho.

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 was intended to demonstrate the model's technology and simulate several irrigation alternatives to determine how the Lemhi River system can be operated to meet negotiated spring streamflow targets. With additional data and further analysis, the LRMBM can be used to develop irrigation operations for later in the irrigation season. If IDWR, Reclamation, and local stakeholders continue to update and refine the LRMBM, it could be used to aid in automation of diversion gates and as real-time operation tool.

10 REFERENCES

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