IDENTIFICATION OF FLOW RESTRICTED DIVERSIONS IN THE THOUSAND SPRINGS REGION USING THE MIKE BASIN MODEL

Prepared for the

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December 2004

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1 ABSTRACT

Springs and streams north of the Snake River between Twin Falls and King Hill, Idaho are presently a focus of water distribution challenges. Development of a clear picture requires analysis of both spatial and tabular information. The MIKE Basin model was selected as a means of integrating, evaluating and displaying this information. This study included (1) development of the Thousand Springs MIKE Basin Model (TSMBM) for surface flows in the Hagerman area in concert with IDWR staff, local waterusers and the watermaster, (2) populating the model with available data using daily time steps, (3) development of Microsoft Excel interfaces to automate data loading and calibration of the TSMBM, (4) development of a Microsoft Excel interface for interested parties to run the model by altering numbers in a spreadsheet and viewing results, (5) development of a web-based interface for displaying base conditions and proposed alternatives from the simulation, and (6) integration of the model with the public via a series of four public meetings. The resulting model was successfully integrated with IDWR operations and was used in identification of flow-restricted diversions with unmet water demand for project evaluation and water delivery system analysis. This model is ready to be used in 2005 for additional calibration and evaluation of water deliveries in the Hagerman area.

2 INTRODUCTION

This report describes the initiative by the Idaho Department of Water Resources (IDWR) to develop a surface water budget model for the Thousand Springs area, Idaho. The purpose for developing the Thousand Springs MIKE Basin Model (TSMBM) is to quantify and collectively represent sources and uses of spring flow and to identify the unmet water right demand in the Thousand Springs area. The current study focuses on Billingsley Creek and the Bar-S and Curren Ditches, however the foundation has been established for extending the model to include springs outcropping along the north canyon rim of the Snake River from Blue Lakes to King Hill, Idaho.

Currently, decreasing spring flows have reduced flows in the Thousand Springs area. The TSMBM has been constructed to illustrate where flow-restricted diversions result in unmet water right demands along Billingsley Creek. This model also can be used to evaluate operational adjustments and new water delivery works designed to provide enough water to meet irrigation and aquaculture needs during periods when spring flow is in short supply.

The TSMBM construction occurred from October 2003 to July 2004. During this period, IDWR and DHI, Inc. personnel built a river network, compiled and populated the model with data, created a spreadsheet housing time series data, developed an ArcIMS interface for displaying model results on IDWR's internet site, and developed a post-processing application for direct comparison of historical use and water rights. Lack of gage data along Billingsley Creek and lack of flow records for several diversions prevented the model from being calibrated. The current model can be used to investigate historical water uses in comparison to water rights per diversion ditch, compile data both spatially and tabularly, and illuminate data gaps to guide further data collection efforts. In addition the current model was used to provide preliminary evaluations of water delivery system enhancements. Future calibrated models will be used to evaluate operational scenarios given changing spring flow conditions and water use demands. The additional analysis and data are necessary to develop a calibrated model, enhance its accuracy, and better address user needs.

This report 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

3 BACKGROUND

The Eastern Snake Plain Aquifer (ESPA) in southern Idaho discharges at many locations, including a series of springs known collectively as Thousand Springs (Figure 1). Historically the ample discharges from these springs resulted in little need for regulation of flows. As a result the water distribution system has not been highly sophisticated, as evidenced by the minimal detail provided in annual water district reports from this area. In recent years, however, flows in the springs have diminished due to (1) reduced upstream surface water recharge, (2) increased upstream pumping of ground water, and (3) reduced natural recharge due to drought conditions in the upper Snake River basin. These reductions in flow have caused some water users to identify water delivery shortfalls, and regulation of upstream ground water rights has been considered.

Water rights in a portion of the Thousand Springs area have been quantified. More than 99 percent of the claimed water rights in IDWR Administrative Basin 36 have been decreed by the District Court of the Snake River Basin Adjudication (SRBA). Claims in IDWR Administrative Basin 37 are presently being evaluated in preparation of a Director's Report of recommendations, which is scheduled to be presented to the SRBA District Court in 2005. However, court decree of the water rights is merely one step in the process of implementing proper water distribution. The water right identifies the *maximum* diversion that is allowed for the associated use – but the demand for water to satisfy the use can vary throughout the year. Thus, IDWR must review the adequacy of water delivery by assessing not just the delivery as compared to the water right, but the delivery must be compared to the *unmet demand* for water under the water right on a given day. This type of assessment in an area of highly complex water distribution plumbing requires a sophisticated analysis tool capable of integrating both spatial and tabular information. IDWR selected MIKE Basin for this task due to previous success with this tool in other locales.

While water distribution review is needed throughout the Thousand Springs area, the most controversial sub-area is in the vicinity of Hagerman. Thus, this sub-area was selected as the focus for model development. The model is readily scalable to the remainder of the Thousand Springs area as time and data compilation resources permit.

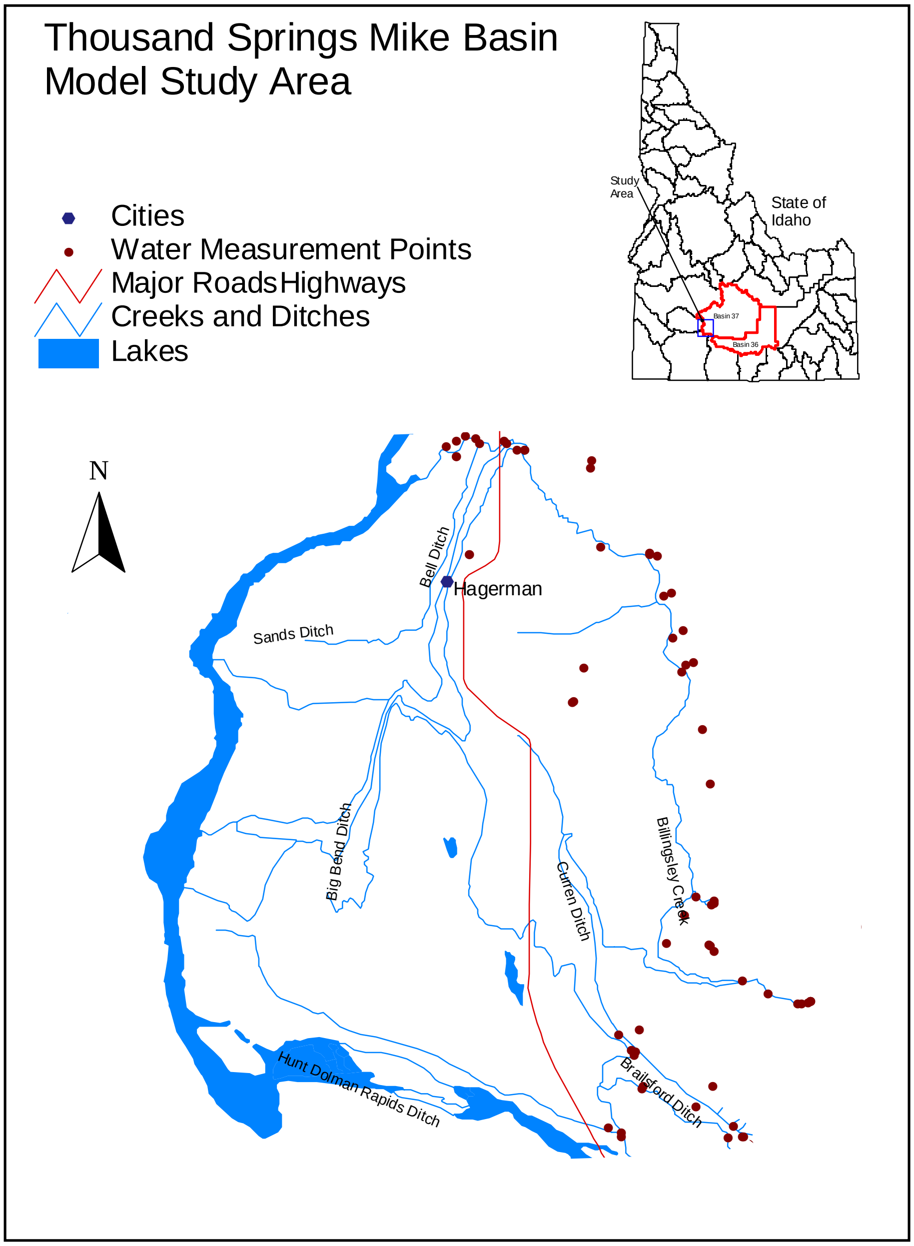


Figure 1. Thousand Springs area, Idaho.

4 MODELING METHOD

4.1 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.

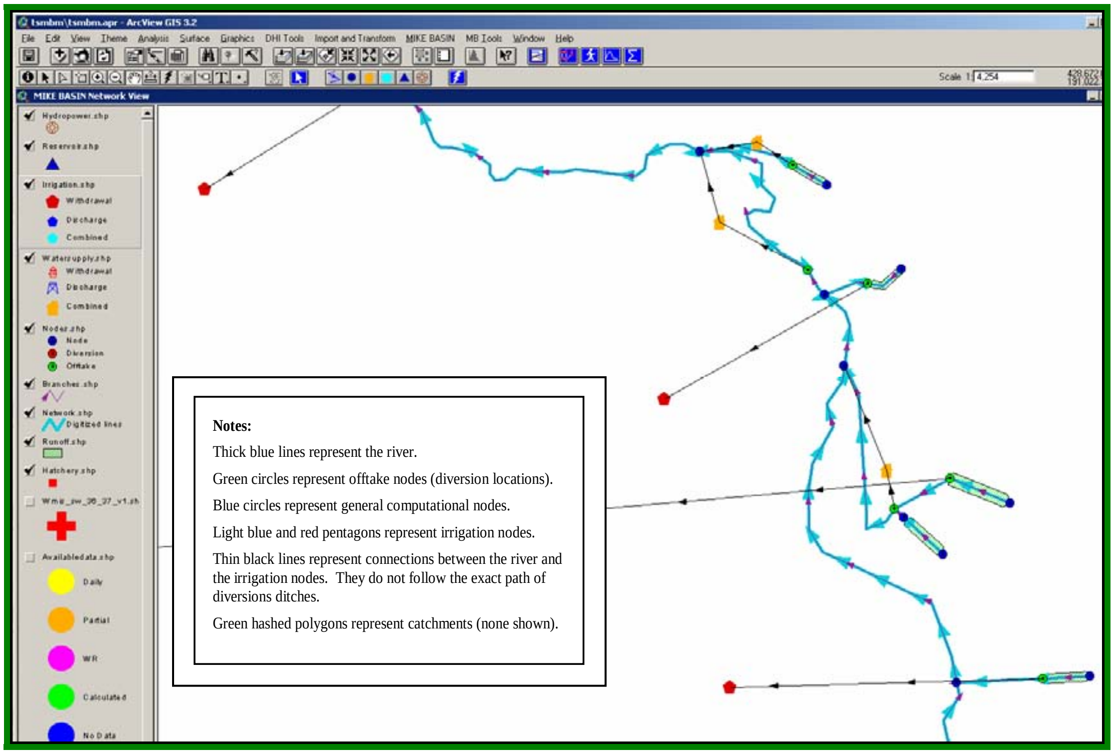


Figure 2 illustrates the network model interface. The branches (lines with arrows) represent individual river sections while the nodes (blue, red, or green filled circles) represent confluences, diversions, locations where certain water activities may occur, or important locations where model results 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.

MIKE Basin is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. 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 or remove 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 domestic, commercial, municipal, or industrial (DCMI) 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. Water supply nodes require time series data for demand, fraction of the demand satisfied by ground water, and the fraction of the demand returning to the river branch. In addition to the time series data needed for a water supply node, irrigation nodes require time series data for lag time for the return fraction to re-enter the river and the deficit demand carry-over from the previous time step. Calculators associated with both water supply nodes and irrigation nodes allow the water demand to be indirectly determined from DCMI or 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 river 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 was created to easily allow expansion to address complex systems if additional analyses are required or to incorporate additional data as it becomes available. MIKE Basin has additional capabilities, including the ability to simulate 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/.

4.2 Thousand Springs MIKE Basin Modeling Methods

Developing the TSMBM and accompanying demand comparison post-processor involved building the river network; compiling, computing, formatting, and inputting the data; calibrating the model; and developing the post-processor. This section describes the methods and assumptions used in construction of the TSMBM.

4.2.1 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. Frank Erwin, Thousand Springs Watermaster, was instrumental in constructing the river network and Tim Luke and Steve Clelland, IDWR, helped verifying that this information represented actual field conditions. After confirming the initial digitized river course and offtake node locations, Mr. Erwin, Mr. Clelland, and Mr. Luke supplied information about irrigated fields and aquaculture facilities as well as the return flow locations for each irrigation and water supply node.

River Network

The TSMBM river network focuses on Billingsley Creek, the Curren Ditch, the Bar-S Ditch, and major tributary springs that feed Billingsley Creek (Figure 3). The major tributary springs include the Curren Tunnel, Spring Creek Springs, Hoagland Tunnel, Weatherby Springs, Weatherby Tunnel, Three Springs, Tupper Springs, Fisher Springs, Big Springs, Sherman Springs, Hidden Springs, Hagerman Water Users Springs, Ruby Springs, Fisheries Development Hatchery Springs, and Florence Livestock Springs. The Sandy Pipeline is also included in the TSMBM model. The creek, ditches, and springs paths were digitized from aerial photographs and irrigation offtake nodes (diversions) were digitized from IDWR's place of use (POU) coverage.

Catchment Nodes

The headwaters of Billingsley Creek, spring flow emergence locations, and reach gains are represented with catchment nodes. As a general rule, catchment nodes were placed on the creek or spring at or near a Water Measurement Information System (WMIS) point that measured the same flow in the system. Springs that have catchment nodes include the Curren Tunnel, Spring Creek Springs, Hoagland Tunnel, Weatherby Springs, Weatherby Tunnel, Three Springs, Tupper Springs, Fisher Springs, Big Springs, Sherman Springs, Hidden Springs, Hagerman Water Users Springs, Ruby Springs, Fisheries Development Hatchery Springs, and Florence Livestock

Springs. The catchment node for the Sandy Pipeline was placed at the Sandy Pipeline vault that is located midway between the ponds and the confluence between the Sandy Pipeline and the Curren Ditch.

Direct precipitation, ground water loss/gain, and unmeasured tributary inflow are not directly accounted for in the TSMBM. To calculate reach gains/losses associated with these contributions to Billingsley Creek, catchment nodes were placed on Billingsley Creek upstream of the University of Idaho Hatchery and Branchflower Hydropower offtake nodes. These nodes represent locations where a minimum stream flow can be calculated in Billingsley Creek.

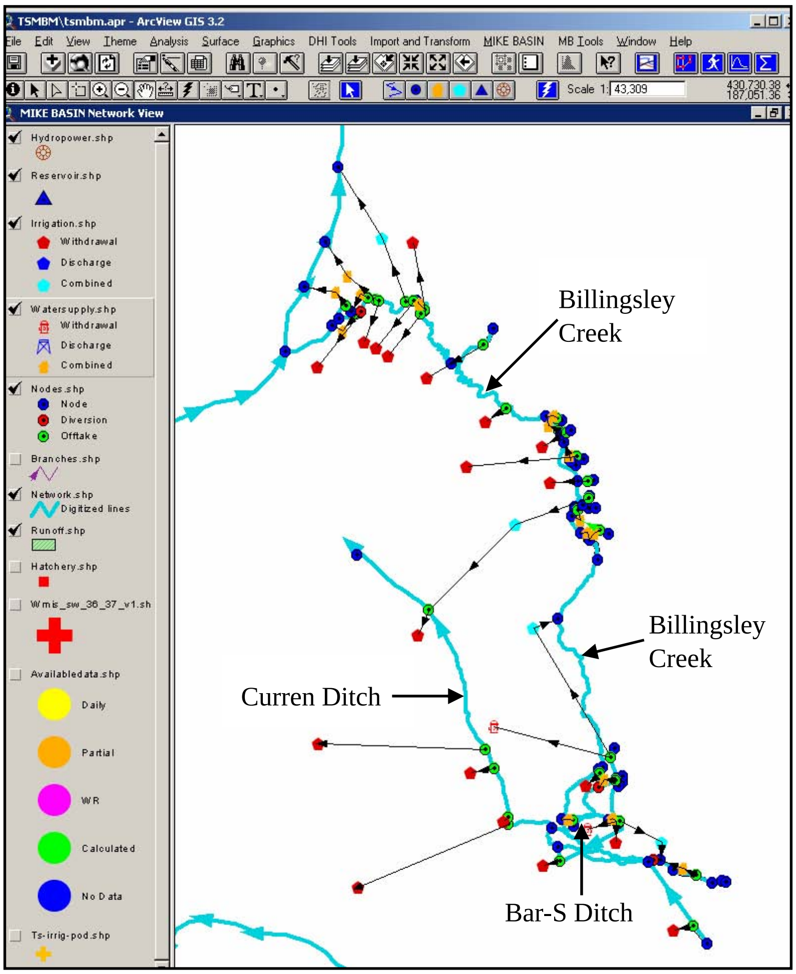


Figure 3. MIKE Basin network setup for Billingsley Creek and the Bar-S and Curren Ditches.

Water Supply and Irrigation Nodes

For most offtake nodes (diversions), multiple aquaculture facilities and irrigation areas share the diverted water throughout the year. As one purpose of the TSMBM is to evaluate if the water rights being serviced by a diversion have historically been met, the off-river node type associated with a diversion reflects the primary water usage for that diversion. For the TSMBM, most water users receiving water from an offtake node are represented by a single irrigation or water supply node because the water is being applied to fields or used by facilities in the same general area.

For an offtake node, water use is represented by one of four methods: 1) irrigated areas represented by an irrigation node, 2) aquaculture and domestic uses represented by a water supply node 3), aquaculture and irrigation uses represented by an irrigation node, and 4) multiple nodes representing the different water uses and their respective places of use (Figure 4).

For the TSMBM, only three offtake nodes have been defined using method four: Tupper Springs (N64), Spring Creek (N68), and Three Springs (N78). These diversions split flows in distinct canals or pipes that service water users in spatially separate locations. If future analysis requires refinement of water allocation within these or other water use and irrigation areas, then the 2004 TSMBM can easily be reconfigured to incorporate additional data and improved knowledge about the system.

4.2.2 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 TSMBM, time series input information from streamflow gaging station records was specified for 15 catchment nodes to define the spring runoff into the model. Time series input information was specified for 17 water supply nodes and 23 irrigation nodes to define water demand, ground water fraction (fraction of demand satisfied by ground water), return fraction (fraction of demanded water that returns to the river at specified return locations), lag time (the linear routing of return flow from the irrigated fields back to the river - irrigation node only), and deficit carryover (the fraction unfilled demand that can be fulfilled in a subsequent time step – irrigation node only). The temporal availability of each data type is presented in Table 2 and Table 3 (Section 5.2.3).

The majority of the time series input files for the TSMBM were obtained from IDWR’s Water Measurement Information System (WMIS) database. The WMIS is currently a standalone SQL server database that uses MS Access as the client or end user software for basic data entry, display and query of diversion records. Most of the diversions in WMIS are ground water diversions located within the ESPA, but spring diversions from the Thousand Springs area are also included. In 2004, several water districts and measurement districts that work from within IDWR offices entered data directly to WMIS. Ground water districts, irrigation districts and others within the ESPA generally use a copy of WMIS and IDWR subsequently appends the data to the database. IDWR is currently working on migrating WMIS into the IDWR Enterprise database and is developing a .Net application so that districts working outside of IDWR can enter measurement data to WMIS directly over the Internet.

Determining Catchment Specific Runoff

In MIKE Basin, catchment nodes are used to introduce water or update stream flow in the river network. Spring flow and ground water inflow constitute the majority of stream flow in the Billingsley Creek system. In the TSMBM, springs discharging into the Billingsley Creek system are represented with catchment nodes. The time series of inflow data for the springs were assumed to be the same as the WMIS point that measures the flow to a hatchery, domestic community, or irrigated area. As the flow measured in the pipes or channel flow-measuring devices may not capture the entire flow emanating from a spring, this measurement represents the minimum spring flow entering the river network from that spring.

Catchment nodes were also used to "update" the stream flows in Billingsley Creek to account for direct precipitation, ground water-surface water exchange, and tributary inflow. Catchment nodes were placed upstream of the University of Idaho hatchery (W16) and the Branchflower Hydropower Facility (W21). While water discharge in Billingsley Creek is not directly measured at these locations, a minimum stream flow in the creek can be determined through surrogate means using WMIS data.

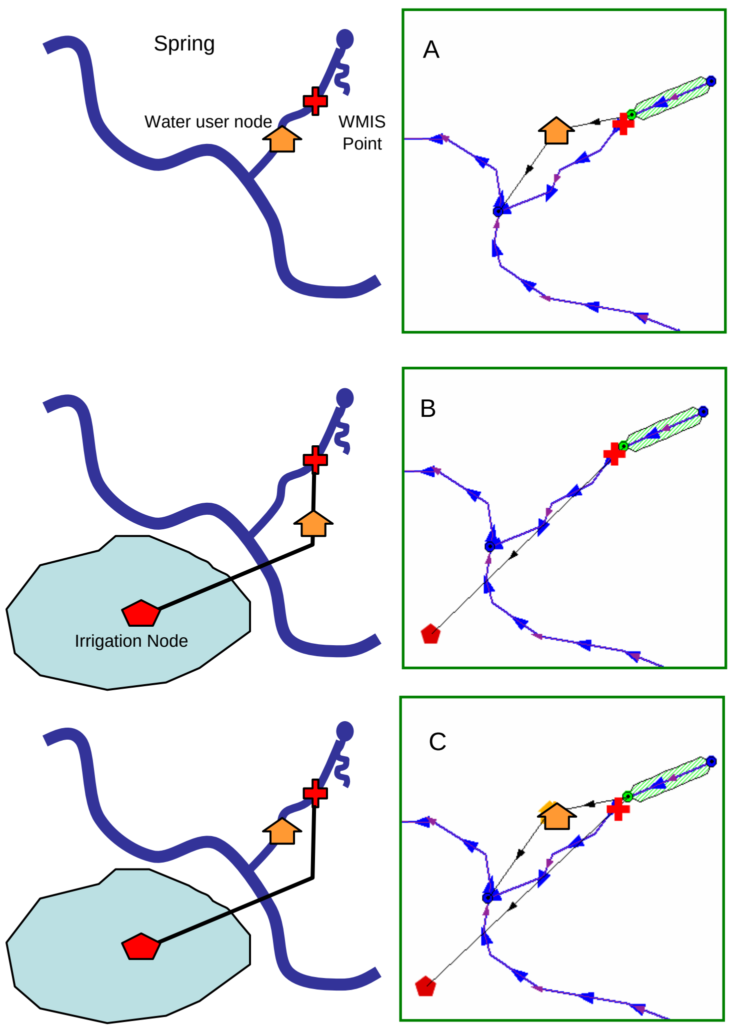


Figure 4. Schematic showing how combined water supply and irrigation schemes are represented in the TSMBM (right set of panels). Figure A represents an aquaculture or domestic user. Figure B represents a diversion ditch that supplies water first to an aquaculture facility and then irrigated area. Note that this setup is also used for a single irrigated area as well. Figure C represents multiple users of the spring that use water in distinctly separate locations.

For the University of Idaho Hatchery, water is diverted and returned to the creek after use in the raceways. Since all the water received for this portion of the hatchery originates and returns to Billingsley Creek, this measured portion of the Billingsley Creek flow can be constituted as the minimum stream flow in Billingsley Creek as the portion of the flow not diverted is not measured.

Billingsley Creek primarily passes the Branchflower Hydropower facility by flowing through the turbines and a fish passage orifice. During periods of high flow, the flow also is routed through a turbine bypass and over a dam. Water discharge is measured through the turbines and a rated fish passage orifice, but the turbine bypass and dam are unmeasured. Therefore, summing the turbine and fish passage orifice flow provides a minimum stream flow passing the Branchflower Hydropower Facility.

Determining Water Supply and Irrigation Demand

In MIKE Basin, "demand" associated with water supply and irrigation nodes is the quantity of water the node requests from the river at the offtake node. For comparison of historic records and demand curves, demand was assumed to be the historic, daily-diverted flows in the WMIS database or derived from the power consumption coefficient (PCC) method. For those irrigation and water supply nodes without daily diverted records, water rights were used for the demand. For irrigation nodes using the water rights for demand, the demand was allocated through the irrigation season. For water supply nodes, the water right calculated demand was assumed to occur all year. For future development, demand curves in the post-processor will be incorporated and used to allocate water according to priority date. In addition, the demand calculator in MIKE Basin could be used for each irrigation node that incorporates crop type, irrigated lands, percentage under sprinkler, and ditch loss.

For offtake nodes with electric motor powered pumps and simple irrigation systems, the PCC method was used for determining historic water use. The PCC is a factor that relates acre-feet of water pumped to kilowatt-hours of electricity used. PCC's are empirically derived and specific to each diversion. For these systems, annual pumped volume records are kept by IDWR. Monthly power use is made available to IDWR through legislated agreements with the utilities. Monthly power records can be accessed from 1995 through 2003 for the Thousand Springs area. Using these monthly power data and the PCC's, monthly diversion volumes were calculated for those Thousand Spring sites on the PCC reporting system. These monthly values were interpolated to a constant daily diversion rate for each month.

Determining the Ground Water Fraction

To the model constructor's knowledge, ground water is not used to augment irrigation in Thousand Springs area. This value in all water supply and irrigation nodes was set at zero.

Determining the Return Fraction

Return fraction is the portion of the demanded flow of a water supply or irrigation node that will return to the downstream connecting node. In MIKE Basin, water supply and irrigation nodes that have both withdrawal and discharge to the river are referred to as "combined" water supply or irrigation nodes. A return fraction of 0 assumes that none the water received from the river will return to that river and a return fraction of 1 assumes all will return. MIKE Basin automatically sets the return fraction to 0 and 1 for withdrawal and discharge type nodes, respectively.

For irrigation nodes, 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 Thousand Springs area, in this particular model, until the next downstream gaging station node.

Figure 5 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 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 TSMBM, 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 Thousand Springs area); 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 will be provided by the landowner or watermaster. For fields irrigated with sprinklers, sprinkler rates were assumed to be 0.75 inches per day per acre in demand calculations.

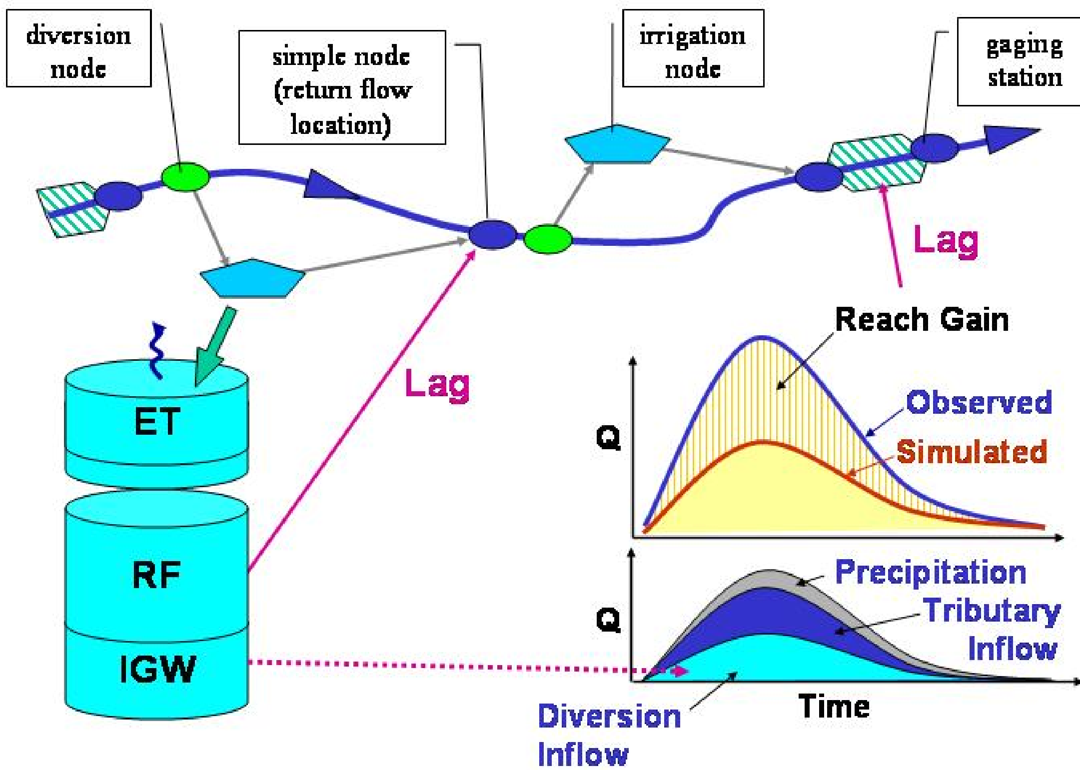


Figure 5. Schematic of the water flow through an irrigation node.

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 Thousand Springs area; entered the points of diversion in ArcView; and digitized the aerial extent of each place-of-use area for each of the water rights, registered aerial photos, and the claims file. The place-of-use area of each water right was assigned to a point of diversion using information collected by the IDWR.

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, AgriMet station ET data, and the Allen-Brockway (A-B) ET using the Hagerman area stations. As there is a lack of gage data, and the majority of the irrigation areas are irrigated by sprinkler irrigation, the ET rate was not calculated at this time. The infrastructure has been introduced to account for ET rates at a later date.

Determining Conveyance Ditch Losses

Conveyance ditch 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

Springs are located at the intersection of the land surface with the ground water table. Therefore, as Billingsley Creek is primary spring fed, the underlying ground water table is believed to be relatively shallow throughout most of the study reach. Future collection of stream gage measurements, examination of well logs within the Thousand Springs area, and calibration of the IGW parameters will be necessary for further refining our understanding of the ground water-surface water relation along Billingsley Creek.

Determining Lag Time

When water is applied to a field for irrigation, the fraction returning to the river network takes time to return. Combined and discharge irrigation nodes in MIKE Basin represent this return with a delayed return flow that 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 6 illustrates, longer lag times slow the return flow rate. In the TSMBM, lag times vary for each irrigation node and will be used to calibrate the model.

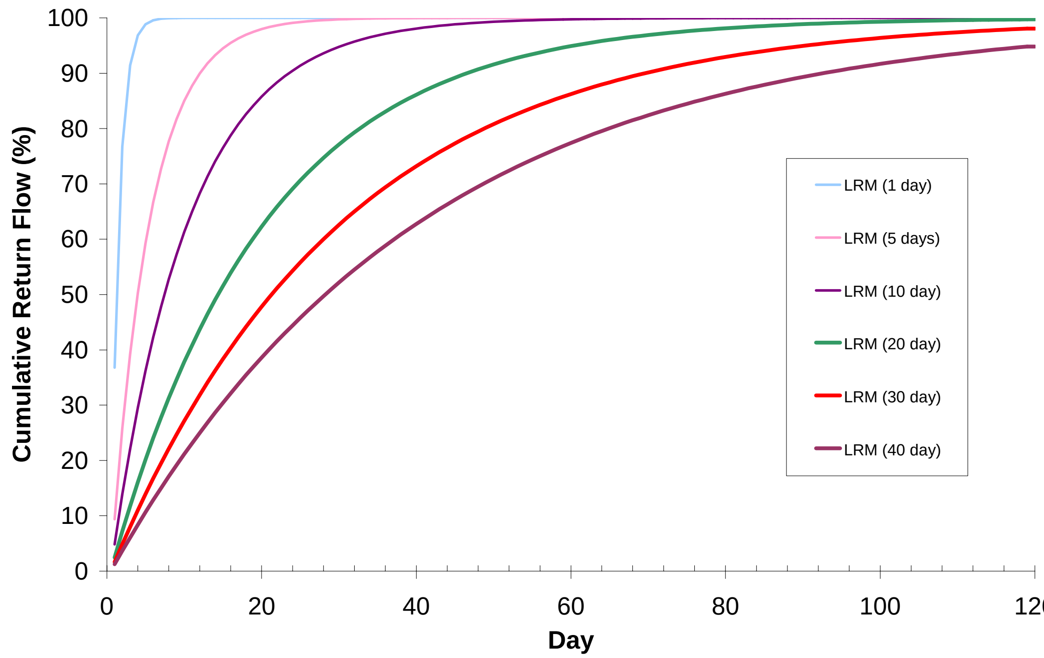


Figure 6. Cumulative return flow fraction by varying the lag time parameter.

4.3 Microsoft Excel Interface

To expedite the processing, formatting, and entering of data into the model, the calibration and running of scenarios, and the comparison of model results with water right demands, DHI personnel developed a series of Microsoft Excel files and associated macros that interface with the TSMBM. 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:

- **TSMBM_InputFiles.xls** – Organizes the input data for all the time series files supporting the TSMBM (catchments and diversion, water supply, and irrigation nodes). Each time series is represented by a worksheet that contains the daily values for the parameters required by MIKE Basin. For the irrigation nodes, the workbook contains the return flow calculator. Buttons embedded in the worksheets activate macros that automatically load the data into the proper TSMBM input files. In addition, all the time series can be loaded from a worksheet if multiple changes have been made. This workbook should be used when running scenarios where inflow or diversion demands have been altered and need to be loaded into the TSMBM.
- **TSMBM_Calib.xls** – Helps calibrate the model. The files run repetitive MIKE Basin simulations for calibration, load results from previous simulations for viewing, calculate reach gains meet observed flows, and calculates quantity to be diverted to the Sturdivan Hatchery off Billingsley Creek. Macros drive all the tasks. 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.
- **TSMBM_PostProcessor.xls** – Facilitates the comparison between water demands and simulation results. Provides a record of the water rights associated with each offtake node (diversion) as well as the macros for creating water demand curves and making comparisons between simulation results and water demand curves. This Excel file is described in greater detail in Sections 4.5.1 and 4.5.4.

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

4.4 TSMBM Calibration

MIKE Basin is a surface water budget model that does not directly account for ground water loss/gain loss to the river, contributions from precipitation, losses due to evaporation, or inflow from tributaries or unmeasured springs. The contributions and losses are usually accounted by calculating the difference between measured and simulated stream flow to determine the reach gains/losses. As Billingsley Creek has not been gaged historically, no direct reach gain or loss could be calculated at the completion of the 2004 TSMBM. Once stream gage data has been collected along Billingsley Creek, then the gains/losses to the river can be calculated and the TSMBM can be calibrated.

4.5 Water Rights Comparison

As stated in Section 2, the objective of the 2004 TSMBM development was to compare diversion flows with the demand curves for an offtake node (diversion) in order to determine diversions that may have unmet demands of senior water rights based on “first in time is first in right” water delivery. Demand curves represent the quantity of water needed for a water user’s beneficial use. The water user is only entitled to the water needed to satisfy the beneficial use requirement on a given day, recognizing that the irrigation requirement is generally less early and late in the season than in mid-summer. In Phase 1, the beneficial use requirements were not constructed, pending the acquisition of additional data. As a place-holder, the full value of the water rights substituted for the demand curves.

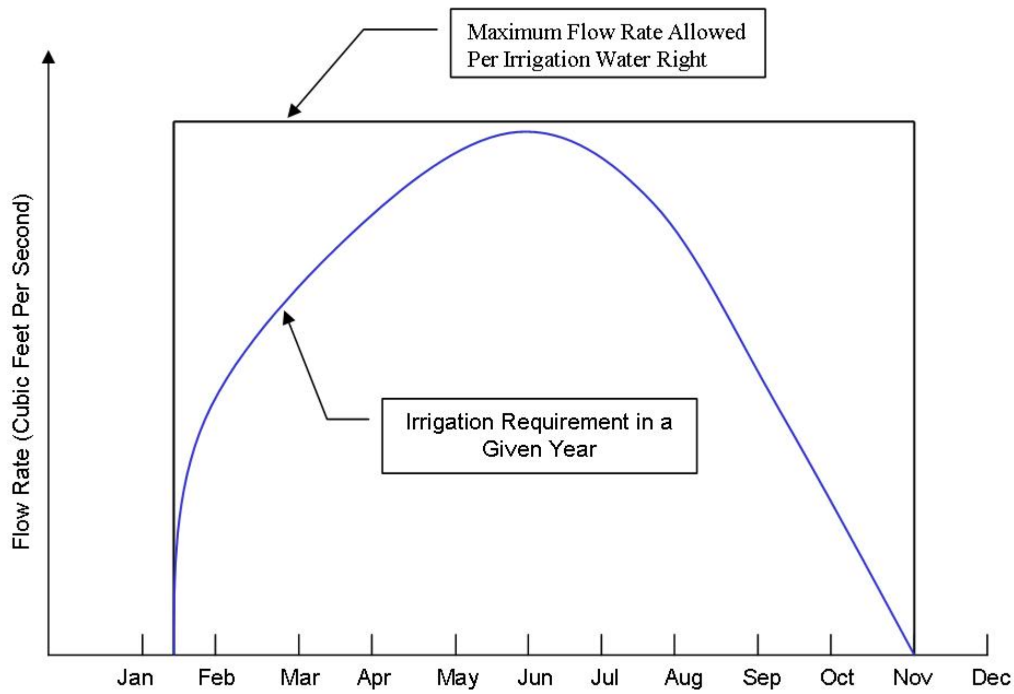


Figure 7. Different demands for the diverted water at a diversion.

The 2003 version of MIKE Basin does not perform comparisons between demand curves and water diverted from a stream, so a post-processing file written in Microsoft Excel was created to hold water right information, develop demand curves (presently using water right curves as substitutes), compare diversion flows with these curves, and present the comparison in the MIKE Basin graphical user interface. The functionality in the post-processing file will provide the basis for developing more refined demand curves and comparison of management alternatives in future developmental phases of the TSMBM.

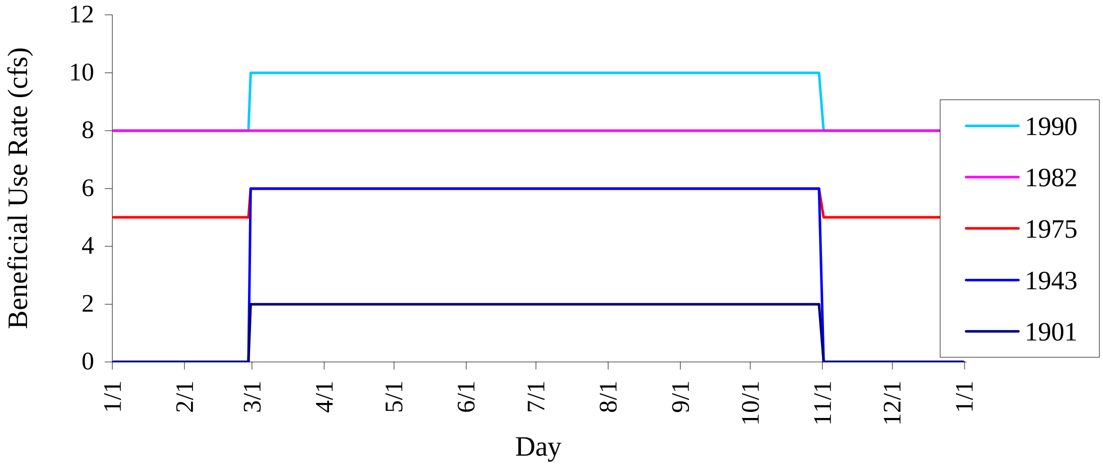
4.5.1 Demand Curve Calculator

For most diversions (offtake nodes), multiple users with one or more water rights call water at a diversion. The water rights also serve multiple uses that may either share or reuse diverted water. For example, a diversion services an aquaculture facility with a 2 cfs beneficial use rate. The discharge from the aquaculture facility is then routed back into the ditch and applied to two irrigated properties with 1 cfs and 2 cfs beneficial use rates, respectively. To satisfy all the beneficial use rates on this ditch, only 3 cfs need be diverted at the source because the water used by the aquaculture facility and irrigated lands is the same water. Stated in another way, consider a situation where water is used under one water right on a pass through basis for fish propagation. The same water is then used under a consumptive use water right for irrigation. In this situation the rate of diversion required is the greater, not the sum, of the two water rights. Often a watermaster will limit his or her perspective to delivery from the source into the diversion. However, in some complex water delivery systems it is important for the watermaster to broaden the perspective to include down-ditch considerations. For example, if the sum of the water rights for a diversion exceeds the ditch capacity to transmit water, then it is physically impossible for all water rights to be delivered simultaneously. Therefore, the ditch's physical limitation of the must be considered when determining if senior water rights have been satisfied at the point of diversion. As another example, if the ditch has ample supplies throughout its length and the outflow at the end of the ditch demonstrates excessive discharge, then the watermaster must further investigate to determine reduction is warranted to cease waste.

To develop a set demand curves for a diversion, a demand curve calculator was developed in Microsoft Excel that automates creating the annual curves. Individual demand curves are entered into the spreadsheet, tagged as either "pass through" or "terminal" use, and the ditch capacity is noted. In the demand calculator, the demand curves associated with the beneficial use rates for every priority date have been combined to form a series of demand curves that reflect the amount of water that should be delivered for a given priority date. The calculator caps the demand curves at the ditch capacity.

An example of how the demand calculator computes the demand curves for a diversion that services five users with different priority dates is shown in Figure 8. Each priority date has been labeled with either a "T" or "P" to designate its use as either an irrigated land or aquaculture facility, respectively. In this example, the full value of the water right is used. As additional information is acquired, the rate of flow needed for beneficial use will be shown. The curve for each priority date is as follows:

1. 1901 priority date: The 1901 irrigation water right would be delivered first for the irrigation season up to its beneficial use rate and 0 cfs during the non-irrigation season.
2. 1943 priority date: Because the two irrigation users share the diverted water, the rates are added. To satisfy the 1943 irrigation water rights' rates, 6 cfs would have to be diverted during the irrigation season.
3. 1975 priority date: Down this diversion canal, the water flowing through the aquaculture facility is reused by the downstream irrigators, thus the greater of the two uses becomes the demand throughout the year. Thus to satisfy the 1975 aquaculture water right, 5 cfs would have to be delivered during the non-irrigation season and 6 cfs would have to be diverted during the irrigation season to satisfy the irrigation water user with senior priority dates.
4. 1982 priority date: Adding the rates for the aquaculture water rights, 8 cfs would have to be delivered year round.
5. 1990 priority date: To satisfy all the water right demands, 11 cfs would have to be delivered during the irrigation season to equal the sum of all the beneficial use rates for the irrigation water users. However, because the ditch capacity is 10 cfs, the demand curve for the 1990 water right is 10 cfs because no more water can be physically delivered.



WR #	*Priority Date*	*Beneficial Use Rate (cfs)*	*Use*	*T/P**
36-22	3/17/01	2	Irrigation	T
36-43	5/23/43	4	Irrigation	T
36-165	5/1/75	5	Aquaculture	P
36-485	10/30/82	3	Aquaculture	P
36-685	2/16/90	5	Irrigation	T

Figure 8. Example of the demand curve calculator for five priority dates and a maximum ditch capacity of 10 cfs. The table below the chart provides the water right number, priority date, beneficial use rate, use, and "terminal" or "passing" flow label used in generating the demand curves chart by priority date.

For the Phase 1 development, the TSMBM compared historic diversion flows with the water right use rates for an offtake node. In subsequent phases, beneficial use rates may replace the water right use rate in calculation of the demand curves.

4.5.2 Water Rights Inventory

Water rights for each water supply and irrigation node have been inventoried by IDWR personnel and included in the Microsoft Excel file "TSMBM_PostProcessor.xls". For each water supply and irrigation node, a list of water rights and their priority date, right ID, water right number, quantity, owner, source, spatial data ID, IDWR metal tags, use, and WMIS (water management information system) database number was compiled. This information for each of the supply nodes has been extracted from maps, images, GIS coverages, and databases of water rights, point of diversions (POD), place of uses (POU), TSMBM model maps and attribute tables, and water management information system (WMIS) in ArcView GIS interface. Overall maximum rate through a particular point of diversion was helpful in determining how the rights are divided. In addition, water rights were labeled either "T" (terminal) or "P" (pass through) depending on the use. Several meeting sessions were conducted with the watermaster, water resource agents, and other IDWR personnel for verification and validation of the database information with the field data.

4.5.3 Maximum Discharge Rate

Maximum discharge rate in a ditch/canal was determined using the historic observed maximum water discharged through the ditch/canal. This information was useful in determining the limitation of the ditch/canal capacity on water right demands.

4.5.4 Post-Processor Development

The TSMBM Post-Processor, built in Microsoft Excel, is comprised of a series of sheets, each representing an offtake node. Basic information on each sheet includes water right information (Section 4.5.2), demand curves for a representative year (Section 4.5.1), ditch capacity, the corresponding file path and name for the TSMBM time series results files, and the comparison of the modeling results and demand curves. The comparison determines if the resulting allocation to the diversion has not been met, met for at least one but not all the water rights, and met for all the water rights. The TSMBM Post-Processor compares the representative demand curves for a year to a simulation of any length by comparing the month and day in the simulation results to the same day in the representative demand curve. Once the comparison is made in the Microsoft Excel file, the comparison results are written to the MS Access result file for display in the map view (Figure 9) and the demand curves to the time series results files (.dfs0 files) for display in the time series editor (Figure 10).

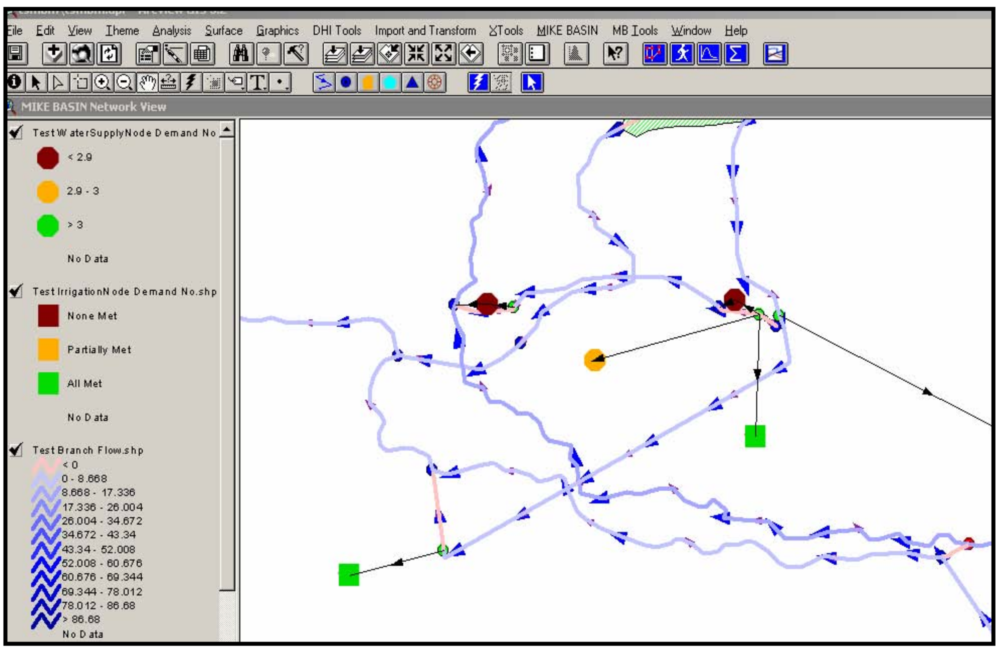


Figure 9. Map view display comparing water demand curves to water received at a diversion. Green, orange, and brown nodes denotes demand curves where all, partial, or none of the water demand curves were met for the time step, respectively.

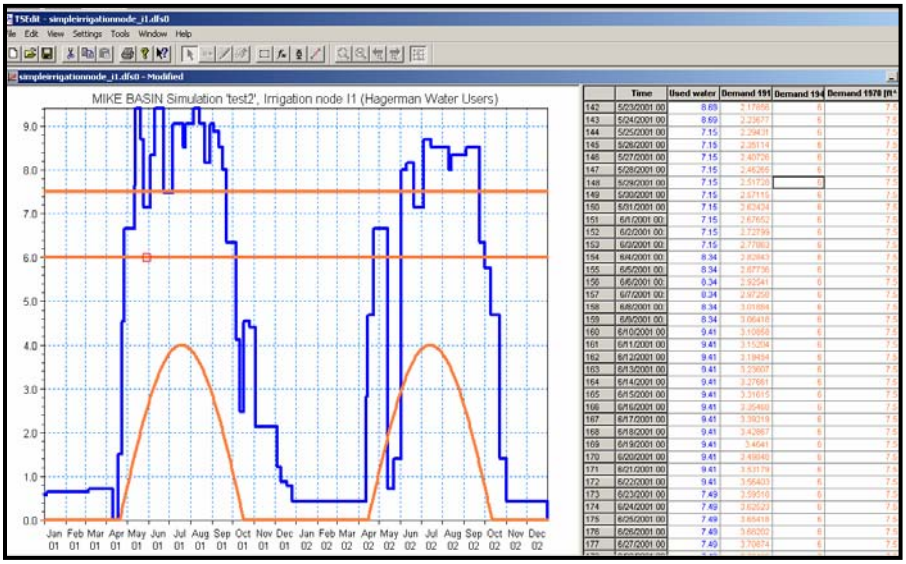


Figure 10. Graphical comparison in the time series editor of demand curves (orange lines) and model results (blue line) for an irrigation node. The right panel in the figure is a tabular view of the data. This view is accessible by clicking on any irrigation or water supply node in the simulation.

The current tool has been created to demonstrate areas of historical water shortages, but can be used to evaluate "what-if" scenarios in future applications. For use in future phases, the post-processor has been created such that it will support most demand curves and be able to evaluate model runs where priority algorithms have been implemented. In addition, future efforts will concentrate on refining the demand curve to represent the beneficial use rate for water users.

5 MODEL RESULTS

5.1 Overview of the TSMBM

The TSMBM encompasses Billingsley Creek from the head waters to the confluence with the Snake River, 14 tributary springs, the Sandy Pipeline, and the Curren and Bar-S Ditches (Figure 3). Initially, the model was intended to include the entire Thousand Springs area from Blue Lakes to King Hill, but increased complexity and lack of time series data prevented inclusion of the entire area. Modeling network infrastructure has been developed for most of the other major ditches in the Thousand Springs area, but time series data have not been associated with the nodes. The spatially limited model network has the following criteria:

- Model simulations are calculated on a daily time step for 37 offtake nodes connected to 17 water supply (representing aquaculture hatcheries and domestic subdivisions) and 23 irrigation nodes (representing the irrigated area associated with the offtake nodes).
- Multiple water supply and irrigation nodes are used on several offtake nodes (Spring Creek Springs, Three Springs, and Tupper Springs) where water is applied in several distinct locations and the water allocations to those places of use have been determined.

- Water supply nodes representing aquaculture hatcheries return water to the creek or spring from which the water was diverted. The exceptions are Idaho Power Ditch (W09) and Sturdivan Hatchery (W20), which divert water from Billingsley Creek and discharge to the Snake River.
- Water supply nodes representing domestic users (W04, W12) are assumed to consume the diverted water so they do not discharge back to the stream network.
- Sandy Pipeline is represented as a stream that enters the Curren Ditch. Inflow to the Sandy Pipeline is represented by a catchment and three users divert water from it before it enters the Curren Ditch. The three users are represented by a single irrigation node (I02).
- Catchment nodes have been used to represent spring inflow into the model downstream of the Curren Tunnel and for the tributary springs. Catchment time series commonly is set to equal the measured diverted flow at a WMIS location.
- Catchment nodes above the diversion for the UI Hatchery at Billingsley Creek and the Branchflower Hydropower facility represent points where reach gains/losses can be incorporated. Limitations in measurements at these locations make these only represent minimum stream flow conditions.

Because contemporaneous data are limited, the model was constructed to reflect the operations from March 1, 1995, to January 1, 2003 (the period of record for the majority of diversions). The model is run on a daily time step from the October 1, 1995, to September 30, 2002 to evaluate the historic diverted flow in comparison to the demand curves. Quantifying streamflow within Billingsley and Curren and Bar-S Ditches will require stream flow be measured in the stream network at several locations.

Several irrigation and water supply nodes do not return water to Billingsley Creek. The Idaho Power Ditch (W09) and Sturdivan Hatchery (W20), located at the lower end of the Billingsley Creek, on average divert 5.25 and 19.63 cfs and return water directly to the Snake River. Two domestic users, Three Springs (W04) and Spring Creek Springs (W12) near the head of Billingsley Creek, are set to demand 3.2 and 0.6 cfs from the river network. These demands are constant and equal water right use rates; therefore they likely do not match the actual diverted water to these water supply nodes.

At the onset of the model construction, the TSMBM was intended to simulate water use along the major ditches in the Thousand Springs area. However, in the process of collecting time series data, it became apparent that data were not sufficient to model diversion from ditches in the system. This finding is consistent with the monitoring requirements of IDWR that require water masters to regulate water distribution only at the diversion point from the sources. Simulation results along the Bar-S and Curren ditches use water rights use rate values for the water supply and irrigation nodes' water demand time series and therefore do not accurately represent the water allocation to these users. If future questions require that water distribution down a diversion be simulated, the TSMBM network can easily be expanded to incorporate the diversion operation and monitoring programs can be implemented to collect the appropriate data for analyzing the situation.

5.2 Input Data Summary

5.2.1 Catchment/Spring Inflows

Catchment and spring flows into the model were based on WMIS data (Table 1, Figure 11, Figure 12). This represents the minimum flow into the model system available at a spring as the measuring point supports the diversion that uses the water. The Rangen Hatchery (R15) and Curren Tunnel (R11) represent the headwaters of Billingsley Creek. Spring Creek Springs (R03), Tupper Springs (R12), and Sherman Springs (R21) springs relied on cumulative measurements of multiple WMIS points. No data was available for Weatherby Springs (R08), Ruby Springs (R09), Hoagland Tunnel (R13), and Riley Creek (R17) so water right information for the associated water supply and irrigation nodes was used to satisfy the specific runoff time series.

Table 1. Summary of the catchment node name, demand flow statistics, period of record, and source of data. Nodes using water rights do not have historic records and thus use the cumulative water use rate for all the water rights serviced by a diversion (offtake node). Replacement of estimates with measurement data is contemplated for future phases. *Sandy Pipeline inflow is measured at the vault located midway between the ponds and the confluence with the Currren ditch.

DHI Node	Catchment Node Name	Diverted Flow (cfs)			Time Series		
		Min.	Aver.	Max.	Start Date	End Date	Source
R01	Billingsley Creek Beside Rangen Hatchery (M1)	0.86	3.50	10.98	3/1/1995	1/1/2003	WMIS: 410089 (partial)
R03	Spring Creek Spring	0.00	4.62	7.39	3/1/1995	1/1/2003	Calculated
R04	Three Springs	0.00	6.68	10.20	1/1/1996	1/1/2003	WMIS: 410069
R05	Big Springs	0.00	10.40	15.07	1/1/1995	1/1/2003	WMIS: 410045
R06	Hagerman Water Users Association	0.00	4.35	10.89	3/1/1995	1/1/2003	WMIS: 410044
R08	Weatherby Springs	-	0.00	-	3/1/1995	1/1/2003	Water Right
R09	Ruby Springs	-	0.62	-	1/1/2002	1/1/2003	Water Right
R10	Fisher Springs	29.47	43.19	55.93	3/1/1995	1/1/2003	WMIS: 410070
R11	Curren Tunnel	0.63	0.76	1.53	1/1/1996	1/1/2003	Calculated
R12	Tupper Springs	0.00	1.47	2.23	1/1/1996	1/1/2003	Calculated
R13	Hoagland Tunnel	-	4.02	-	1/1/2002	1/1/2003	Calculated
R14	Hidden Springs	0.00	8.52	13.50	3/1/1995	1/1/2003	WMIS: 410087
R15	Rangen Hatchery/Billingsley Ck	8.80	21.68	37.89	3/1/1995	1/1/2003	WMIS: 410089
R16	Florence Livestock Spring	0.00	5.32	7.00	1/1/1995	1/1/2000	WMIS: 410043
R17	Riley Creek	-	0.01	-	1/1/1981	1/1/1982	Water Right
R18	Fisheries Development Springs	4.36	9.98	12.21	1/1/1999	1/1/2003	WMIS: 410048
R20	Sandy Pipeline	0.00	18.41	29.37	5/30/2003	9/03/2003	*see header
R21	Sherman Springs	-	1.60	-	1/1/2002	1/1/2003	Calculated from Water Right

5.2.2 Gage Data

No gages exist along Billingsley Creek, but there are three locations along the creek where the majority of stream flow can be measured: Rangen Fish Hatchery (N65), University of Idaho's Aquaculture facility (N71), and Branchflower Hydropower Facility (N161). Based on the historic flow records from March 1995 to December 2002, Billingsley Creek at Rangen Fish Hatchery, University of Idaho Hatchery, and the Branchflower Hydropower Facility was flowing 24.2, 62.0, and 87.1 cfs, respectively. The University of Idaho Aquaculture Facility record reflects only three years of data as the recorded diversion rate is 0.0 cfs from June 1998 to the present. Though diversions remove water from Billingsley Creek, measured stream flows indicate that the study reach is a gaining reach.

To the authors' knowledge, no stream gages exist along the Bar-S and Curren ditches outside of the measurement at the diversion points for the ditches. On average, the Curren Ditch diversion has diverted 21.4 cfs from Billingsley Creek and the Bar-S ditch has diverted 5.2 cfs from the Jones Hatchery.

5.2.3 Offtake Node (Diversion) Time Series Data

For Phase 1, historic flow or cumulative water right use rates were used to determine the demand for irrigation nodes and water supply nodes (Figure 11, Figure 12). For the irrigation nodes that have historical diversion records, the average diversion rates ranged from 0.17 cfs (I16) to 24.40 cfs (I35) and averaged 6.95 cfs for all diversion (Table 2). The Sands Ditch (I35), Curren Ditch (N85), and Buckeye Ditch (I37) diverted the most water on average at 24.40, 21.44, and 20.57 cfs, respectively.

Water supply nodes reflect diversion of more water on average than irrigation nodes in the study reach (Table 3, Figure 11, Figure 12). For the water supply nodes that have historical diversion records, the average diversion rates ranged from 1.47 cfs (W15) to 91.42 cfs (W02) and averaged 24.88 cfs for all diversions. On average, Fisheries Development from Billingsley Creek (W02), University of Idaho Hatchery from springs (W01), Jones Hatchery (W03), Rangen Hatchery (W05), University of Idaho Hatchery from Billingsley Creek (W16), and Branchflower Hydropower (W21) divert greater than 20.00 cfs from Billingsley Creek or springs that feed Billingsley Creek. In the TSMBM, the return flow from these diversions returns to Billingsley Creek directly or via the spring from which they diverted the water.

For water supply and irrigation nodes using cumulative water right use rates, the majority of the flow diverted rates are below 5.00 cfs. South Pipeline (I08), an offtake node from the Curren Ditch, has water rights totaling 79.50 cfs. Given the historical diversion records of the Curren and Bar-S Ditches, the total of the water rights has not been delivered. The authors are unaware of the conveyance capabilities of the Curren Ditch and the South Pipeline itself, but these too could further limit delivery of water to the full water use rate for the offtake node.

Table 2. Summary of the irrigation node name, demand flow statistics, period of record, and source of data. Nodes using water rights do not have historic records and thus use the cumulative water use rate for all the water rights serviced by a diversion (offtake node). Replacement of estimates with measurement data is contemplated for future phases.

DHI Node	Irrigation Node Name	Diverted Flow (cfs)			Time Series		
		Min.	Aver.	Max.	Start Date	End Date	Source
I01	Hagerman WUA	0.00	4.35	10.89	3/1/1995	1/1/2003	WMIS: 410044
I02	Three Pipes (Musser, Morris, Candy)	0.00	0.91	4.15	1/1/1995	1/1/2003	PCC: 410038,39,40
I03	Billingsley Creek Ranch	-	4.34	-	1/1/2002	1/1/2003	Water Right
I04	Butch Morris	-	3.30	-	1/1/2002	1/1/2003	Water Right
I07	North Pipeline	-	4.69	-	1/1/2002	1/1/2003	Water Right
I08	South Pipeline	-	79.50	-	1/1/2002	1/1/2003	Water Right
I09	Western Legends	-	14.74	-	1/1/2002	1/1/2003	Water Right
I11	Ronnie Smith	-	2.00	-	1/1/2002	1/1/2003	Water Right
I12	Omohundro	-	1.42	-	1/1/2002	1/1/2003	Water Right
I14	Big Spring WUA	0.00	10.40	15.07	1/1/1995	1/1/2003	WMIS: 410045
I15	Florence Livestock Spring	0.00	5.32	7.00	1/1/1995	1/1/2000	WMIS: 410043
I16	Emerald Valley Ranch	0.00	0.17	0.74	11/30/1994	1/31/2004	PCC: 101171
I17	Padgett Ditch	0.00	6.80	16.16	3/1/1995	1/1/2003	WMIS: 410010
I18	John Bell Ditch	0.00	4.32	9.22	3/1/1995	1/1/2003	WMIS: 410008
I19	Shady Grove Dairy	0.00	0.38	1.06	11/30/1994	1/31/2004	PCC: 410037
I20	Larry Littlefair	-	0.72	-	1/1/2002	1/1/2003	Water Right
I32	Barlogi Ditch	0.00	4.53	7.94	3/1/1995	1/1/2003	WMIS: 410001
I33	Dave Cropper	-	1.60	-	1/1/2002	1/1/2003	Water Right
I34	Norwood subdivision	-	0.62	-	1/1/2002	1/1/2003	Water Right
I35	Sands Ditch	0.00	24.40	36.80	3/1/1995	1/1/2003	WMIS: 410007
I36	E.M. Bell Ditch	0.00	5.16	23.32	5/21/1995	1/1/2003	WMIS: 410006
I37	Buckeye Ditch	0.00	20.57	40.80	3/1/1995	1/1/2003	WMIS: 410003
I38	Jones Hatchery Irrigation	-	5.00	-	1/1/2002	1/1/2003	Water Right
N85	Curren Ditch	0.00	21.44	39.60	3/25/1995	1/1/2003	WMIS: 410004

Table 3. Summary of the water supply node name, demand flow statistics, period of record, and source of data. Nodes using water rights do not have historic records and thus use the cumulative water use rate for all the water rights serviced by a diversion (offtake node).

DHI Node	Water Supply Node Name	Diverted Flow (cfs) Min.	Aver.	Max.	Start Date	Time Series End Date	Source
W01	UI Hatchery from Springs	29.47	43.19	55.93	3/1/1995	1/1/2003	WMIS: 410070
W02	Fisheries Development from Billingsley Ck.	12.00	91.42	133.00	3/1/1995	1/1/2003	WMIS: 410047
W03	Jones Hatchery	4.46	37.11	52.86	3/1/1995	1/1/2003	WMIS: 410067
W04	Subdivision	-	3.20	-	1/1/2002	1/1/2003	Water Right
W05	Rangen Hatchery	8.80	20.73	37.89	3/1/1995	1/1/2004	Calc: 410089
W08	Boyer Diversion	0.00	2.96	13.27	11/1/1995	1/1/2003	WMIS: 410002
W09	Idaho Power Ditch	0.00	5.25	7.34	3/1/1995	1/1/2003	WMIS: 410009
W12	Subdivision	-	0.6	-	1/1/2002	1/1/2003	Water Right
W13	Schrank Hatchery	0.00	3.38	5.90	3/1/1995	1/1/2003	WMIS: 410072
W14	Johnson Hatchery	0.00	3.36	5.90	1/1/1997	1/1/2003	WMIS: 410073
W16	UI Hatchery from Billingsley Ck	0.00	25.72	109.85	3/29/1995	1/1/2003	WMIS: 410071
W15	Tupper Hatchery	0.00	1.47	2.23	1/1/1996	1/1/2003	WMIS: 410065
W17	Fisheries Development from springs	4.36	9.98	12.21	1/1/1999	1/1/2003	WMIS: 410048
W18	Hidden Springs Hatchery	0.00	8.52	13.50	3/1/1995	1/1/2003	WMIS: 410087
W19	Talbott Hatchery	5.21	13.39	20.07	1/1/2002	1/1/2004	WMIS: 36A20020001
W20	Sturdivan Hatchery	0.00	19.63	56.30	1/1/1998	1/1/2003	WMIS: 410011
W21	Branchflower Hydropower	0.00	87.12	153.40	3/1/1995	1/1/2003	WMIS: 410012

5.2.4 Water Supply and Irrigation Node Parameters

For the TSMBM, all water supplies representing hatcheries and domestic users had return fractions of 1 and 0, respectively. The return fraction for irrigation nodes varied depending on irrigation method, crop type, and percent of the diverted flow believed to enter the intermediate ground water zone. Irrigation nodes that had systems using sprinkle irrigation were assumed to have a return fraction of 0. Return fraction was calculated using a return flow calculator (Section 4.2.2) in the Microsoft Excel file “TSMBM_InputFiles.xls” (Section 4.3) for irrigation nodes I03 (Billingsley Creek Ranch), I14 (Big Springs Water Users), and I17 (Padgett Ditch). As the model was unable to be calibrated due to lack of stream gage data, the return fraction and IGW factors were unable to be completed. Therefore, a default ET value for pasture was input into the calculator until the model is to be calibrated.

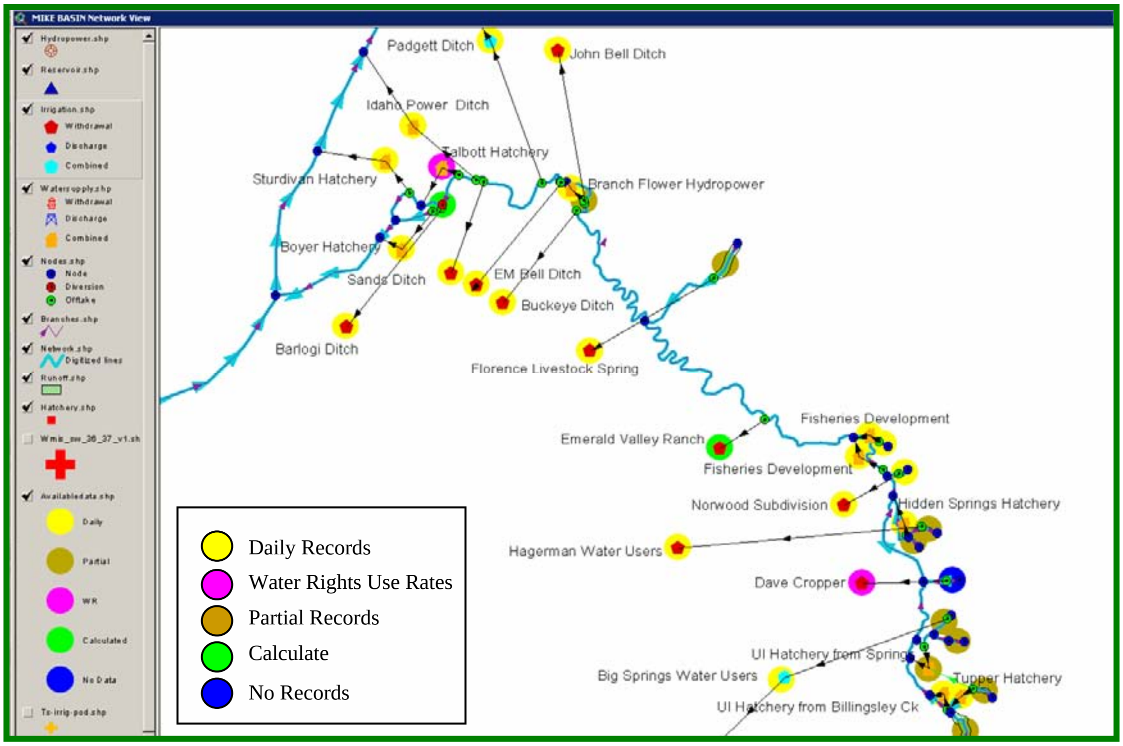


Figure 11. Source of time series data used in the TSMBM, lower reach of the study area.

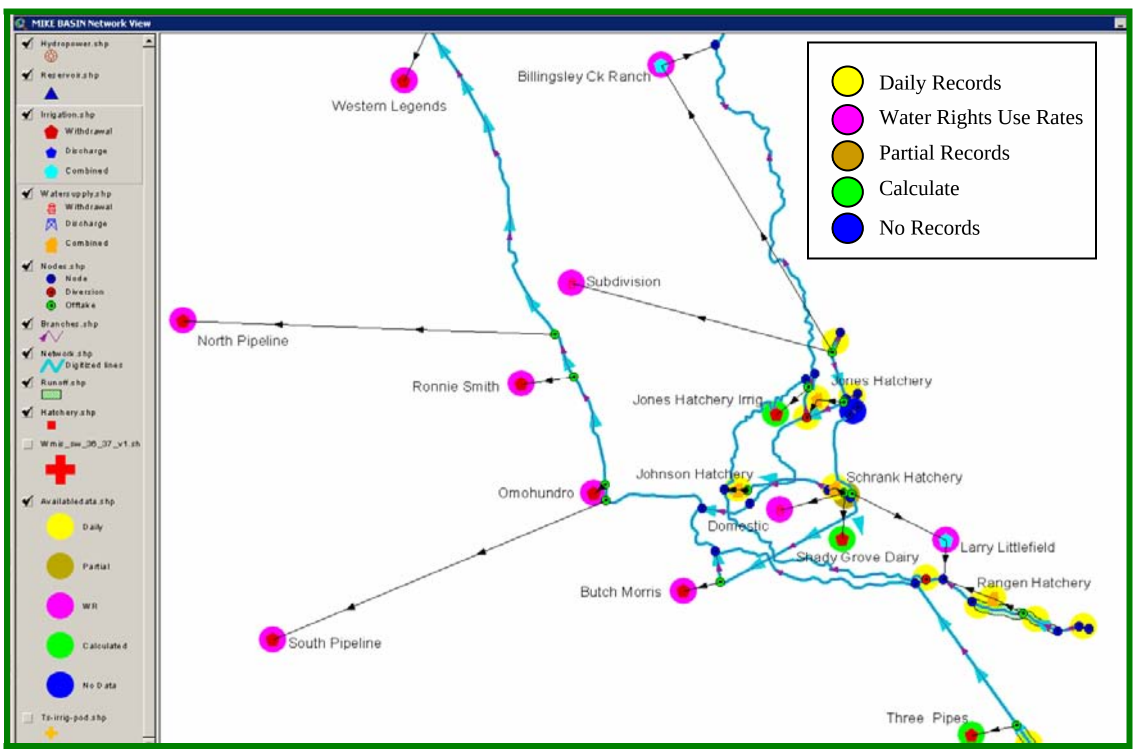


Figure 12. Source of time series data used in the TSMBM, upper reach of the study area.

5.3 Water Supply and Irrigation Node Demand Curves

For each irrigation and water supply node, IDWR inventoried the water rights and the purpose of use and use rate (Table 4). The number of water rights per node ranged from 1 to 78 (Buckeye Ditch (I37)) and includes the full and subordinate water right uses covering aquaculture, aesthetics, domestic, irrigation, hydropower, recreation, stock, and wildlife. While a comprehensive list of the water rights for each node has been developed, the inventory is considered preliminary as IDWR is still refining the water rights for each diversion.

5.4 Model Results

5.4.1 Comparison of Hydrographs

At the completion of this phase, the model was set up to simulate water movement from October 1, 1995 through September 30, 2002. Currently, no stream gages exist along Billingsley Creek or the Curren Ditch to directly compare observed and simulated stream flows for verification of model setup. Full calibration of the TSMBM will be possible upon installation of stream gages along Billingsley Creek and in the Curren Ditch (Section 8.1.1).

Historically, the water has been managed and recorded as it is diverted from Billingsley Creek. Therefore, diverted flow records are available for the head of Curren and Bar-S Ditches, but not for the diversions off the ditches. Therefore water rights are used for the nodes representing North Pipeline (I07), South Pipeline (I08), Western Legends (I09), Ronnie Smith (I11), and Omohundro (I12).

5.4.2 Areas of Variable Accuracy

In the model setup, three accuracy zones have been identified to quantify stream flow.

- High accuracy zones represent springs with measuring devices where the flow is well quantified. Spring flow at these locations can be used to determine the absolute flow in a channel. However, these may still under-represent the quantity of water flowing from a spring if not all the spring discharge is captured.
- Medium accuracy zones occur along Billingsley Creek at regions where the minimum stream flow can be determined by aggregating measurements. Flow indicated by model results in medium accuracy zones may be much less or much greater than what the actual result would be for a specified operation. 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 creek. 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.
- Low accuracy zones occur in regions where only water rights information is used to compute flow. This zone should only be used to determine the necessary quantity of water to satisfy the water rights and should not be used to quantify stream flow in the creek or ditch.

Table 4. Number of water rights, the range of priority dates, and the number of passing and terminal designations for each irrigation and water user node.

DHI Node	Node Name	Water Rights			Priority Dates		Uses+
		Total	T*	P^	Earliest	Latest	
I01	Hagerman WUA	2	2	0	12/7/1905	12/31/1998	I
I02	Three Pipes (Musser, Morris, Candy)	9	9	0	10/9/1884	12/1/1908	I
I03	Billingsley Creek Ranch	5	2	3	2/17/1896	4/12/1994	F, I, R
I04	Butch Morris	3	3	0	12/12/1901	11/1/1915	I
I07	North Pipeline	18	18	0	3/8/1902	3/23/1932	I
I08	South Pipeline	6	2	4	3/8/1902	9/24/1987	D, I
I09	Western Legends	2	1	1	9/10/1884	2/15/1946	A, I, R
I11	Ronnie Smith	2	2	0	9/1/1889	3/8/1902	I
I12	Omohundro	2	2	0	9/1/1889	12/12/1901	D, I
I14	Big Spring WUA	4	2	2	3/21/1901	4/12/1994	F, I M, S
I15	Florence Livestock Spring	14	12	2	4/1/1900	12/31/2001	D, F, I
I16	Emerald Valley Ranch	1	1	0	11/4/1885	-	I
I17	Padgett Ditch	11	10	1	6/26/1881	12/31/1999	F, I
I18	John Bell Ditch	28	28	0	6/26/1881	12/31/1999	D, I
I19	Shady Grove Dairy	1	1	0	4/1/1886	-	I
I20	Larry Littlefair	3	3	0	12/12/1901	1/1/1920	D, I
I32	Barlogi Ditch	5	4	1	4/1/1880	12/31/1999	I, H
I33	Dave Cropper	2	2	0	7/26/1910	12/31/1999	I
I34	Norwood subdivision	2	2	0	11/4/1969	8/16/1976	D, I
I35	Sands Ditch	31	30	1	4/1/1885	12/31/1999	D, F, I, S, W
I36	E.M. Bell Ditch	16	16	0	3/30/1884	12/31/1999	I
I37	Buckeye Ditch	78	76	2	3/30/1884	4/30/1993	A, D, F, I, R, S, W
I38	Jones Hatchery Irrigation	5	5	0	2/1/1888	12/31/1999	I, S
W1	UI Hatchery from Springs	2	0	2	8/5/1954	12/21/1959	F
W2	Fisheries Development Co.	2	0	2	11/29/1976	6/2/1982	F, H
W3	Jones Hatchery	4	3	1	2/1/1888	7/8/1969	F, I, S
W4	Weatherby Tunnel	11	11	0	2/1/1888	12/31/1999	D, I
W5	Rangen Hatchery	5	2	3	10/9/1884	4/12/1977	F, I
W8	Boyer Hatchery	3	1	2	4/1/1888	11/1/1970	F, I
W9	IDPCO Power Ditch	4	4	0	4/1/1880	12/10/1948	I, P
W12	Domestic	8	8	0	4/1/1886	-	D, I
W13	Lee Hatchery	2	1	1	4/1/1886	3/20/1973	D, F
W14	Johnson Hatchery	1	0	1	2/14/1973	2/14/1973	F
W15	Tupper Hatchery	5	2	3	4/1/1881	2/12/1979	F, I
W16	UI Hatchery from Billingsley Creek	2	0	2	10/5/1965	12/1/1965	F
W17	Fisheries Development Spring Hatchery	2	0	2	8/22/1969	7/8/1977	F
W18	Hidden Spring Hatchery	2	0	2	11/6/1969	2/18/1971	F
W19	Talbott Hatchery	1	0	1	3/15/1973	3/15/1973	F
W20	Sturdivan Hatchery	4	1	3	4/1/1880	12/31/1986	F, I
W21	Branch Flower Hydropower	2	0	2	-	-	H

* "T" denotes terminal water use, ^ "P" denotes pass through water use, + "A" denotes aesthetic water use, "D" denotes domestic water use, "F" denotes aquaculture water use, "H" denotes hydropower water use, "I" denotes irrigation water use, "R" denotes recreation water use, "P" denotes hydropower water use, "S" denotes stock water use, and "W" denotes wildlife water use

5.4.3 Post-Processor Results

The 2004 TSMBM compares water right use rates to historic diverted flow records. As the demand curves are developed from water right use rates that represent a maximum diversion rate and this rate is held constant throughout the irrigation season, many of the nodes exhibit deficiencies in water delivery early and late in the irrigation season (Figure 13, Figure 14). These are times in the irrigation season when the full water right delivery may not be necessary to satisfy the water user needs.

Legally, the watermaster for the Thousand Springs area is responsible for the delivery of the water at the point of diversion directly from the source. With this in mind, the TSMBM has been constructed to represent and examine if water is being delivered at the points of the diversion along Billingsley Creek. The 2004 TSMBM can show water master, stakeholders, agency personnel how water has historically been allocated along Billingsley Creek. In addition, it can be used to run “what-if” scenarios such as the influence of lining stream channels and reducing diverted flows to a diversion. However, as the demand curves are developed from water right use rates and estimates on ditch capacity, the 2004 TSMBM results should be considered preliminary until these can be verified through quality assurance examination. Further refinement of demand curves is necessary to represent the actual beneficial use demand for each node.

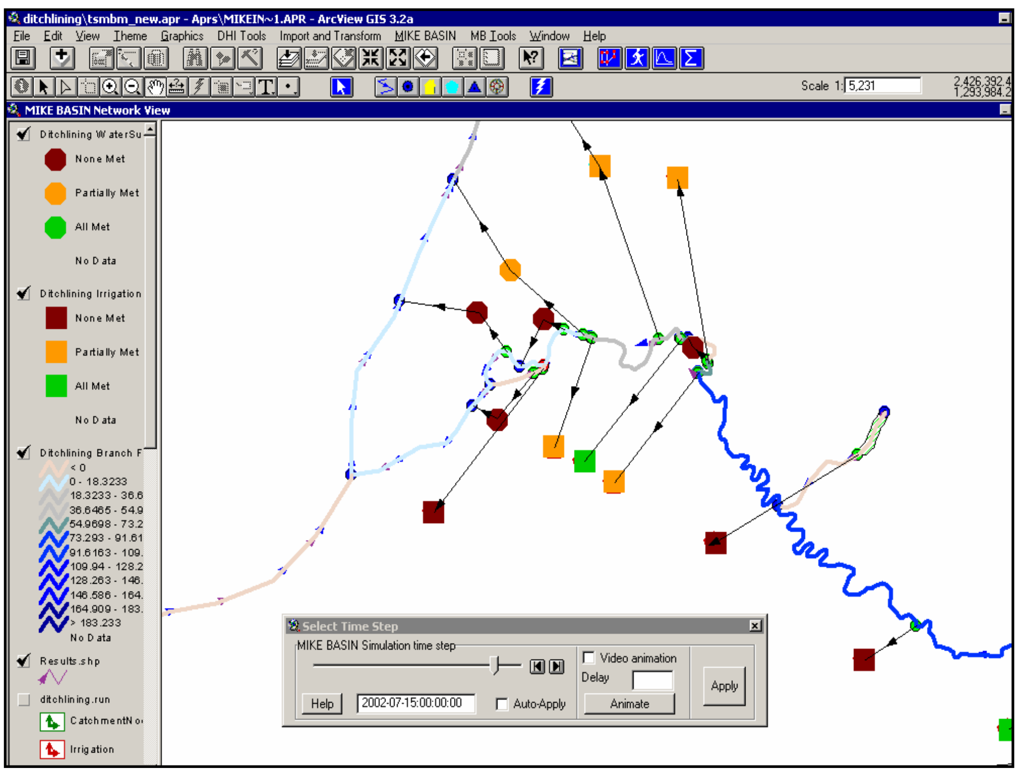


Figure 13. Historic diverted flow versus demand curves for the lower Billingsley Creek on July 15th, 2002. Nodes denoted in green, orange, and brown represent diversion rates where the demand curves are fully, partially, or incompletely met, respectively. The demand curves represent full water rights and can be modified in the future to represent the actual beneficial rate needed to satisfy water users.

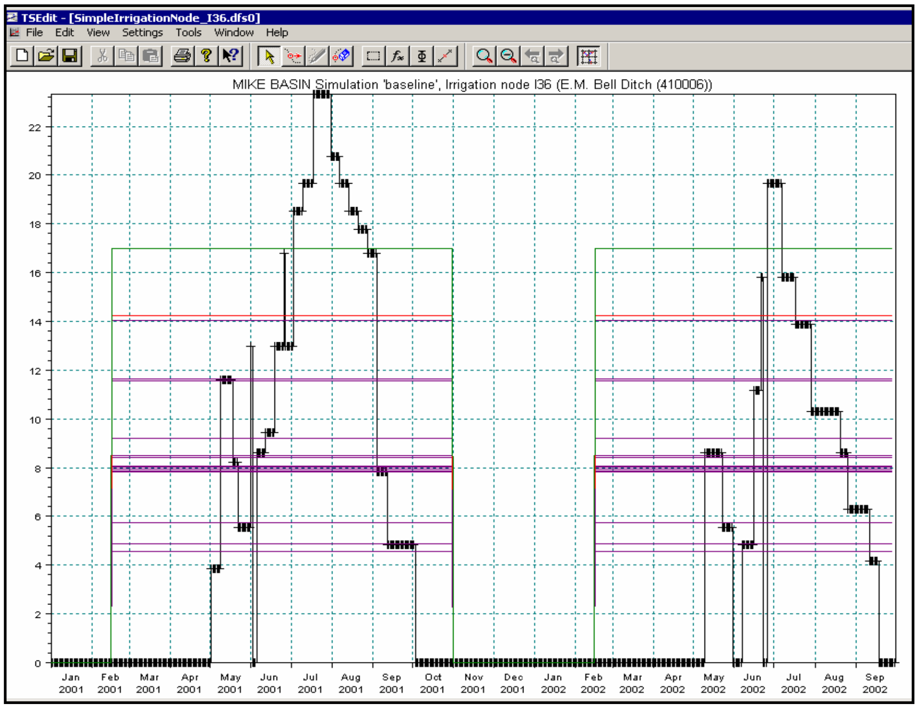


Figure 14. Historic diverted flow (black lines) versus demand curves (green and purple lines) for the EM Bell Ditch from January 2001 to October 2002. The demand curves were developed using water right rates and therefore remain constant throughout the irrigation season. In the future, the demand curves can be developed to represent the actual water needs for a diversion. The y-axis in the graph is water discharge in cubic feet per second (cfs).

6 PUBLIC REVIEW AND COMMENT

Throughout the development of the TSMBM, 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 both Hagerman and Boise, Idaho included:

- October 2003, January 2004, and March 2004 to review and comment on the model configuration, model assumptions, and preliminary simulation results.
- August 2004 to provide a final review of the 2004 TSMBM.

Public comments helped the developers alter and recalibrate the TSMBM. Comments from local water users directed IDWR and DHI to additional sources of data. In addition, IDWR staff used the model to produce a preliminary evaluation to show how lining ditches would assist in alleviating shortages for diversions along Billingsley Creek.

IDWR staff and the watermaster of the Thousand Springs area have advised DHI staff that the TSMBM has dramatically increased their understanding of water distribution in the Thousand Springs area. This increase in understanding is also evidenced by the change in focus of the questions, comments, and suggestions concerning the model over the series of presentations.

7 TSMBM LIMITATIONS

Limitations of the TSMBM arise from the inherent limitations of network models, the lack of detailed input and calibration data (e.g. diversion and stream flow data), and incomplete water right records used in the post-processor.

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 be needed. While these models could be used to answer physically-based questions in the Thousand Springs area, 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 TSMBM.

If physically-based questions need to be addressed for the Thousand Springs area, 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 the 2004 TSMBM analysis include:

- Lack of gage data along the Billingsley Creek.
- Lack of flow data for the Hoagland tunnel inflow.
- Lack of flow data for diversions along the Curren Ditch.
- Lack of data to quantify the excess spring flow that bypasses the devices measuring flow diverted to hatcheries and irrigated lands.
- Missing data in the daily stage records for diversions along Billingsley Creek and the Curren Ditch.
- Poor measuring devices for some diversions.
- Multiple water diversions within several irrigated areas.
- Uncertainty associated with the ground water-surface water interaction.

Along Billingsley Creek, the lack of stream gages allows no calibration. 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. As data are collected in the future, the 2004 TSMBM can easily accept the new data and the parameter configuration can be updated.

Ground water and spring flow play a significant role along Billingsley Creek flows throughout the year. Minimum stream flow measurements along Billingsley Creek at Rangen Hatchery, UI Hatchery from Billingsley Creek, and Branchflower Hydropower Facility indicate that Billingsley Creek gains water by ground water or spring flow downstream. Spring flow is recorded at measuring devices designed to quantify the spring flow diverted to a facility and may miss excess spring flow not diverted to the facility. Therefore, model reaches far downstream of a gage may indicate less in-stream flow than most likely exists in the river because the model currently does not distribute gains to subreaches between gauging stations. This could be problematic if the model simulates a shortage to a diversion that relies on the river gains that actually occur in a subreach but are not currently represented in the TSMBM. Gains could be linearly pro-rated and added incrementally to simulated streamflow between gauging stations as a rough approximation to account for gains between gauging stations, but in sections where confidence in the in-stream flows is deemed important, additional gauging station would need to be added.

Accuracy of the historic daily diverted water computed for each diversion is a function of the quality of the measuring device. Uncertainty in the reading arises from the inherent uncertainty in the measuring device as well as the frequency between discharge readings. For many measuring devices, discharge is read once a week and assumed to be constant until it is visited again. This uncertainty can lead to erroneous estimates for the quantities of water diverted from the river and thus add error during model calibration.

7.3 Modeling Limitations

The TSMBM does not directly account for ground water – surface water interaction in the Thousands Springs area. This interaction is significant for both the spring flows and the reach gains along the stream. The 2004 TSMBM accounts for this interaction using historic reach gains derived from stream flow measurements that may not capture the full flow in Billingsley Creek. If reach gains are determined to have a significant contribution to the flow in Billingsley Creek, then running “what-if” scenarios may need to examine the relationship between stream reach gains and aquifer head values. Alternate methods for developing the reach gain involve simulating the ground water with another algorithm. A linear ground water algorithm in MIKE Basin provides a simplified method for simulating ground water. Fully distributed ground water models such as the Eastern Snake Plain Model would provide a more complex and robust solution to the ground water – surface water interaction in the Thousand Springs area.

Water enters the diversion ditches through headgates located at the points of diversion in the Thousand Springs area. The quantity of water passing through the headgates is a function of the gate opening and the river stage. Increases in the river stage result in an increase in the quantity of water diverted. Therefore, when evaluating scenarios, it is anticipated that discharge in the

Thousand Springs area 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.

The watermaster in the Thousand Springs area is required to manage the water diverted to ditches from sources such as Billingsley Creek and is not responsible for monitoring the water used once it has left the source. Initially, the TSMBM was intended to include all the major ditches in the Thousand Springs area. During the model construction, IDWR and DHI staff discovered that very few of the diversions from the ditches are monitored for diverted water. Without water measurement devices, the quantity of water diverted is not available and therefore the historic water demand cannot be evaluated. An example of this is the Curren Ditch in the current model where none of the five intra-ditch diversions records the diverted water rate. Therefore, extending the model to include intra-ditch analysis will require further data collection.

7.4 Post-Processor

Evaluation of historic allocations in the 2004 TSMBM involved comparing historic diverted flows to water rights. Compiling the data for this comparison involved inventorying water rights, determining ditch and pipe capacity, and using the historic diversion record. Accuracy of the comparison relies on the accuracy of the data used in creating the curves and measuring the historic diversion records. For an offtake node, unaccounted for water rights could under-predict the demand curves for that offtake node indicating that an offtake node’s demand has been fulfilled when it was actually short water. Similarly, using the maximum historic flow delivered to an offtake node may not represent the maximum capacity of the ditch or pipe and thus may be indicated as fulfilled when in reality it was short water. Finally, poor flow records for an offtake node could falsely indicate that the water supplied was either short or fulfilled.

8 Recommendations for Overcoming TSMBM Limitations

Additional data collection is the key factor for improvement of the model. These recommendations are directed to improvement of the model in general and 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 Thousand Springs area, and thus can provide a greater foundation for the enhancement of the TSMBM.

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 TSMBM. The following is a list of data collection needs, organized by importance.

8.1.1 Install Additional Stream Gages

Stream gages are used to determine the water entering the river network and to update flows in a channel with respect to unmeasured contributions from precipitation and tributary inflow as well as reach gains and losses due to ground water interaction. As of August 2004, no stream gages existed along Billingsley Creek to directly measure streamflow. Addition of stream gages along Billingsley Creek in upstream of the UI Hatchery along Billingsley Creek and near the Branchflower Hydropower facility would allow the model to be calibrated for the offtake nodes in those reaches.

8.1.2 Install Flow Measuring Structures on Springs and Diversions

Inaccuracy in quantifying inflow and diversions arises from flow measurements determined by power consumptive curves or gages that have a poor stage-discharge rating, or in locations were no measurement device exists. Replacing or installing flow measuring structures at offtake nodes where the flow measuring devices provide unsatisfactory measurements would provide greater accuracy in the quantifying the amount of water diverted or inflow into the system. Suggested locations for installation of a flow measuring device along Billingsley Creek are at nodes representing Hoagland Tunnel (R13), Larry Littlefield (I20), Jones Hatchery Irrigation (I38), UI Hatchery (W1) source from Tupper Springs, Emerald Valley Ranch (I16), Dave Cropper (I33), Shady Grove Dairy (I19), Norwood Subdivsion (I34), Sands Ditch (I35), and the E.M. Bell Ditch (I36). Along the Curren Ditch the nodes include South Pipeline (I07), North Pipeline (I08), Western Legends (I09), Ronnie Smith (I11), and Omohundro (I12). These locations were selected because they have no flow record or are measured using the power consumptive curve method. As the accuracy, quantity, and automation of input data increases, the 2004 TSMBM 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 water supply and in-stream targets.

8.2 Modeling

8.2.1 Expand the Study Reach

Expand the model domain to include the entire Thousand Springs area from Blue Lakes to King Hill as well as the intra-ditch analysis. Much of the model network infrastructure has been developed for most of the other major ditches in the Thousand Springs area, but time series data have not been associated with the nodes.

8.2.2 Linking to a Ground Water Model

The spring flows are linked to precipitation and surface and ground water use on the Snake River Plain aquifer. Therefore, to determine the how to allocate based on the effects of changing land use on the Snake River Plain on spring flows in the Thousand Springs area, the TSMBM should be linked to a ground water model. The link should either be through transferring result files between separate models or by linking the two models. Based on the ground water that the TSMBM will receive, temporal and scalar differences in spring flows will need to be addressed. Linking the models will allow hydrologists, scientist, planners, managers, stakeholders, and government personnel to evaluate water management alternatives regarding the surface and ground water interaction in the Thousand Springs area.

8.3 Post-Processor

8.3.1 Verify the Ditch Capacity for Each Offtake Node

In the post-processor, the demand curves are capped at the ditch capacity. The 2004 ditch capacity for each node was assumed to be the maximum observed value during the period of record. As the maximum discharge value is based on a measured value, it may not represent the maximum capacity of the ditch or pipe if that maximum rate had not been reached during the period of record. Therefore, assessment of the ditch capacity for each node should be conducted to determine the maximum capacity of the ditch or pipe for each node.

8.3.2 Calculate Demands Curves Based on Beneficial Use Rates

The demand curves in the 2004 TSMBM are developed from the water rights rates for each node. These represent the maximum quantity of water an offtake node could potentially divert. To truly evaluate the required water for a diversion, beneficial use curves will need to be developed. These curves need to be derived using factors including, but not limited to, crop type, ditch loss, evapotranspiration rates, and climatic contributions to demand. Once implemented, beneficial use rate curves implemented in the post-processor will provide a more accurate measure of diversions that are short water.

8.3.3 Perform Quality Assurance on Water Rights Inventory

IDWR staff worked rapidly to compile the water rights for each node in the 2004 TSMBM. Due to the complexity and large quantity of the water rights in the Thousand Springs area and their importance in the post-processor analysis, it is recommended that the water rights inventory be checked to verify that all the water rights have been included for the analysis.

9 CONCLUSIONS

From October 1, 2003, until August 31, 2004, IDWR and DHI personnel completed the first phase in the surface water budget model development for the Thousand Springs area, 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 networks and their various demands for water.

The completed first phase in the 2004 TSMBM development has resulted in a surface water budget model and Microsoft Excel interface that allows IDWR, local stakeholders, and other interested parties to have a working MIKE Basin surface water budget model for Billingsley Creek and Curren and Bar-S Ditches. This tool enables them to evaluate historic diversion flows in comparison to water demand curves representing beneficial use 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, calibration, and post-processing comparison of the results to the TSMBM. 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 TSMBM involved building the river network; compiling, computing, formatting, and inputting the data; developing the Microsoft Excel interfaces, and computing demand curves. The river network configuration primarily reflects Frank Erwins' knowledge of the Billingsley Creek system. The TSMBM encompasses Billingsley Creek from the head waters to the confluence with the Snake River, 14 tributary springs, the Sandy Pipeline, and the Curren and Bar-S Ditches. The model is run on a daily time step from March 1, 1995, to December 31, 2001. The simulation time period is restricted by the lack of contemporaneous data.

Time series data include spring flow gage records and daily diversion data for each water user and irrigation node. For the majority of water supply and irrigation nodes, the WMIS data was used. Nodes that did not have daily diverted rates either used interpolated rates from monthly power consumption or cumulative water right use rates. As most of the irrigated nodes used sprinkler irrigation or did not return flow back to Billingsley Creek, the return flow was set to zero. For the two nodes with return flow, a calculator developed in Microsoft Excel can be used 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. However, as an initial assumption for the 2004 TSMBM, the return flow for the two nodes was set to 0 indicating that none of the demanded water will return to the channel. Microsoft Excel sheets were developed to augment data processing, data population into the time series files that support MIKE Basin, calibration of the TSMBM, and analysis of alternatives.

Public involvement throughout the project augmented the development of the TSMBM and increased local awareness. Through a series of meetings, DHI and IDWR personnel gained insight into how water moves through the Thousand Springs area; this knowledge helped them better develop the TSMBM 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 TSMBM will provide an excellent platform for future discussions on water operation plans in the Thousand Springs area.

Limitations of the TSMBM arise from the inherent limitations of network models, the lack of detailed input and calibration data, lack of stream gages, and inaccuracies associated with simulating the return flow lag time. The primary limitation is the absence of quality data.

Though IDWR and DHI personnel worked diligently to complete the 2004 TSMBM 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 are limited or poorly understood. Specific recommendations include installing two stream gages on Billingsley Creek; installation of measuring devices at diversions on the Curren Ditch (I07, I08, I09, I11, and I12), the Hoagland tunnel, water supply nodes W04 and W12, and irrigation nodes I03, I20, I33, I34, I35, and I36; and improving monitoring of discharge on diversions with poor stage-discharge rating curves.

The TSMBM is a dynamic model that can be refined and expanded as data become available and as new questions are identified. The 2004 TSMBM development was intended to demonstrate the model's technology, provide insight into the how historical diversion rates compare to demand curves, and provide the foundation for future model developments. With additional data and further analysis, the TSMBM can be used to develop water allocation operation alternatives in response to changing spring inflows. If IDWR and local stakeholders continue to update and refine the TSMBM, it could be used to aid in automation of diversion gates and as real-time operation tool.

10 REFERENCES

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