ESTIMATING WATER BUDGET IN A REGIONAL AQUIFER USING
HSPF-MODFLOW INTEGRATED MODEL
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ABSTRACT: Integrated water resources management is important, especially in
watersheds where substantial interactions exist between the ground and surface water
sources. It necessitates the need for reliable estimates of an overall basin water budget
and reliable estimates on hydrologic fluctuations between ground water and surface water
sources. The objectives of this study were to estimate the total water budget and to
simulate the effects of the management of water in the Big Lost River Basin in Idaho.
The study used the FIPR Hydrological Model (FHM). FHM is a hydrological model
developed by the University of South Florida for the Florida Institute of Phosphate
Research (FIPR). It is an integrated model that simulates the full water budget of the
surface and ground water systems. It has two public domain components: Hydrological
Simulation Program – FORTRAN (HSPF) and MODFLOW. This study quantified the
hydrologic fluxes between ground water and surface water and determined a
comprehensive and accurate water budget for the Big Lost River. The study showed that
surface water and ground water in the Big Lost River are hydrologically connected to a
large degree and, therefore, should be managed simultaneously using an integrated
management process. The study is useful in developing and calculating the annual water

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budget in the Big Lost River, and this process should be applicable to estimating water budget in other basins.

(KEY TERMS: watershed modeling, Big Lost River; Snake River; Idaho; surface water; ground water.)

INTRODUCTION

In water resources management, quantifying the influence of ground water withdrawals on stream flows is an important component of water budget development and water rights adjudication (Kollet et al., 2002). In order to understand this influence, the natural hydrologic conditions and interaction should be quantified as well as the anthropologic impacts on the system. Ground water pumping can cause reductions in stream flow and lower water levels, affecting the ecology and wildlife of an area and reducing water available for senior water rights. Some of the surface water infiltrates into ground water. As a result, surface water and ground water should be studied simultaneously taking into account all these factors.

Integrated surface water and ground water models can be used to estimate current and future water budgets for a basin. However, a stand-alone surface water model or a ground water model cannot be used alone for long-term predictive simulations where the interactions between surface water and ground water are significant.

The advantage of integrating surface water and ground water models is that they can derive recharge and evaporation from surface water and ground water based on a detailed quantitative procedure. The integrated approach simulates the entire hydrologic
cycle including the subsurface portion. The processes that control net recharge to the system, such as precipitation, interception storage, runoff, evaporation, and evapotranspiration (ET), are accounted for in a quantitative and interdependent fashion.

There are a number of integrated models have been developed in the past 10 to 20 years including, MIKE SHE, HMS, SWATMOD, MODBRANCH, and FHM. MIKE SHE and HMS link ground and surface water components created as part of a unified model development process while SWATMOD, MODBRANCH, and FHM were created by linking previously developed surface water and groundwater models (CDM, 2001). MIKE SHE is used to simulate flow and transport of solutes and sediments in both surface water and groundwater (DHI, 1999). The Hydrologic Model System (HMS) was developed based on the BSHM (Basin-Scale Hydrologic Model) (Yu and Schwartz, 1998). SWATMOD links the SWAT model with the MODFLOW. SWAT is a watershed-scale model used to predict water, chemical, and sediment movement in large basins (Sophocleous et al., 1999). A limitation in this is the inability to model the unsaturated zone beyond the root zone. Therefore percolation (recharge) is applied directly to the groundwater table. MODBRANCH links the one-dimensional model of unsteady flow in open-channel networks (BRANCH) to MODFLOW. MODBRANCH simulates the interaction between streamflow and subsurface flow in areas with dynamic, hydraulically connected groundwater and surface water systems coupled at the stream/aquifer interface (Swain and Wexler, 1993).

FHM model was chosen for this study because it utilizes widely used models for performing water flow calculations and the model is public domain software (Ross et al., 1997). The objectives of this paper are to understand and simulate the hydrologic system.
using the FHM integrating model and to estimate the total water budget in the Big Lost River Basin, in Idaho, and provide the management with the foundation for future decisions that can be made for better conjunctive use of water.

**BIG LOST RIVER BASIN**

The Big Lost River drains about 3,730 km$^2$ (1,440 mi$^2$) and is a major tributary to the Snake River Plain aquifer (Figure 1). Mackay Dam, the only artificial storage in the basin, was completed in 1917, and it is the major artificial water control on the Big Lost River. The mean altitude of the valley is about 1,829 m (6,000 ft) and average precipitation is about 300 mm/year (12 in/yr) and it is approximately evenly distributed throughout the year.

Until 1964, the water table in most of the Big Lost regional aquifer was only a short distance, less than 3 m, below the surface (Mundorff et al., 1964). The Big Lost River flows through the valley until Arco where it enters the Eastern Snake River Plain, flows to its terminus, or is lost via seepage to the Eastern Snake River Plain aquifer. The ground water in the aquifer flows through the valley and discharges to Eastern Snake River Plain aquifer directly.

The Big Lost River is a losing stream down-valley from the Howell Ranch gaging station, and all tributaries lose a large part of their flow in the alluvial fans at their mouths or in the alluvial deposits of the main valley before reaching the Big Lost River. The Big Lost River recharges and percolates into the Snake River Plain aquifer near Arco and
terminates in playas, sinks, and spreading areas at the Idaho National Engineering and Environmental Laboratory (INEEL) as shown in Figure 1.

**Precipitation**

Precipitation time series is the main input for surface water modeling. The average precipitation is about 300 mm/year (12 in/year) and it is approximately evenly distributed throughout the year. Precipitation for the year 2000 was obtained from NOAA, 2001.

**Evapotranspiration**

The method selected for this study is the empirical equation of Jensen and Haise (1963). This method has been shown to be reliable for arid and semiarid Intermountain West (Jensen and Haise, 1963; Robb, 1966). This method is based on solar radiation and similar to the Penman–Monteith method without a requirement for the wind velocity factor. The general equation is as follow:

$$ET_p = \left[0.245 \times 10^{-4} \times R_s \times [(0.025 \times T_a) + 0.08]\right]$$

(1)

where:

- $ET_p$ = monthly mean of daily potential evapotranspiration (mm/day),
- $R_s$ = monthly mean of daily global (total) solar radiation (kJ/m²/day), and
- $T_a$ = monthly mean of daily air temperature ($°C$).
Since this method is based on monthly mean values for daily solar radiation and temperature, therefore, it can be applied to any time period on the basis of daily values.

**Surface Water Flow**

The estimated annual water yield of the Big Lost River basin is 58,000 hectare-meters (470,000 acre-ft), while an average of 6,660 hectare-meters (54,000 acre-ft) are lost as surface water discharged from the valley to the Snake River Plain at Arco, 38,000 hectare-meters (308,000 acre-ft) are discharged as subsurface flow, and 13,450 hectare-meters (109,000 acre-ft) are lost by evapotranspiration, annually. There are 8,758 hectares (21,642 acres) irrigated land above Mackay Dam and 20,147 hectares (49,785 acres) irrigated land below Mackay Dam.

**Ground Water Flow**

About 104 hectare-meters/day (424 acre-ft/day) or 65% of the total water yield of the basin discharges ground water past Arco (Crosthwaite et al., 1970). Pumping from wells would serve to decrease the quantity of water leaving the basin. In 1970, the water table in the Big Lost River regional aquifer is less than 15 m but near the river it may be less than 3 m below the surface. The ground water gradient varies greatly from season to season, from three to hundreds of meters per kilometers at different places in the valley. In the outer reaches of the valley, high on the alluvial fans, water might be found at more
than 100 m, and in some places, especially in the lower end of the valley, some of the water-bearing zones are more than 200 m below the surface.

In 1995, the altitude of the water table in the Snake River Plain aquifer at the INEEL was about 1,396 m (4,580 ft) above mean sea level in the northern part and about 1,350 m (4,420 ft) above mean sea level in the southwestern part (Bartholomay, 1995). In the eastern plain of the Snake River Plain, a thick sequence of thin-layered basalt flows yields large volumes of water to wells. A significant portion of the ground water moves through the upper 244 m (800 ft) of saturated rocks. Wells in Butte City penetrate a section consisting of approximately equal thickness of basalt and sedimentary materials with a bottom layer of sand and gravel extending from 137 to 152 m (450 to 500 ft).

Bennett (1990) reported that depth to the regional aquifer below the river channel ranges from about 207 m (680 ft) at the western boundary of the INEEL (see Figure 1) to about 64 m (210 ft) at Playa 4. Stream flow is not affected by regional changes in the aquifer because of the thickness of the unsaturated zone.

*Surface and Ground Water Interaction*

Surface and ground water are known to be hydraulically inter-connected throughout the basin except at INEEL. A distinctive feature of the Big Lost River Basin is the large interchange of water from surface streams into the ground and from the ground into the surface streams (Crosthwaite et al., 1970). There are few comprehensive studies addressing the interaction between surface water and ground water in the Big Lost River (Mundorff et al., 1964; Crosthwaite et al., 1970). After Crosthwaite et al. (1970),
intensive agricultural development in the valley was occurred based on their recommendation. Most development was in the lower part of the basin using the ground water. Since then, the interaction of ground and surface water has been shown to be a significant concern in the valley. There is a strong need to address this issue using new technology to update the old studies and provide the concern people with the latest situation of water resources in the valley after the fact.

METHODS

This study uses an integrated hydrologic surface water and ground water model called FHM, a hydrological model developed by the University of South Florida for the Florida Institute of Phosphate Research (FIPR). This model simulates the full water budget of the surface and ground water systems. It is made of two public domain components: HSPF and MODFLOW models. HSPF, supported by the U.S. EPA and U.S. Geological Survey, simulates the surface water system and hydrologic water cycle (Johanson et al., 1984). HSPF was developed to simulate the hydrologic and water quality processes on pervious and impervious land surfaces, and transport within streams and reservoirs. MODFLOW, supported by the USGS, computes aquifer flows and storages (McDonald and Harbaugh, 1988). MODFLOW was developed to simulate ground water flow in three dimensions using a block-centered, finite-difference approach. It provides for simulation of unconfined and confined ground water flow conditions. The model includes a stream package, which is used in conjunction with the HSPF stream reach feature to include base flow dependent on stream stage. FHM first uses HSPF to
calculate runoff, infiltration, recharge, surface evapotranspiration and storage on an hourly basis. The code then uses MODFLOW to calculate groundwater flow for a daily time step. This sequence is repeated until the simulation time is completed (Ross et al., 1997).

The procedure in this study is as follows:

1. Data collection: HSPF and MODFLOW take large amount of data to apply it to a real site (i.e., a complete HSPF data set with meteorologic input files and a complete ground water data set compiled from hydrogeologic data).

2. Geographic Information System (GIS) tools are useful to get Digital Elevation Model (DEM), slope, soils, and land use. GIS is also used as a pre- and post-processor for the aquifer characteristics, such as transmissivity, wells, rivers, and ground water contours.

3. Pre-calibration of the surface water and ground water applications is needed prior to performing comprehensive integrated simulations. Initial static head will be obtained from MODFLOW outputs of steady-state simulation. Recharge to the aquifer will be obtained from HSPF output.

4. HSPF is applied to get recharge rates and total surface evapotranspiration. This application is followed by MODFLOW application to the unconfined aquifer in a steady-state ground water flow using the average conditions of the calendar year 2000 to get the initial condition for the final application of confined/unconfined transient flow with variable transmissivity.

5. Model calibration for the transient simulation includes the observed and simulated ground water levels, base flow, and surface runoff.
Base flow separation can be used to evaluate model performance. A comparison between the separated and simulated base flow will be presented later in this paper. Base flow was separated with the USGS public domain hydrograph separation software HYSEP (Sloto and Crouse, 1996). Figure 2 shows an example of the base flow and surface runoff separation for the stations number 13120500 (Howell Ranch near Chilly, Idaho). The HYSEP program uses three methods to separate the base flow and surface runoff components of the stream flow hydrograph—fixed interval, sliding interval, and local minimum. These methods can be described conceptually as three different algorithms to systematically draw connecting lines between the low points of the stream flow hydrograph. The sequence of these connecting lines defines the base flow hydrograph. Using of these methods requires the number of days after which surface runoff ceases, N. This value is obtained from an empirical relation:

\[ N = A^{0.2} \]  

(2)

where A is the drainage area in square miles. The interval 2N used for hydrograph separation is the odd integer between 3 and 11 nearest to 2N. The hydrograph separation begins one interval (2N days) prior to the start of the date selected for the start of the separation and ends one interval (2N days) after the end of the selected date to improve accuracy at the beginning and end of the separation.
In this study, the local minimum method was used. This method checks each day to determine if it is the lowest discharge in one-half intervals minus one (0.5(2N-1)) days before and after the day being considered. If it is, then it is a local minimum and is connected by straight lines to adjacent local minimums. An interval of 9 days is used in this study for the hydrograph separation.

Figure 2 indicates that most of the stream flow is dominated by base flow except for the period May-July where surface runoff is at its maximum due to snow melting. However, this base flow is relatively large and the actual base flow need to be measured. Although flow in the main stem of Big Lost River is perennial from its head to a few kilometers below Howell Ranch, large volumes of water percolate from the river channel into the ground in the reach from Howell Ranch to near the upstream end of Mackay Reservoir (Crosthwaite et al., 1970).

**Surface Water Simulation**

The Big Lost River watershed consists of 12 sub-basins range in area from 5.2 to 655 km² (2 to 253 mile²). Figure 3 shows the sub-sub-basins and their numbers that have been used in this study. Each sub-basin is normally comprised of many unique areas, which represent uniform characteristics, such as soil type and vegetation.

The number of reaches is chosen as 10, which includes the main stem and the main tributaries of the Big Lost River (Figure 4). Estimation of the sub-basin parameters used by HSPF is obtained from HSPF manual (Bicknell et al., 1997), FHM Manual (Ross et al., 1997), U.S. EPA (1999), and GIS data.
The soils of the Big Lost River watershed are formed from river alluvium. They have moderate to moderately rapid permeability and very low or low water holding capacity of 17 to 106 mm (0.65 to 4.16 inches). Approximately 70% of the basin consists of grasslands and forest. The slope and elevation were taken from the GIS files of DEM and slope driven using the GIS DEM files of and slope driven using the IDWR GIS database (IDWR, 2003).

Ground Water Simulation

Transmissivity and Storage Coefficient. The ground water domain uses a grid that is discretized into 35 rows and 50 columns with a uniform cell size of 867 m in each direction (Figure 5). It is assumed one layer of 244 m depth. Ten MODFLOW packages were used: Basic, Output Control Option, Block Centered Flow, River, Recharge, Well, Evapotranspiration, General Head Boundary, Snow, and Preconditioned Conjugate Gradient. The solution starts with an unconfined steady-state aquifer with constant transmissivity to get the initial ground water elevations. Next, a transient flow solution was performed but with variable transmissivity. The transmissivity was examined during simulation and model calibration.

Transmissivity in the Big Lost River valley commonly exceeds 9,290 m²/day (100,000 ft²/day) and, in places, 92,900 m²/day (1 M ft²/day). The average hydraulic gradient for the valley is about 3.41 m/km (18 ft/mi), the width of the saturated alluvial deposits is about 5.6 km (Whitehead, 1992). Bassick and Jones (1992) stated that the Theis type-curve analysis indicates that aquifer transmissivity ranged in the lower part of
the valley from 5,670 to 30,700 m²/day (61,000 to 330,000 ft²/d); values of 12,000 to 20,440 m²/day (129,166 to 220,014 ft²/d) were most probable. Jacob’s method yielded transmissivity values of 5,667 to 16,723 m²/day (61,000 to 180,000 ft²/d).

The dimensionless storage coefficient is the change in aquifer water volume by gravity per unit surface area of the aquifer per unit water table elevation. As in this study, the storage coefficient is the same as the specific yield.

The storage coefficient ranges from (0.0001 to 0.02); the value of about 0.001 is most probable. Jacob’s method yielded storage coefficients of 0.0006 and 0.001 (Bassick and Jones, 1992).

In this study, we have the following hypotheses:
1. The river loses (leaks) most of its ground water beneath the INEEL.
2. Transmissivity at INEEL is much higher than transmissivity in the rest of the basin.
3. Storage coefficient at INEEL is about double elsewhere in the watershed.

It is assumed that the average depth of the aquifer is 244 m. The values for transmissivity, hydraulic conductivity, and storage coefficient are shown in Table 1.

**Leakage and Conductance.** Leakage from river bottom is controlled by river conductance, which is a numerical parameter that represents the resistance to flow between the surface water body and the ground water. The conductance for the streams of the Big Lost River in m²/day was calculated as:

\[
C = \frac{KLW}{M} \tag{3}
\]

where:
L = the length of a reach through a cell (cell size spacing 867 m),
W = the width of the river in m,
M = the thickness of a river bed in m, and
K = the hydraulic conductivity of the riverbed material in m/second.

The width, W; the thickness, M; and the hydraulic conductivity, K were obtained from the Idaho Department of Water Resources (IDWR) field measurements.

The riverbed materials range from silt clay to very coarse pebble but most of them are coarse sand and pebble. The predominant gravels in the river bottom are quartzite and limestone. The majorities of river bottom soils are shallow, 254 to 508 mm (10 to 20 inches), to sand and gravel (Jensen, 1982).

The river boundary allows the water to be exchanged between the river and the aquifer. However, the nature of the Big Lost River as a losing stream and according to the hypothesis that the river leaks most of its water beneath the INEEL, a General Head Boundary (GHB) was installed before the boundary and where most of the water is lost. The leakage between these two aquifers was calculated using the following equations (Ross et al., 1997):

\[ L_g = L(H_c - H_a) \]  \hspace{1cm} (4)
\[ L = \frac{K}{M} \]  \hspace{1cm} (5)

where:

\[ L_g \] = leakage in m/day,
\[ L \] = leakage in day\(^{-1}\)
\( H_e, H_a \) = heads in the Big Lost River and the Eastern Snake River aquifers in m

\( K \) = hydraulic conductivity of the Big Lost River aquifer in m/day

\( M \) = thickness of confined bed in m.

**Pumping Wells.** Another important input is the ground water pumping rates for the existing wells. Based on data provided by the Idaho Department of Water Resources Adjudication Bureau, there are 695 stations that have data of water level. Forty-nine of them that have long time series data are chosen for analysis. The data is not distributed evenly, some years have 40 to 80 records per year, but for some other years, there are only 1 to 7 records per year, especially for the recent 10 to 20 years. Pumping for irrigation was estimated from electrical power records using the relation described by Bigelow et al., (1987). Ground water pumping ranged from 4.4 to 252.4 Liter/sec in the calendar year 2000.

*Water budget*

ZONEBUDGET is a program that uses flow results from the MODFLOW to construct the water budgets of individual zones or river reaches (Harbaugh, 1990). The main items of the flow budget are the base flow, seepage, and recharge for every sub-basins. These items are used to construct the water budget of the basin while the base flow obtained from MODFLOW and surface runoff obtained from HSPF are used for model calibration.
MODEL CALIBRATION

Model calibration was performed in three steps. In each step, model parameters calibrated simultaneously. The first and second steps were made for the GHB and ground water levels, respectively to compare the levels and directions of ground water flows from the Big Lost River aquifer to the Snake River Plain aquifer. The third step was made for the stream flows to compare the observed and simulated stream flows in different surface water stations. These steps were repeated in sequence until the model calibration is completed.

**GHB Calibration**

The GHB was used to adjust the ground water levels and directions as shown earlier in Figure 5. The observed ground water levels shows that the levels in the wells in the downstream end of the watershed are not the lowest one. Table 2 shows the well numbers, well locations, and the measured and simulated values. Although wells 18 are downstream of wells 14 and 15, it shows higher ground water elevations. This indicates that the water presumably moves from the Big Lost River aquifer downward to the Snake River Plain through the GHB and then the water move southwestward. This also indicates that the location of the GHB is not at the downstream boundary of the basin and the location shown in Figure 5 is the right location. Accordingly, hypothesis 1 is valid and the river leaks beneath the INEEL site.
**Ground Water Level Calibration**

Figure 6 and Table 2 show a comparison between the observed and simulated head with correlation coefficient of 0.97 and mean absolute error (MAE) of 20 m. The locations of these wells were downloaded from the USGS online database (USGS, 2003a) as shown in Table 2. Since the MODFLOW solution was based on a confined/unconfined aquifer with variable transmissivity, the transmissivity and storage coefficient are the major parameters that can be adjusted during the simulation. The resulting ground water levels at the downstream part of the basin are in the range of 1,300 – 1,500 m as mentioned in Bartholomy (1995). This indicates that hypotheses 2 and 3 are valid.

**Stream Flow Calibration**

In the second step, sub-basins numbers 1 and 3 (North/East Fork zone and Mackay sub-basin) were chosen to calibrate the model with respect to the daily stream flows. Data for these stations were downloaded from USGS online database (USGS, 2003b).

The observed and simulated stream flows are shown in Figure 7 for Howell Ranch station. This figure shows that the simulation is matching, in time and volume, the general trend of the stream flows with small discrepancies. Another comparison between separated and simulated base flow will be presented later in this study. However, this comparison did not used to calibrate the model due to the uncertainty in separated base flow.
RESULTS AND DISCUSSION

Initial and transient conditions

The head results of the steady-state condition are used to develop the initial conditions for the transient ground water flow. The transient simulation represents the conditions present during the year 2000. The ground water elevations range from 1,356 to 2,255 m (4,450 to 7,400 ft) above mean sea level. The recharge and ET used were derived from the surface water simulation.

The surface water simulation computes the monthly output basin water balance. These water balances were used to develop an array for each stress period for both the recharge and ET packages. The monthly recharge rates for the sub-basins varied from a low of 0.6 to 26.7 mm (0.02 inches to 1.05 inches). Total recharge for the year was about 1,468 mm (57.8 inches). The monthly ET rate (remaining potential ET) was about 3.8 mm (0.15 inch). Total ET for the year was 374 mm (14.72 inches).

Surface Water Budget

Table 3 shows that the lower part of the watershed (Arco, Butte, and INEEL sub-basins) has negative net recharge, which indicates that pumping from the ground water would lower the heads with time.

The following equation was used to formulate the water budget estimation. Because total ET includes ground water ET, net recharge was used in this equation (Ross et al., 1997).
Precipitation + Net Recharge + Unsaturated Storage = Total ET + Runoff, or

Net Recharge + Unsaturated Storage = Precipitation + Total ET + Runoff  \hspace{1cm} (6)

*Integrated Water Budget*

The average recharge for the whole watershed was found as 48.37 m$^3$/sec, and the maximum recharge occurs in May as shown in Figure 8. At the beginning of the year, both recharge and base flow were small. However, in the March-May time frame, the recharge was greater than the base flow, which indicates that there was positive net recharge to the aquifer. The recharge increased in May when the snow melted and that increased the base flow after the aquifer got enough water to support the streams. With the increased amount of water used in irrigation from May to September, the amount of recharge started to decrease but there are still amounts of base flow that support the end of the irrigation season. Table 4 shows the total water budget for the individual zones. However, a comparison between base flow separated from surface runoff using HYSEP as shown earlier in Figure 2 and simulated base flow is shown in Figure 9. The simulated base flow, in general, is less than the separated values, which strengthen the conclusion that separated base flow is relatively high. However, the separated base flow needs to be measured to validate the methods used in the HYSEP program.

The North/East Fork sub-basin has the maximum recharge while the Butte sub-basin has the minimum recharge (Figure 10). Maximum base flow occurs in May, and a major part of this amount is returned to the streams as base flow and is calculated as 36.48 m$^3$/sec, while a minor part (6.25 m$^3$/sec) was used as withdrawal by wells close to
the seepage from streams (5.25 m³/sec). The ground water ET is the difference between the total available ET 377.7 mm (14.87 in), and the potential ET, 373.9 mm (14.72 in) over the entire watershed with its area of 3,729.6 km² (1440 mi²). This amount was estimated as 0.45 m³/sec (15.91 ft³/sec). An amount of 10.44 m³/sec (48.37 + 5.25 – 6.25 - 36.48 - 0.45) left the basin to the ground water and compares with the 12 m³/sec that was mentioned by Crosthwaite et al. (1970).

From the water budget, there are many management challenges that look practical. First, no excessive pumping should be allowed in Arco and Butte sub-basins. However, further development can be allowed in other sub-basins, especially the Thousand Springs, North/East Forks, and Antelope sub-basins. Second, the 10.44 m³/sec that left the system to the underground past Arco should be captured. This might require ground water surveys to determine the most suitable areas that can be developed without negative impacts on the already developed areas or the areas that are already depleted.

Another challenge is the amount that goes to the ground water by seepage from river bottoms, which is calculated as 5.25 m³/sec, which is approximately equal to the amount used by all the wells in the watershed (6.25 m³/sec). In addition, some water remains after the irrigation season, especially in September and October. This amount can be recharged to the aquifer in carefully selected locations according to the ground water survey.

CONCLUSIONS
Integrating of surface water and ground water in management is beneficial, especially where a strong interaction occurs between the two sources. This integration estimates a clear and comprehensive water resources budget that could make water management more efficient. Using the FHM to integrate the HSPF and MODFLOW with triple calibration can help predict the ground water elevations efficiently and estimate the different components of the water budget.

Knowing the amounts of recharge, seepage, and base flow is necessary to determine the component of water budget development and water rights adjudication. The Big Lost River has a large interchange of water from surface water sources into the ground and from the ground into the surface streams. Direct precipitation is the major source of recharge to the local aquifer of the Big Lost River. A significant amount of the ground water recharge, estimated at 48.37 m$^3$/sec, returns to surface water as base flow. This base flow is estimated at 36.48 m$^3$/sec and has its peak in May through July while the recharge is achieving its maximum rate in May. The amount of ground water pumped by wells is estimated at 6.25 m$^3$/sec, and this amount is close to that lost by seepage, which is estimated at 5.25 m$^3$/sec. The North/East Forks zone has the maximum amount of recharge, while the Thousand Springs zone produces the maximum amount of base flow. The minimum recharge is in the Butte sub-basin, and this sub-basin along with the INEEL and Arco sub-basins have the minimum base flows within the valley. However, there is an amount of 10.44 m$^3$/sec that leaves the basin and is lost and never returns to the system.

Determining the different components of the water budget benefits the integrating of management, however, it also provides some challenges. One of these challenges is
how to recover and use the amount of water lost through ground water, which is about double the amount of the ground water pumped by wells. Another challenge is how to reduce the seepage losses. Although part of the seepage is returned to the river as base flow, there might be some other part that is lost from the system and this may require a ground water survey to determine what places should be controlled to reduce losses from the river. In addition, artificial recharge of the aquifer in good water years will raise ground water levels, especially in the lower part of the basin. However, excessive ground water pumpage from the aquifer increases seepage losses from the river, therefore, some restrictions on wells in the lower part of the basin may need to be encouraged.

The results indicated that there are some sub-basins that need no more stresses, such as Arco and Butte, while some others can have more development potential if they can sustain viable crops/beneficial uses; these include: North/East Forks zone, Thousand Springs zone, and Antelope sub-basin.

Overall, the knowledge and understanding of water budgets can be used for better conjunctive use management. Conjunctive use of both surface and ground water provides the most efficient use of the Big Lost River water resources. This would provide a system that could draw heavily on the ground water during dry years. During wet years, the draft on ground water should be minimized and excess stream flow artificially recharged to the ground water aquifer. Only through this kind of exchange can use of all the water resources of the basin be optimized.

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Ross, M. A., P. D. Tara, J. S. Geurink, and M. T. Stewart, 1997. FIPR Hydrological Model, Center for Modeling Hydrologic and Aquatic Systems, Department of Civil and Environmental Engineering and Department of Geological, University of South Florida, Tampa, Florida.


Table 1. Transmissivity, Hydraulic Conductivity and Storage Coefficient.

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>Transmissivity</th>
<th>Hydraulic Conductivity</th>
<th>Storage Coefficient</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>m²/day</td>
<td>ft²/day</td>
<td>m/day</td>
</tr>
<tr>
<td>Butte sub-basin</td>
<td>37,160</td>
<td>400,000</td>
<td>46</td>
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<tr>
<td>INEEL sub-basin</td>
<td>92,903</td>
<td>1,000,000</td>
<td>116</td>
</tr>
<tr>
<td>The rest of the watershed</td>
<td>6,830</td>
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Table 2. Pumping Wells Numbers, Locations, and Measured and Simulated Levels

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<tr>
<th>Index</th>
<th>Well Number</th>
<th>LAT (m)</th>
<th>LONG (m)</th>
<th>Measured (m)</th>
<th>Simulated (m)</th>
<th>Absolute Error</th>
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Mean Absolute Error (MAE) 20
<table>
<thead>
<tr>
<th>Sub-Basin</th>
<th>Precipitation (mm)</th>
<th>Stream Flow (mm)</th>
<th>Base Flow (mm)</th>
<th>Runoff (mm)</th>
<th>Total ET (mm)</th>
<th>Net Recharge + Unsaturated Storage (mm)</th>
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<tr>
<td>North/East Fork</td>
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<td>47.24</td>
<td>327.66</td>
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<tr>
<td>Thousand Springs</td>
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<td>119.38</td>
<td>24.77</td>
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<td>Mackay</td>
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<td>97.97</td>
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<td>Arco</td>
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<td>5.00</td>
<td>0.97</td>
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<td>Butte</td>
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<tr>
<td>Sub-Basin</td>
<td>Precipitation</td>
<td>Runoff</td>
<td>Base</td>
<td>Actual Flow</td>
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<td>(mm)</td>
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<tr>
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<td>3.63</td>
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</tbody>
</table>
Figure Captions

Figure 1
Big Lost River Watershed Location

Figure 2
Monthly Stream Flow, Surface Runoff, and Base Flow at Howell Ranch

Figure 3
Sub-basins for the Big Lost River: sub-basins 1, 2, 3, and 4 form the North/East Fork Zone, sub-basin 5, 6, and 7 form Thousand Springs Zone

Figure 4
Big Lost River and its Tributaries

Figure 5
Model Discretization

Figure 6
Normal Plot with Reference Line for ground Water Levels

Figure 7
Observed and Simulated Stream Flows at Howell Ranch Station
Figure 8
Flow Distribution during the Year of 2000

Figure 9
Comparison between Observed and Simulated Base Flow

Figure 10
Water Budget for the Big Lost River for the Year 2000
Figure 2
Figure 3
Figure 5

Direction of flow in the Snake River Plain

GHB
Figure 6

The graph illustrates the comparison between measured and simulated ground water levels. The line of best fit has a coefficient of determination ($R^2$) of 0.97, indicating a high degree of correlation between the measured and simulated data.
Figure 7

Streamflow, m³/sec

Date


Observed  Simulated
Figure 8

[Graph showing flow, m$^3$/day, with months on the x-axis and flow on the y-axis. Lines represent different sources: Seepage, Recharge, Wells, and Baseflow.]
Figure 9

![Graph showing baseflow over months with separate and simulated lines.](Image)
Figure 10

A graph showing the flow in m³/sec for different sub-watersheds:

- **North/East Fork**
- **Thousand Springs**
- **Mackay**
- **Antelope**
- **Arco**
- **Butte**
- **INEEL**

The graph uses different markers to represent different data categories:

- **Seepage** (△)
- **Recharge** (●)
- **Wells** (◇)
- **Baseflow** (×)