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Date: February 6, 2005

Project: DHI project No: 4021.252
IDWR contract No: 00629

Subject: Rainfall-Runoff Modeling Report for the Stanley and East Fork Salmon River Basins

Memorandum

This memorandum describes the initiative by Idaho Department of Water Resources (IDWR) and DHI, Inc. (DHI) to develop rainfall-runoff models that support the Stanley Basin MIKE Basin model (SBMBM) (DHI, 2003) and the East Fork Salmon River MIKE Basin Model (EFMBM) (DHI, 2005). MIKE Basin models require stream inflow time series in order to model the water allocation within the basin. As of 2004, many of the tributaries modeled by the MIKE Basin models were ungaged and thus had no flow records to use for satisfying boundary condition requirements. Developing the rainfall-rainfall models provided streamflow boundary conditions for use in the MIKE Basin models. This memorandum provides background; describes the model used, its construction, the data used, results; and provides suggestions for future developments.

The US Bureau of Reclamation (Reclamation) is acknowledged and appreciated for funding this project. Appreciation is also expressed for the assistance of Bill Graham and Sudhir Goyal from IDWR, and Jack Doyle from USGS.

Background

IDWR and DHI have developed MIKE Basin models of the Stanley Basin (SBMBM), and more recently the East Fork Salmon River (EFMBM), to evaluate water distribution associated with irrigation practices within these basins (DHI, 2003; DHI, 2005). Both models have inflow boundary condition requirements for simulated tributary streams. As of 2004, the majority of the tributary streams in these models are ungaged and inflow quantities are not well understood by water managers. Therefore, a method was needed for developing time series streamflow for the ungaged tributaries.

Several alternatives for developing streamflow time series in the ungaged tributary streams were investigated for this project. The first method is to install stream gages, thus providing a measured streamflow record. While this is the most accurate method, the equipment and manpower expense make this alternative cost impractical. In addition, development of a record takes time to acquire the data and thus several years would have to pass in order to use this data.

The second method for developing streamflow time series is to extend or transfer the flow record from a nearby catchment with similar geologic, climatic, topographic, vegetative, and landuse characteristics to the ungaged stream's catchment. Statistical methods for extending or transferring time series include linear regression, power equation, double mass curves, maintenance of variance method 1, and maintenance of variance method 2 (Hirsh, 1982). As both basins are devoid of stream flow records, this method was impractical.

A third method for developing streamflow time series is the use of regional hydrologic curves or equations that predict peak and monthly statistical flows. The US Geological Survey (USGS) has developed regional equations that provide peak annual and monthly average runoff for a stream in the Salmon River drainage (Lipscomb, 1998, Hortness and Berenbrock, 2001). The USGS also developed methods for evaluating flow-frequency and flow duration statistics in ungaged basins based on catchment area and flood magnitude (Kjelstrom and Moffat, 1981, Kjelstrom, 1998). Although these equations may present reasonable estimations of stream flow, results are average monthly values that will likely under predict some peak events and over predict critical low flow periods. In order to evaluate irrigation practices, the SBMBM and EFMBM have been established to simulate daily flow thus use of the monthly values are expected to hinder the goal of addressing critical low flow periods that may extend for only a short period during certain years . In addition, changing climatic conditions are not easily addressed without reformulating the regression analysis.

The rainfall-runoff model is a fourth method for developing streamflow time series. Rainfall-runoff models use algorithms to simulate the catchment's processing of precipitation into streamflow. The general requirements are basin area and precipitation. Depending on the algorithm chosen, additional parameters may be necessary. The advantage of using rainfall-runoff models is the ability to predict runoff given known attributes for the catchment as well as the ability to evaluate how changing precipitation rates will affect streamflow runoff.

Model Used: Nedbør-Afrstrømnings-Model (NAM)

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

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

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

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

Model Construction

IDWR and DHI constructed a NAM model to predict daily streamflow for each tributary in the SBMBM and the EFMBM. Catchment boundaries were determined using MIKE Basin catchment delineation tools applied to USGS 30m NED digital elevation model (DEM) (USGS, 2003). Delineations are based on a catchment pour point, typically located at the upstream boundary of the tributaries developed in MIKE Basin models. Results were compared to watershed coverages provided by IDWR to ensure reasonable catchment delineation.

Fifteen and eight NAM models were created for the Stanley and East Fork Salmon River Basins, respectively (Figure 1, Table 1). The catchments modeled by NAM in the Stanley Basin include Valley Creek (both above diversions and at Stanley), Elk Creek, Stanley Creek, Iron Creek, Goat Creek, Meadow Creek, Fisher Creek, Fourth of July Creek, Champion Creek, Alturas Lake Creek, Beaver Creek, Smiley Creek, Pole Creek, and the headwaters of the Salmon River. The catchments in the East Fork Salmon River Basin include Big Boulder Creek, Little Boulder Creek, Big Lake Creek, Pine Creek, Herd Creek, West Pass Creek, Road Creek, and the headwaters of the East Fork Salmon River.

Time Series Data

Time series data required for the NAM models include concurrent precipitation, temperature, evapotranspiration, and streamflow. Summary of the data and stream flow data are available below.

Climatic Data

Precipitation and temperature data were collected from the Banner Summit, Galena City, Galena Summit, Vienna Mine, and Lost-Wood Divide weather stations (Table 1, Figure 2). Station elevation effects quantity of precipitation recorded. In general, accumulated precipitation is quite similar between the Vienna Mine and Banner Summit stations, and also between the Galena City and Galena Summit stations. The Lost-Wood station tends to correlate better with the Galena stations. Precipitation recorded at the Stanley climate station averages 13.5 inches per year in comparison to the Banner and Galena Summit that average 42.5 and 32.9 inches per year, respectively. The monthly reference evapotranspiration (ETr) data supplied by IDWR based on the Stanley climate station is applied throughout the model.

Stream Discharge

The only long term stream gage with records concurrent to the climatic data is the USGS Valley Creek at Stanley gaging station (13295000). Seven other seasonal stream gages have been installed by the USGS to support fish habitat studies in the basin (Table 2**,** Figure 2) (Maret, Hortness, and Ott, 2004). These gages were operational for only a portion of the year; typically beginning in May or June and continuing into late summer or early fall. Some streams were monitored during both 2003 and 2004, while others were only monitored during one summer (Table 2). All streamflow data collected after October 2003 and presented in this report is provisional in nature and may be changed prior to becoming final. Table 3 lists the three permanent USGS gaging stations with data that have concurrent time periods of record as meteorological station data. The meteorological stations are within close proximity to the gaging stations. Only stream discharge station 13295000 (Valley Creek at Stanley) continues to be operated and with a sufficiently long record with concurrent climate data to support calibration of the rainfall/runoff model.

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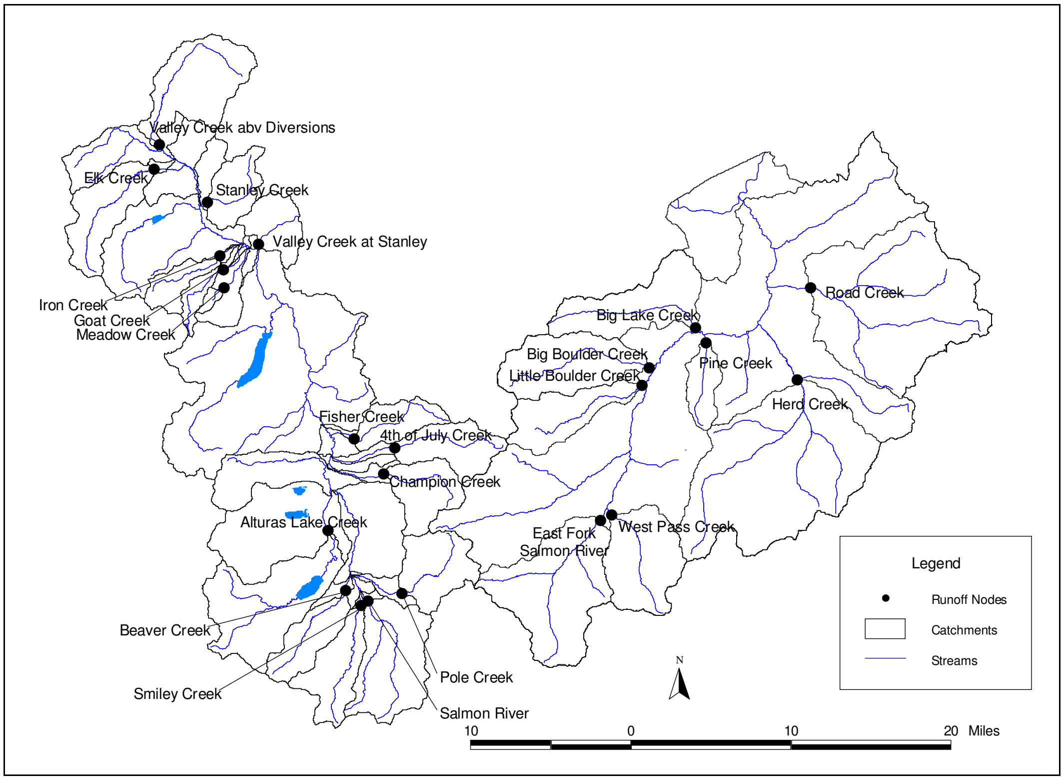

Figure 1. Catchment delineation and outflow location for the Stanley and East Fork Salmon River Basins.

Table 1. Catchments for each model, climate stations used, and availability of streamflow gage data.

Stream Name	*Stream Gage*	*Precip. Station**	*Stream Name*	*Stream Gage*	*Precip. Station**
SBMBM			*EFMBM*		
Valley Creek at Stanley	Y	B	East Fork Salmon River (headwaters)	N	G
Valley Creek (above diversions)	Y	B	West Pass Creek	N	G
Iron Creek	Y	B	Big Boulder Creek	N	G
Elk Creek	Y	B	Little Boulder Creek	N	G
Stanley Creek	N	B	Big Lake Creek.	N	G
Goat Creek	N	B	Pine Creek	N	LW
Meadow Creek	N	B	Herd Creek	N	LW
Fisher Creek	N	G	Road Creek	N	LW
Fourth of July Creek	Y	G			
Champion Creek	N	G			
Pole Creek	Y	G			
Salmon at Pole Creek	Y	G			
Smiley Creek	N	VM			
Beaver Creek	N	VM			
Alturas Lake Creek	N	VM			

* B = Banner Summit, G = Galena Summit, VM = Vienna Mine, LW = Lost-Wood Divide

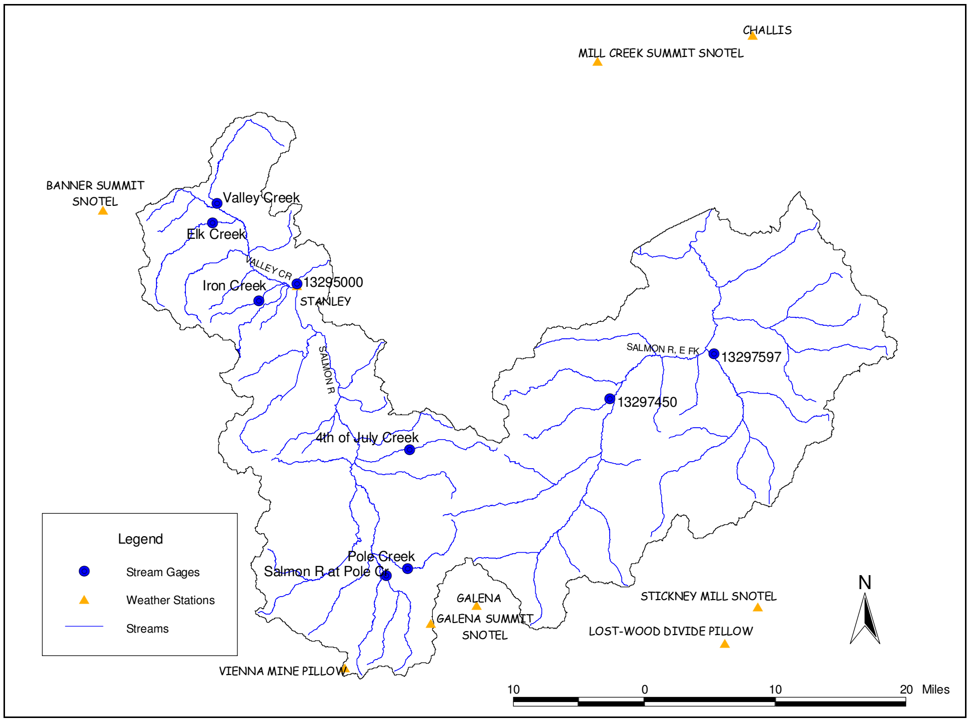

Figure 2. Stream gaging and meteorological station locations in the Stanley and East Fork Salmon River Basins.

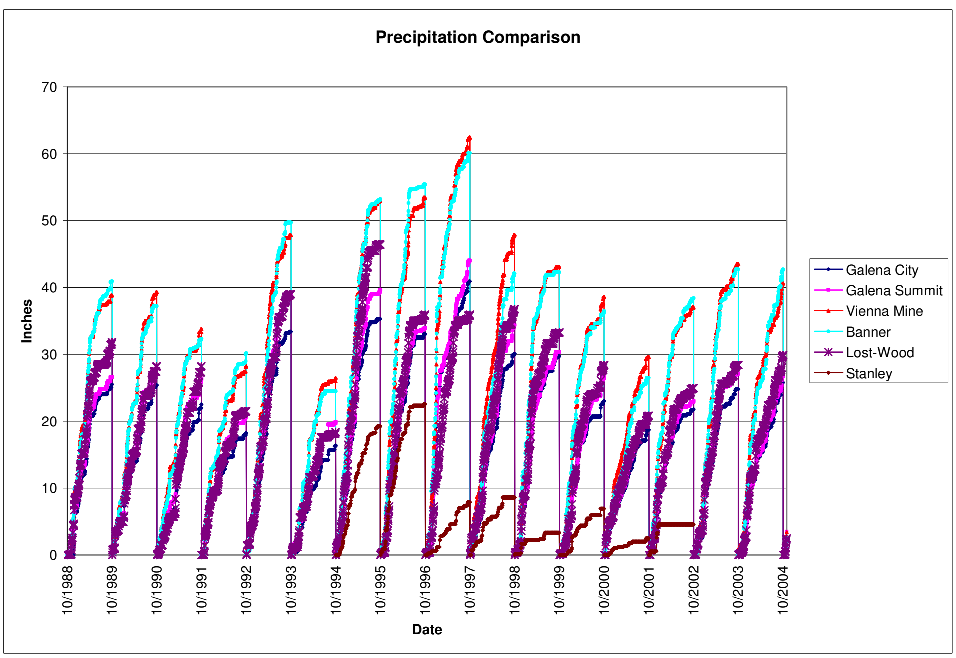

Figure 3. Comparison of accumulated precipitation at selected stations in the Upper Salmon River area.

Table 2. Temporary USGS stream gaging stations in the Stanley Basin.

Station ID	*Station Name*	*Period of Record*
13292280	Salmon at Pole Creek	5/1/03 – 10/6/03, 4/13/04 – 9/13/04
13292380	Pole Creek below Ranger Station	6/1/03 – 10/6/03, 4/14/04 – 8/16/04
13293350	Fourth of July Creek abv diversions	6/1/03 – 10/6/03, 5/7/04 – 8/16/04
13294600	Valley Creek above diversions	5/1/03 – 9/29/03, 4/12/04 – 9/12/04
13294640	Elk Creek above diversion	6/1/03 – 9/30/03
13294880	Iron Creek above diversions	4/13/04 – 8/15/04

Results and Discussion

It was originally intended to produce six calibrated NAM models in representative catchments and transfer the parameters to ungaged stream catchments in the Stanley and East Fork Salmon River basins. Upon review of the data, IDWR and DHI found that concurrent climatic and stream flow data was unavailable for calibration for all but Valley Creek at Stanley. Specifically, stream gage records in the basins pre-date the period of record for climatic stations (Figure 4, Figure 5).

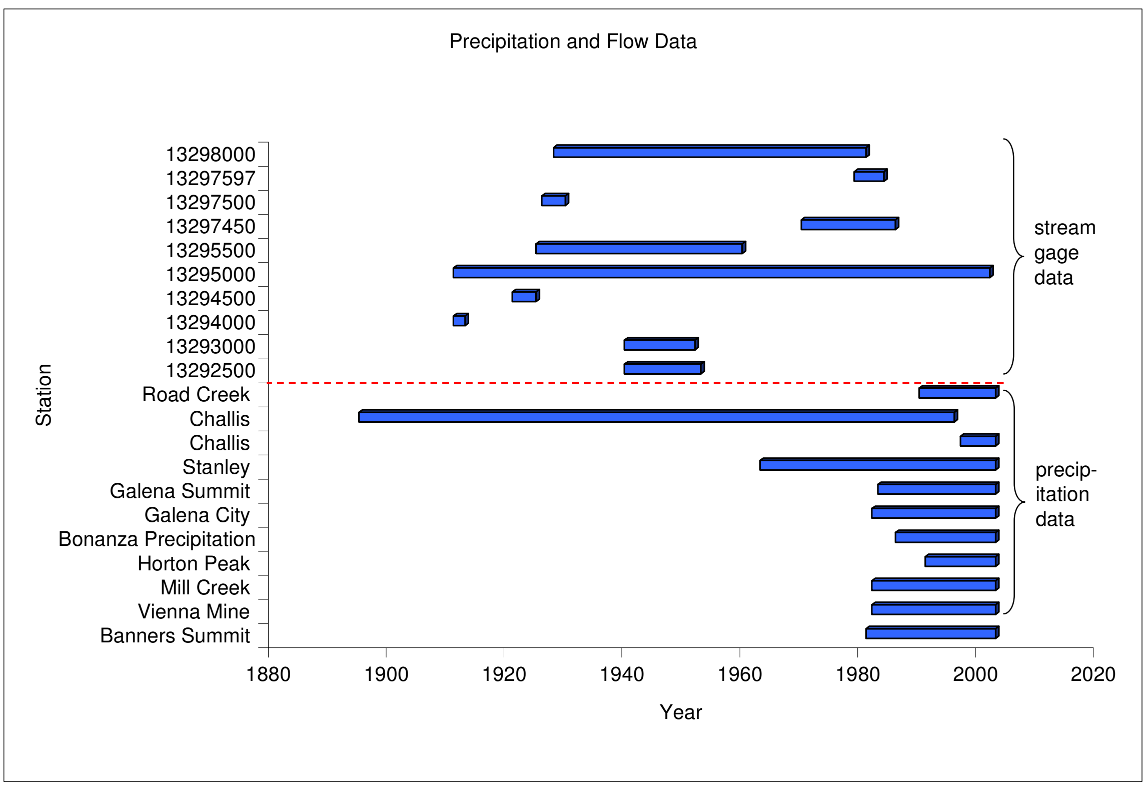

Figure 4. Stream gaging and precipitation data period of record. Stream gages, above the dashed line, are listed by number and climatic stations are listed by name.

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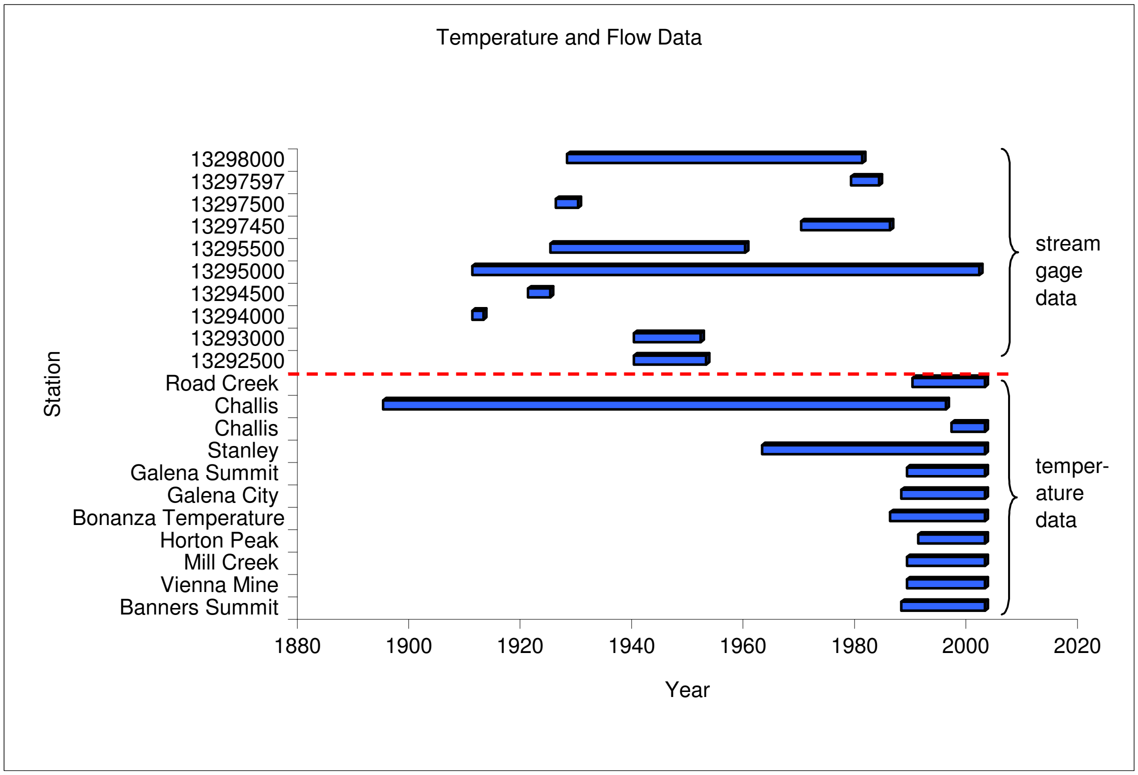

Figure 5. Stream gaging and temperature data period of record. Stream gages, above the dashed line, are listed by number and climatic stations are listed by name.

Table 3. Concurrent time periods of data.

Gaging Station	Meteorological Station with Concurrent Periods of Record and Close Proximity to Gaging Station	Comment
13295000	Banner Summit and Stanely	
13297450	Galena City and Galena Summit	Precipitation Only
13297597	Galena City and Galena Summit	Precipitation Only

The objective for this calibration project was to produce a simulation with an overall good fit to observed data and with a strong emphasis on summer-time base flows to target flow regimes that are of highest concern to fish populations. The calibrated model produces a good visual fit to observed discharge for the Valley Creek at Stanley gage (Figure 6), with simulated discharge providing a reasonable match to observed discharge including timing and magnitude of peaks and troughs, and timing of rising and receding limbs. On average, the simulated peak discharge tends to be a little lower than observed, while the simulated low flow tends to be a little higher than observed (Table 4, Figure 6). Accumulated runoff volume is under-predicted by approximately 13 percent (Figure 7).

Table 4. Annual observed and simlated peak and low discharges (cfs) for Valley Creek at Stanley.

Year	Observed Peak	Simulated Peak	Observed Low	Simulated Low
1994	441	531	34	24
1995	1020	1081	45	31
1996	1540	1060	75	101
1997	1600	1220	77	85
1998	883	746	63	85
1999	1220	940	62	63
2000	707	722	55	67
2001	582	578	37	44
2002	853	745	49	46
2003	1350	871	60	67
2004	508	803	55	59

Input data used to calibrate the NAM parameters for Valley Creek at Stanley includes: Daily accumulated precipitation and average daily temperature recorded at the Banner Summit climate station; daily stream discharge from Valley Creek at Stanley; monthly evapotranspiration from the Stanley climate station; and catchment area. Calibrated NAM parameters for Valley Creek at Stanley are presented in Table 5. These parameters are applied to other NAM models of catchments identified in Table 1. Several of these catchments include those where USGS temporary stream gage stations were installed during 2003 and/or 2004 (Valley Creek above diversions, Fourth of July Creek, Iron Creek, Pole Creek, Elk Creek, and Salmon River above Pole Creek). For these streams, comparisons between observed and simulated discharge are presented (Figure 8 through Figure 13). Several of these comparisons produced a good match between peak discharge, timing of the receding limb, and base flow. One notable exception is Pole creek, which has a significantly higher than expected base flow. Discharge volume comparisons are not made for stream gages operated for only a portion of the year as the available data does not support such analysis. None of the temporary 2003/2004 gaging stations were located in the East Fork Salmon River basin; therefore no figures are presented for streams in that basin. It is important to understand that streamflow reported here from October 2003 through 2004 is **provisional** and will likely change prior to becoming final. Final USGS measurement records, once they become available, should be used to re-check the comparisons.

Table 5. NAM parameters determined during calibration of Valley Creek at Stanley and applied to other Stanley Basin and East Fork Salmon River catchments.

Parameter	Description	Value
Umax	Maximum water content in surface storage	0.06 ft
Lmax	Maximum water content in root zone storage	0.9 ft
CGOF	Overland flow runoff coefficient	0.25
CKIF	Time contstant for routing interflow	800 hrs
CK1,2	Time constant for routing overland flow	80 hrs
TOF	Root zone threshold value for overland flow	0
TIF	Root zone threshold value for interflow	0
Tg	Root zone threshold value for GW recharge	0
CKBF	Time constant for routing baseflow	6000 hrs
Carea	Ratio of GW-area to catchment area	0.4
Csnow	Constant degree-day coefficient	0.045 in/°F/Day
T_0	Base temperature (snow/rain)	32°F

Total rainfall accumulation in 2004 was very similar to 2003 (refer to Figure 3). However, runoff characteristics were quite different as apparent in any of the comparison figures that include both 2003 and 2004 observed discharge. In general, peak discharge was higher than simulated in 2003, and lower than simulated in 2004, as apparent in Figures 6, 8, 11, 12 & 13. Also, based on observed gage records, the 2004 snow melt appears to be delayed when compared to 2003.

Limitations

Several factors may contribute to the discrepancy between observed and simulated discharge, including:

- Lack of Climate Data – There are relatively few weather stations available in the Upper Salmon River area. One station, Banner Summit, is applied to the Valley Creek drainage, and this station is likely not completely representative of the whole basin which has a variety of topographic, climatic, and geologic characteristics.
- Lack of Stream Gage Data – Only one currently active long term gage is available for calibration in the two basins of interest. Discontinued gages with older data do not have corresponding nearby climate data. Temporary station discharge is very useful for comparing the adequacy of transferring parameters developed for Valley Creek to other drainages. However, these records are inadequate for calibration of individual streams because the discharge data are not continuous nor of adequate length of time.
- Influence of Irrigation – Diversions of streamflow for irrigation upstream of the Valley Creek at Stanley gage (13295000) likely influence discharge at that station, particularly during the lower summertime baseflows that are a primary target of calibration. Calibration parameters are developed for the lower end of Valley Creek, below the influences of irrigation. However, they are then applied to other streams where observed discharge is above the influences of irrigation.
- Variable Basin Characteristics – The various basins have differing characteristics of elevation, geology, vegetation, soils, snow accumulation and melt, runoff, etc. Although parameters developed for Valley Creek at Stanley appear to apply surprisingly well to several other catchments, differing basin characteristics likely play a part in the differences between observed and simulated discharge.

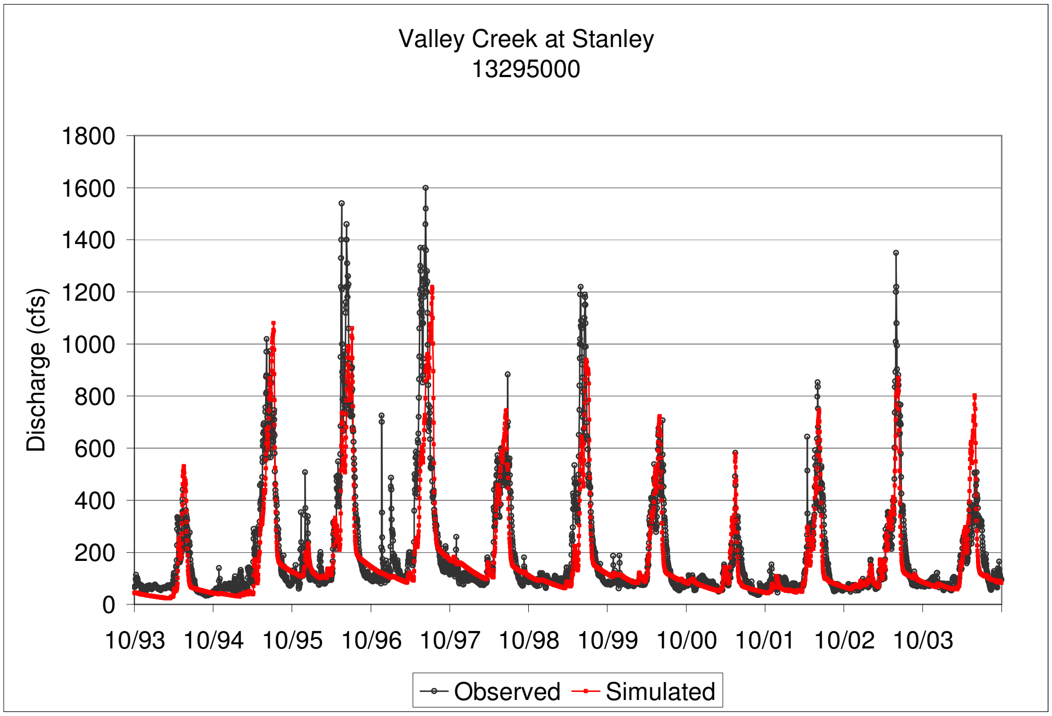

Figure 6. Observed and simulated daily discharge for Valley Creek at Stanley.

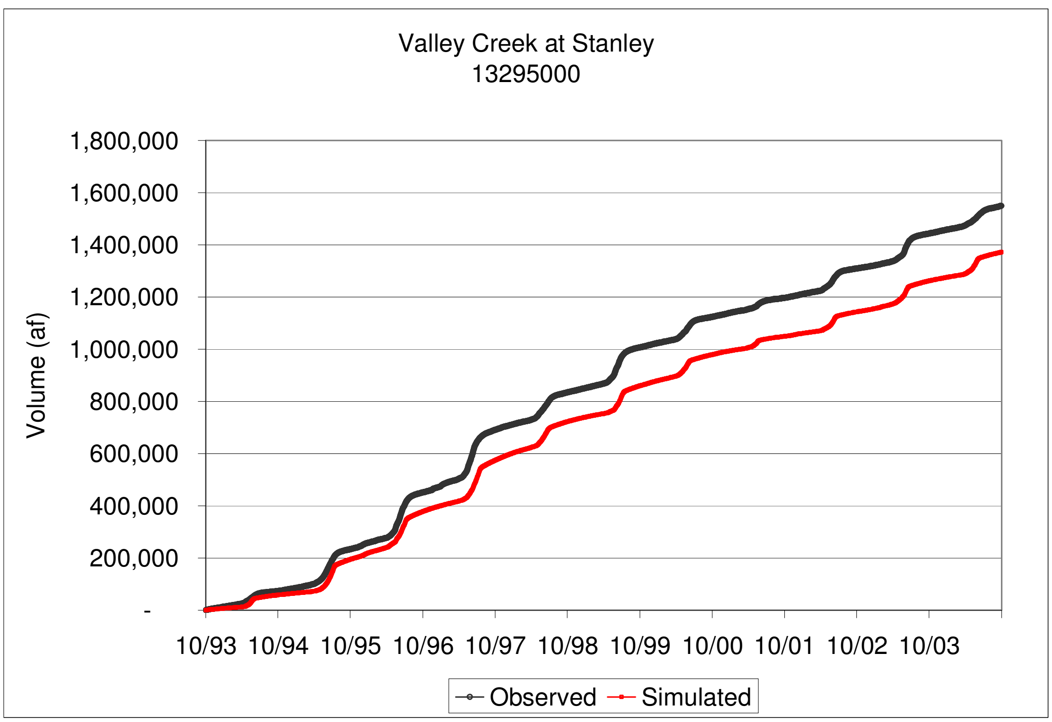

Figure 7. Observed and simulated accumulated discharge volume for Valley Creek at Stanley.

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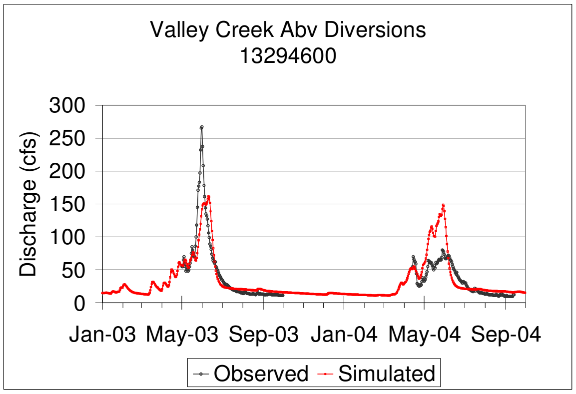

Figure 8. Observed and simulated daily discharge for Valley Creek above diversions.

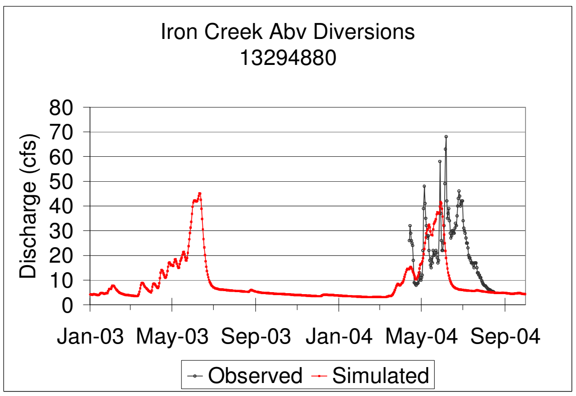

Figure 9. Observed and simulated daily discharge for Iron Creek.

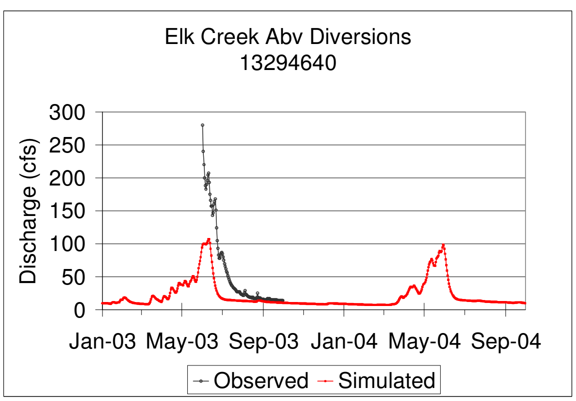

Figure 10. Observed and simulated daily discharge for Elk Creek.

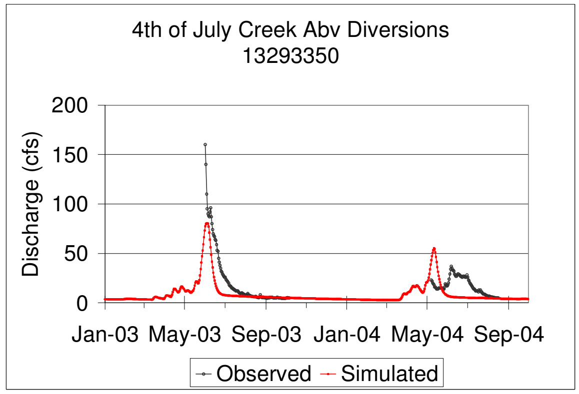

Figure 11. Observed and simulated daily discharge for 4th of July Creek.

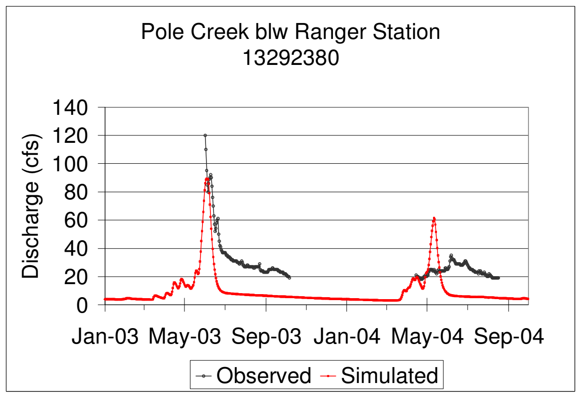

Figure 12. Observed and simulated daily discharge for Pole Creek below Ranger Station.

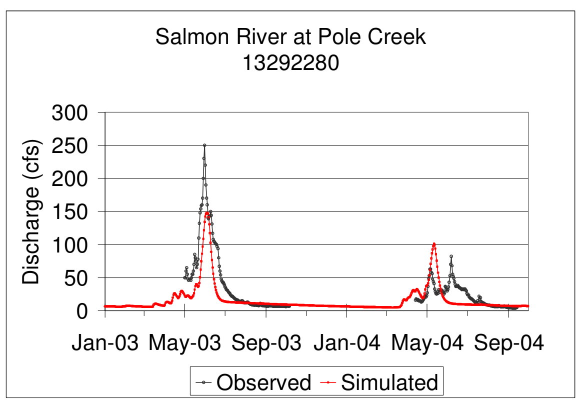

Figure 13. Observed and simulated daily discharge for Salmon River at Pole Creek.

Future Efforts

Given the data limitations, DHI and IDWR constructed the NAM model parameters using the available data. To improve and augment the NAM models, further data collection and analysis are recommended. Specific recommendations include:

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- Stream flow gaging – The lack of current stream gage data hindered the ability to establish calibrated NAM models for ungaged tributaries. It is recommended that stream gages be placed above diversions in representative tributaries for the entire year. Currently, IDWR is working to remedy this limitation in the basin. Specific streams recommended for stream gage installation include Herd Creek, Big Boulder Creek, Elk Creek, Iron Creek, Pole Creek, 4th of July Creek, and Salmon River at Pole Creek.
- Recalibrate the NAM models using stream gage data – As additional streamflow data is collected and new stream gages come on-line, NAM models should be re-calibrated using the new data.
- Use multiple snow zones - In this phase of NAM develop, a single elevation zone was applied for all catchments. Given the variation in precipitation and snowmelt with elevation, application of snowmelt zones and/or groundwater component of NAM will likely result in more accurate predictions of runoff.
- Include irrigation in Valley Creek at Stanley calibration – Quantify and include the influence of irrigation on streamflow for the Valley Creek at Stanley NAM model.

Conclusions

The NAM model developed to simulate runoff in the Stanley and East Fork Salmon River basins is calibrated based on stream discharge from the USGS Valley Creek at Stanley gage along with precipitation and temperature data from the Banner Summit weather station. The calibration results in a good visual fit compared to observed discharge. Parameters developed for Valley Creek at Stanley are applied to numerous other drainages in order to simulate discharge that will be used as upstream boundary conditions in developed MIKE Basin models. Simulated discharge in several of these other tributaries is compared with streamflow measurements collected by IDFG during 2003 & 2004. Initial results indicate that these transferred parameters appear to result in fair to good simulations, and base flow is closely targeted in 5 of 6 cases. It is unknown how well the model performs for ungaged catchments as there no observed data for which to compare simulation results.

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