Idaho Water Resources Research Institute

Preliminary Hydrologic Assessment of the Lower Teton Basin in Southeast Idaho

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Preface

Water has been playing a significant role in the development of the Western United States as soon as the first settlers arrived. At the time the main concern of people was the quantity of water available for their personal and other traditional uses (e.g., irrigation, mining and hydro-power). Nowadays, as the population grows and people's activities diversify, water is even more crucial. Concerns of part of the population have broadened to include issues of water quality preservation, endangered species protection, restoration of wildlife habitat and others. For them, it does not seem reasonable to maximize the amount of water available for irrigation to the detriment of fish populations, nor to allow a community's wastewater to damage water quality.

To evaluate the effects of competing demands for water and their effects on water quality, there is a need to study in parallel the different water and land uses within watersheds. In this context, Lockheed-Martin Idaho Technologies Company has dedicated a Laboratory Directed Research and Development grant toward the development of an integrated water management model. This model will simultaneously address many of the issues concerning a river system, such as surface and ground-water flows, water quality and fish habitat. It will first be applied to the Teton River basin in southeastern Idaho, where population growth is one of the most rapid in the United States.

As part of the initial phase of model construction, the Idaho Water Resources Research Institute has been asked to help develop a conceptual model of the lower Teton River system (below the failed Teton Dam site), review selected existing watershed models and evaluate their data needs, and investigate the availability of hydrologic data. This report presents the results of this initial phase.

Contents

Introduction

In an effort to assist a Laboratory Directed Research and Development (LDRD) project of Lockheed-Martin Idaho Technology in the development of an integrated water management model applicable to the lower Teton River basin (below the failed Teton Dam site), the Idaho Water Resources Research Institute (IWRRI) has prepared a preliminary hydrologic assessment of the lower Teton River basin in Southeast Idaho. This assessment includes the following tasks and components:

- development of a conceptual model of the hydrologic system of the lower Teton River, including a preliminary water budget model,
- a critical review of some existing watershed models including an evaluation of their data needs and,
- an investigation of the availability of hydrologic data.

The conceptual model of the lower Teton River system has been established after reviewing previous investigations in the area, including information gathered from Water District 01 of the Idaho Department of Water Resources (IDWR), Fremont Madison Irrigation District and other sources.

Four existing models were reviewed: an integrated ground water and surface water model (IGSM), two surface water models (MODSIM and WEAP), and the snowmelt and runoff model developed by Dr Kim (1987).

The identification of the major existing hydrologic data sets, their characteristics and availability have been determined from interviews with government agencies and private entities.

Chapter 1. Development of a Conceptual Model

1.1. Introduction

This chapter presents a conceptual model and a preliminary water budget model of the lower Teton River basin. The conceptual model, described in section 1.2., details the major sources and diversions of water from the lower Teton River. The conceptual model has been established after reviewing previous investigations in the area, including information gathered from the Idaho Water District 01, Fremont Madison Irrigation District and other sources. A schematic of the river system is provided in Figure 1.2 (page 8). Section 1.3. presents the results of a preliminary water budget model of the lower Teton River system.

1.2. Conceptual model

1.2.1. Lower Teton River.

The lower Teton River extends from the Teton Dam site to its confluence with the Henrys Fork of the Snake River (Figure 1.1.). Downstream from the Teton Dam site for about 10 miles, the river is formed by a single channel, often referred to as the central Teton River, beyond which the river divides into two branches, referred to as the North Fork and the South Fork of the Teton River. The area between the two forks of the Teton River is called Teton Island. The separation between these two forks takes place at a diversion structure located north of the city of Teton, referred to as the 'splitter'.

The water of the Teton River is used intensively for irrigation purposes. Most of the irrigators are associated with canal companies some of which were formed at the end of the 19th century. The canal companies divert water from the Teton River (natural flow and storage water) in accordance with water rights under the authority of the IDWR. Once the water is delivered to the canal head gates, Fremont-Madison Irrigation District personnel distribute it to individual users.

The following sections detail the canal companies or water user organizations that divert water from the lower Teton River. Figure 1.2.presents a schematic of the diversions and return flows in this part of the river.

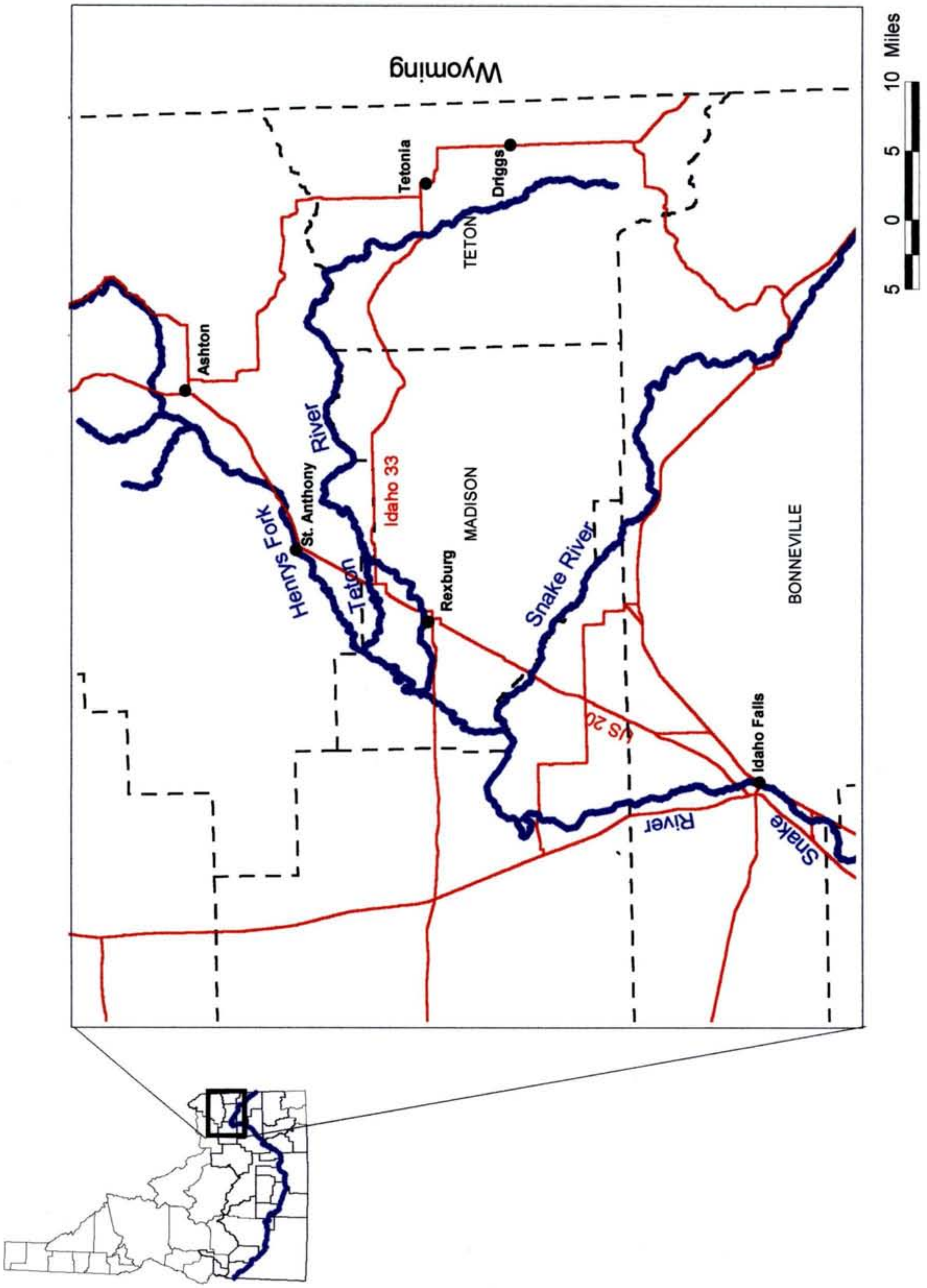

Figure 1.1. Map of the lower Teton River

1.2.2. Diversions from the Central Teton River

Water is diverted from the central Teton River by four diversion structures. In a downstream direction, these diversion structures belong to the following irrigation companies:

Wilford Irrigation and Manufacturing Company
Wilford Irrigation and Manufacturing Company diverts water from the north side of the Teton River with a concrete dam. The water is then conveyed in an unlined ditch for about 0.5 mile, after which the ditch splits into two branches (north and south branches).

Teton Irrigation , Teton Generation Station and Siddoway Ditch
Teton Irrigation, Teton Generation Station and Siddoway Ditch share a common diversion structure on the south side of the central Teton River Canal but, have their own individual head gates. The diverted water is first conveyed in a mill-race for two miles. Pumps have been set into the mill-race to supply water to the Siddoway Ditch users. After the mill-race the water is divided between Teton Irrigation Canal and the Teton Generation Station. The water that runs through the Teton Generation power station returns back to the South Fork of the Teton River. The unused water of the Teton Irrigation Canal empties into Moody Creek.

Pioneer Ditch
Located between Teton Irrigation canal and Steward Ditch, the Pioneer Ditch diverts water out of the central Teton River on the north side of the river.

Steward Ditch
Steward Ditch diverts water from the north side of the river in the vicinity of the 'splitter'.

1.2.3 Diversions from the North Fork of the Teton River

The North Fork of the Teton River runs westward from the 'splitter' to its confluence with the Henrys Fork of the Snake River. Water is diverted from the North Fork of the Teton River by six canal companies. In a downstream direction, these canal companies are as follows:

Pincock-Byington Ditch
Pincock-Byington Ditch is the most upstream diversion company of the North Fork of the Teton River, its diversion structure is located about 3/4 mile below the 'splitter'.

Teton Island Feeder
The Teton Island Feeder diverts water from the south side of the North Fork of the Teton River to the Teton Island Canal, the Salem Irrigation Company Canal, and the Wolf Slough Ditch Company. About two miles downstream from the diversion structure, water is pumped from the Teton Island Feeder to be distributed to the Wolf Slough Ditch water users. Half a mile further downstream, The Teton Island

Feeder divides into the Salem Irrigation Company Canal and the Teton Island Canal. The Salem Irrigation Company Canal runs south-westerly and empties into the Island Ward Canal. The return flows from the Teton Island Canal reach the South Fork of the Teton River close to the Rexburg airport.

North Salem Agriculture and Milling Canal
The North Salem Agriculture and Milling Canal diverts water from the north side of the North Fork of the Teton River about 2 miles north of the city of Salem. It later merges with the Salem Union Canal originating from the Henrys Fork of the Snake River.

Roxana Canal
The Roxana Canal diverts water to lands north of the North Fork of the Teton River.

Island Ward Canal
The Island Ward Canal diverts water to lands on the Teton Island. It receives the return flows of the Salem Irrigation Company Canal and empties into the South Fork of the Teton River.

Saurey-Sommers Canal.
The Saurey-Sommers Canal is the lowest diversion on the North Fork of the Teton River. It is located and irrigates land on the south side of the river.

1.2.4. Diversions from the South Fork of the Teton River

The South Fork of the Teton River runs southwesterly from the ‘splitter’ to the city of Rexburg. After Rexburg, the river flows mostly in a westerly direction to its confluence with the Henrys Fork of the Snake River. Six canal companies divert water from the South Fork of the Teton River. In a downstream direction, these companies are:

Pincock-Garner Canal Company
The Pincock-Garner Canal is located approximately one mile downstream of the ‘splitter’. It diverts water from the north side of the South Fork of the Teton River. Half a mile after the diversion, the waters of Pincock-Garner Canal pass through a flume to the Teton Island Feeder.

Mc Cormick Ditch
The Mc Cormick Ditch is privately owned by a single water user. It diverts water from the north side of the South Fork of the Teton River to irrigate lands located on Teton Island.

Biglr Slough Ditch
Located between the Mc Cormick Ditch and the Woodmansee-Johnson Canal, Biglr Slough Ditch diverts its water from the south side of the South Fork of the Teton River and delivers it to a very small number (three or four) of water users.
Woodmansee-Johnson Canal
The Woodmansee-Johnson Canal provides water to lands located south of the South Fork of the Teton

River. During the irrigation period, users of this canal also can also use the water carried by Moody Creek, a natural tributary of the South Fork of the Teton River.

City of Rexburg Canal
The City of Rexburg Canal diverts water from the south side of the South Fork of the Teton River.

Rexburg Irrigation Company
The Rexburg Irrigation Company diversion point is located about 1/4 mile downstream from the City of Rexburg diversion point. The water is conveyed north of Rexburg. On the west edge of town, the canal divides into three branches, named the Golf Course, the West and the South Branches. Some return flows from the Rexburg Irrigation Company reach the Henrys Fork of the Snake River.

1.2.5. Exchange well program

The Teton River extending upstream from Teton Dam site is incised in Teton Canyon. Prior to the construction of the dam, most of the farms on the high plateaus surrounding Teton Canyon were dry-farmed. With the construction of the dam, additional water supplies would have been available for these dry-farmed lands and the landowners made substantial investments in pumps and irrigation equipment. After the dam failure and despite the loss of the storage water supply to be provided by the dam, these landowners were authorized to pump water out of Teton Canyon, provided they would compensate downstream water users by pumping groundwater into the river at downstream locations. The wells used for this purpose are called exchange wells. The amount of water returned to the river by the exchange wells is intended to equal the amount taken upstream by the Teton Canyon users. The exchange wells are located along the central Teton River, the North Fork and the South Fork of the Teton River. Their discharge is monitored by Idaho Water District 01. The locations of the exchange wells indicated on figure 1.2. are only indicative.

1.2.6. Inter-basin exchange canal

The Cross Cut Canal, constructed in the 1930's, diverts water from the Falls River and delivers it to the Teton River a few miles downstream of the Teton Dam site, increasing the amount of water available in the lower Teton Basin.

1.2.7. Return flows

The water flowing through the canals that is not used by the irrigators nor lost during its conveyance (via seepage to the aquifer) may return to the river. The location of the confluence between a canal and the river is in some cases identifiable on USGS topographic maps (scale: 1/24,000). In some other cases, canals divide into laterals that further divide into numerous ditches that apparently do not return to the river. Irrigation return flows that benefit the lower Teton River basin mostly originate from canals diverting water from the Falls River and the Henrys Fork of the Snake River. The following sections describes return flows in more detail.

Return flows in the central Teton River

There is apparently no major return flow in the central Teton River

Return flows in the North Fork of the Teton River

The North Fork of the Teton River receives the return flows of the Salem Union Company and the Farmer's Friend Canals. The Island Ward Canal that is diverting from the North Fork of Teton River receives the return flows of the Consolidated Farmers Canal.

Return flows in the South Fork of the Teton River

Water diverted from the central Teton River and run through the Teton Generation Station returns to the South Fork of the Teton River. Although this does not constitute return flow in the strict sense of the term, it does contribute to flow of the South Fork of the Teton River. The discharge of Moody Creek, a tributary of the South Fork of the Teton River receives the return flows of the Teton Canal, East Teton Canal and Enterprise Canal, increasing the discharge of the South Fork of the Teton River. Moody Creek's water can also be diverted by the Woodmansee-Johnson Canal users. It is speculated that the Woodmansee-Johnson Canal users divert almost all the water of Moody Creek during the irrigation season. The unused water of Teton Island Canal also returns to the South Fork of Teton River.

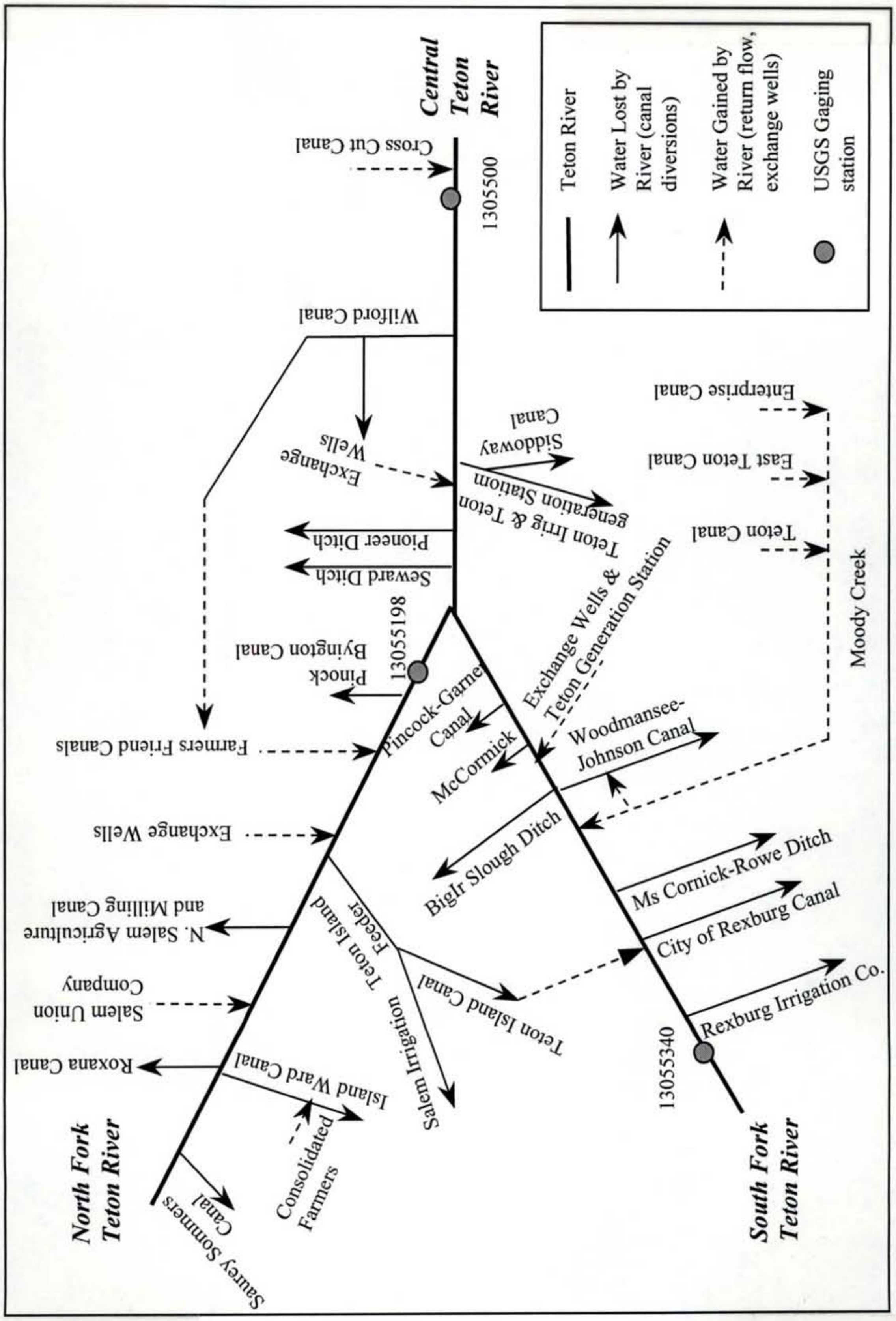

Figure 1.2. Schematic of the diversions and return flows for the lower Teton River system below the Teton Dam site

1.3. Preliminary water budget model.

To quantify the hydrological regime of the lower Teton River system, a simple water balance computer model was developed. The model requires data from the numerous discharge points described above. Measurement and recording of discharges are described below.

1.3.1. Discharge measurement and recording.

The amount of water diverted by every canal company is measured daily by the watermasters of Fremont-Madison Irrigation District or by automatic measuring and recording devices (Hydromet stations). This information is transmitted to the Idaho Water District 01 and used in a water allocation program (Water Right Appropriation Program).

Idaho Water District 01 is responsible for the allocation of all surface irrigation water in the Snake River system upstream from Milner Dam. To guarantee data quality, Idaho Water District 01 hydrologists measure the discharge of every canal on a regular basis and if necessary, gaging stations are recalibrated. All canal diversions and amount returned by exchange wells (daily and monthly values) are published in the annual reports of Water District 01.

The USGS measures discharges daily at three gaging station in the lower Teton River basin.

- USGS gage 13055000 (Teton River at St. Anthony) is located downstream from the confluence point of the Cross Cut canal and the central Teton River, and upstream of the diversions taking place in this part of the river (Figure 1.3.).
- USGS gage 13055198 (North Fork of Teton River at Teton) is located a few hundred yards downstream from the splitter but upstream of the diversion points on the North Fork of the Teton River.
- USGS gage 13055340 (South Fork of Teton River at Rexburg) is located on the South Fork of the Teton River downstream from all the diversion points on this part of the river.

1.3.2. Processes modeled

The hydrologic features considered in the preliminary water budget model are:

- canal diversions,
- exchange well inflows,

- return flows from the canals to the river, and
- interaction between surface and ground water.

The time step used in the model is the month and the discharge unit is acre-feet. The model has been run for the water years 1989 and 1992, which represent wet and dry years, respectively. Also, the water year 1992 is the most recent year included in Idaho Water District 01 printed reports.

Canal diversions and exchange well inflows

The amount of water diverted from or returned to the Teton River is published in the annual report of Idaho Water District 01.

Return flows from the canals to the river

Returns flows are not routinely monitored by the Idaho Water District 01. Wietzes (1981) estimated the return flows for most of the canals in the upper Snake River basin at between 5% and 10% of the amount diverted. The USGS measured the return flows of the Independent Canal during water years 1989 and 1990 (gage 13050543). The Independent Canal diverts water from the Henrys Fork of the Snake River near St. Anthony and returns the unused water to the Henrys Fork of the Snake River in the Cartier Slough area. The discharge of the Independent Canal is comparable to the one of the largest canals in the lower Teton River basin. Based on the USGS return flow measurements and the diversion records of Idaho Water District 01 for the same period, the return flows of the Independent Canal can be estimated at 7% of the amount diverted. This value has been used in the model.

(Note : the only return flows considered in the model are the return flows of the canals presenting a clear confluence with the river.)

Interaction between surface and ground water

The relationship between a river and the underlying groundwater body can be studied in a simple way with a mass balance approach.

If no diversion nor inflow occurs in a given reach, the sign of the difference between the reach inflows (Q1) and outflows (Q2) indicates the direction of the flow between the river and the groundwater. A positive difference ($Q1 - Q2 > 0$ or $Q1 > Q2$) indicates that the reach is losing water to the aquifer. A negative difference ($Q1 - Q2 < 0$ or $Q1 < Q2$) indicates that the reach is gaining water from the aquifer.

In the case of the lower Teton River, the mass balance principle has been used the following way (figure 1.3.):

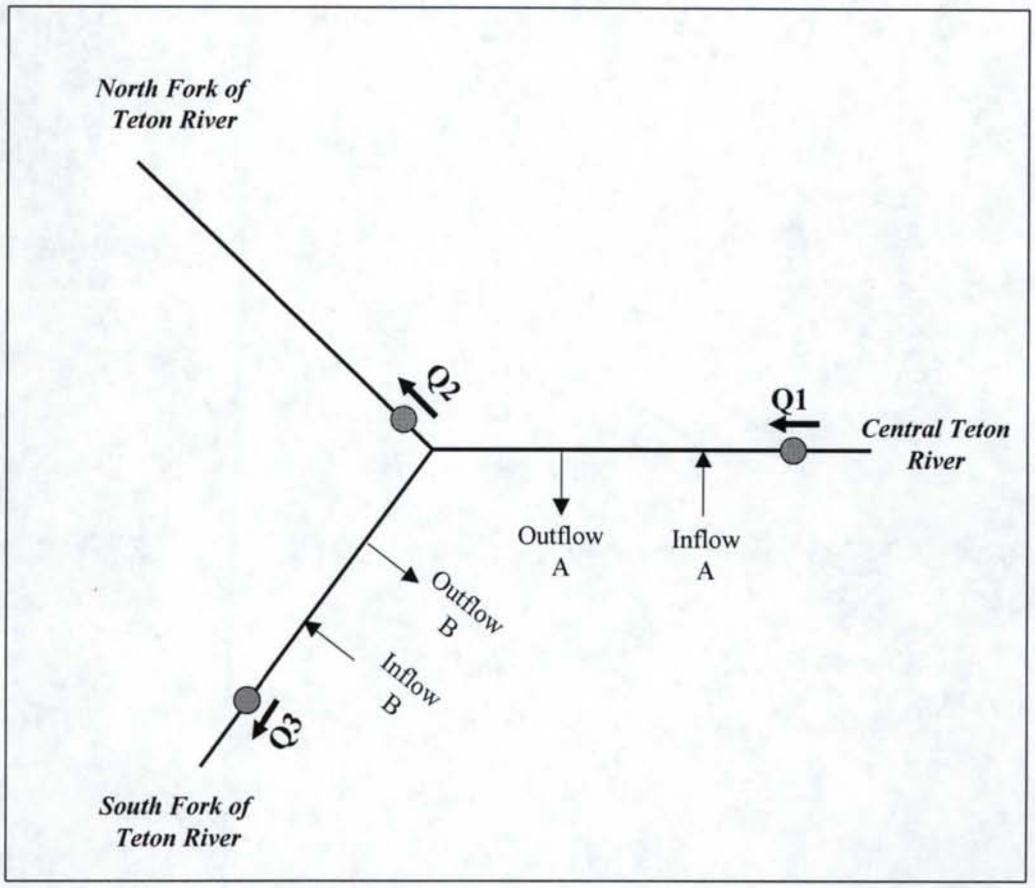

Figure 1.3. Application of the mass balance principle for the study of the interaction between the Teton River and the underlying aquifer

If
- Q1 is flow of the central Teton river at USGS gage 13055000, prior to any diversion
- Q2 is the flow of the North Fork of the Teton River, at USGS gage 1305519, prior to any diversion, and
- Q3 is the flow of the South Fork of the Teton River, at USGS gage 13055348, downstream from all the diversions taking place in this segment of the river,

and if there is no interaction between the Teton River and the underlying ground water body,

then the sum of Q2 and Q3 could be estimated by

$$[Q2+Q3]_{est} = Q1 - \text{outflow A} + \text{inflow A} - \text{outflow B} + \text{inflow B} \qquad \text{(Eq. 1.)}$$

with Outflow A = sum of the diversions taking place in the central Teton River
Outflow B = sum of the diversions taking place in the South Fork of the Teton River
Inflow A = sum of the return flows and exchange well discharges in the central Teton River
Inflow B = sum of the return flows and exchange well discharges in the South Fork of the Teton River

The estimated sum of Q2 and Q3 ($[Q2+Q3]_{est}$) can be compared to the sum of the measured values of Q2 + Q3 ($[Q2+Q3]_{mes}$). If $[Q2+Q3]_{est} > [Q2+Q3]_{mes}$, the central Teton River and its South Fork are losing water to the aquifer. If $[Q2+Q3]_{est} < [Q2+Q3]_{mes}$, the central Teton River and its South Fork are gaining water from the aquifer.

1.3.3. Results

Tables 1.1. and 1.2. show the results of the application of equation 1 to the water years 1992 and 1989. The discharge units used is the acre-foot/month (AF/month).

A comparison of $[Q2+Q3]_{mes}$ with $[Q2+Q3]_{est}$ suggests that, on average, the central Teton River downstream from USGS gage 13055000 and the South Fork of the Teton River upstream from USGS gage 13055348 are losing reaches.

Some surface water models (e.g., MODSIM and WEAP) define the intensity of seepage to an aquifer as a percentage of the flow entering a reach. In the present example, the corresponding mathematical expression is given by:

$$\text{Seepage rate (\%)} = \{ [Q2+Q3]_{est} - [Q2+Q3]_{mes} \} \; / \; Q1 \qquad \text{(eq 2)}$$

Equation 2 leads to an average seepage rate of 0.27 during 1992 and 0.17 during the 1989.

These results have been obtained under the assumptions that:

- the return flows constitute 7 % of the amount diverted, and
- Moody Creek waters are totally diverted by the Woodmansee-Johnson Canal Company users (no return flow into the Teton River).

Table 1.1 Water budget components for the 1992 water year.

Month	Q1 AF/ month	Change AF/ month	$[Q2+Q3]_{est}$ AF/ month	$[Q2+Q3]_{mes}$ AF/ month	$[Q2+Q3]_{est}$ - $[Q2+Q3]_{mes}$ AF/ month	Seepage (%)
Nov	25530	274	25256	18030	7226	0.28
Dec	20240	60	20180	16180	4000	0.20
Jan	17590	64	17526	13920	3606	0.20
Feb	20470	75	20395	14190	6205	0.30
Mar	28200	2016	26184	18280	7904	0.28
Apr	40750	8097	32653	22620	10033	0.25
May	69990	20863	49127	39910	9217	0.13
Jun	55480	11138	44342	33900	10442	0.19
Jul	49700	13851	35849	24820	11029	0.22
Aug	42600	13987	28613	18484	10129	0.24
Sep	29820	13641	16179	10213	5966	0.20

Table 1.2. Water budget components for the 1989 water year.

Month	Q1 AF/ month	Change AF/ month	$[Q2+Q3]_{est}$ AF/ month	$[Q2+Q3]_{mes}$ AF/ month	$[Q2+Q3]_{est}$ - $[Q2+Q3]_{mes}$ AF/ month	Seepage (%)
Nov	22144	760	21384	15880	5504	0.25
Dec	21013	611	20402	16430	3972	0.19
Jan	20704	475	20228	15240	4989	0.24
Feb	18766	302	18463	13470	4994	0.27
Mar	32589	136	32453	24410	8043	0.25
Apr	52533	685	51846	43770	8076	0.15
May	124867	19463	105404	90610	14794	0.12
Jun	135453	29883	105570	86820	18745	0.14
Jul	74205	31958	42246	37050	5196	0.07
Aug	53156	21296	31859	25970	5889	0.11
Sep	43887	17154	26732	21050	5682	0.13

Change = outflow A + outflow B - inflow A - inflow B

Seepage (%) = { Qe - (Q2 + Q3) } / Q1

Chapter 2. Review of Existing Models

2.1. Introduction

This chapter summarizes the main features and data needs of four models. The first one, IGSM (Integrated Groundwater and Surface Water Model) performs detailed simulation of a groundwater system and the corresponding surface water system. In contrast, MODSIM and WEAP, presented in section 2.2. and 2.3. focus on surface water systems; the interaction between the surface water system and the underlying groundwater is tackled only in a simplified fashion. The last model reviewed is the snowmelt and runoff model developed by Dr. Sung Kim.

2.2. The IGSM model

2.2.1. Background

IGSM is a comprehensive basin planning model which includes groundwater flow, surface water flow, groundwater quality and reservoir operations routines. IGSM was originally developed in 1976 at the University of California, LA. Since then it has undergone several revisions. This review is based on an evaluation of the IGSM user's manual written by Montgomery Watson (1993).

The groundwater portion of IGSM operates on the principle of conservation of mass and Darcy's law. Groundwater flows are simulated using a finite element approach. The stream flow simulation operates on the principle of conservation of mass and includes hydrologic budget analysis for rainfall percolation, runoff and evapotranspiration. Interaction between surface and groundwater flow is taken care of by a soil moisture and unsaturated flow accounting system. The time step used for the groundwater simulation is one month. Surface water simulation can be performed on a monthly or daily basis.
The main features of IGSM are described below:

a. Soil Moisture Accounting

Changes in soil moisture are modeled as a function of :

- previous moisture conditions,
- infiltration (note: infiltration corresponds to the difference between precipitation and direct runoff, direct runoff is computed using the SCS method),
- deep, and
- evapotranspiration.

b. Streamflow Simulation

Changes in streamflow from reach to reach are modeled as a function of:

- rainfall runoff (note: drainage areas must be provided by the user),
- water diversions (note: water diversions are computed by the model considering the water requirements of downstream senior water rights - similar to the Water Rights Appropriation Program of District 01),
- irrigation return flows (note: irrigation return flows are set to a specified percentage of the amount diverted), and
- streamflow gains or losses to the aquifer system (note: the streamflow losses can be computed as saturated or unsaturated flows).

c. Groundwater and Surface Water interactions

Groundwater and surface water interactions are represented at the intersections of the streams nodes with the ground water grid nodes. Three situations which are simulated differently can occur at these points. These situations are:

- flow out of the stream into the subsurface under saturated conditions (note: this situation occurs when the stream bed is comprised of materials similar to surrounding soils),
- flow out of the stream into the subsurface under unsaturated conditions (note: this situation occurs when the stream bed materials are finer than surrounding soils), or
- flow from the subsurface back into the stream.

Each of these flows is computed with Darcy's law in saturated (first and third situations) or unsaturated conditions (second situation).

d. Groundwater Simulation

The model can simulate any combination of multiple-layer confined, unconfined and leaky aquifers and can convert between these aquifer types as water levels fluctuate.

Boundary conditions can be incorporated as:

- prescribed flows (Neuman condition),
- specified head,

- mixed head (combinations of head and flows),
- general head, or
- small watershed inflow.

The other processes modeled are:

- lake interactions with the groundwater (note: the lake storage and groundwater interactions are computed as the result of various phenomena such as rain, evaporation, and inflows to the lake), and
- leakage from fractured bedrock underlying the aquifer.

e. Land and Water Use

- *Land Use and Crop Acreage*

The area of each element must be divided (%) among:

- agricultural area,
- urban area,
- natural area, and
- riparian vegetation area.

The model expects crop acreage data to be specified every year on a subregional basis

- *Distribution of Ground Water Pumpage*

The pumpage amounts and locations can be defined by element, subregion or by specific well locations. Besides the amounts, the type of water use (e.g., urban and agricultural) should also be defined. If well locations are specified, the vertical distribution of pumping to each aquifer is proportional to the well screen length. If the pumping is defined on an element or a regional basis, vertical distribution coefficients are to be provided by the user.

- *Surface Water Diversion*

Surface water or streamflow diversions are defined in terms of stream nodes and subregion. Conveyance losses are defined as a fraction of the diversion or by specified quantities. Conveyance losses must be defined as recoverable (deep percolation to the aquifer) or not recoverable (evaporation). The model sums the pumping and surface water diversions (minus conveyance losses) and divides the total into 2 parts: agricultural and urban supplies. These supplies are delivered to corresponding subregions and elements based on land use. The model computes surface return flows as a fraction (provided by the user) of the supply.

- *Urban Use*

The user must provide monthly urban water use, percentage of indoor use (assumed to return to the stream) and percentage of outdoor use (treated as agricultural use).

- *Agricultural Demand*

Irrigation water requirements are computed on a monthly basis as a function of minimum soil moisture requirements, soil moisture content at the beginning of the month, effective rainfall (rainfall - runoff and deep percolation), actual evapotranspiration and irrigation efficiency.

- *Imports and Exports of Water from the Studied Area*

Groundwater basins are subject to both imports from sources outside the modeled area and exports of water to other areas. The amount of water imported and exported should be specified by the user.

f. Reservoirs and Stream Flows Operations

IGSM can simulate reservoir operations and diversions based on a designated water rights system. These water rights can be attached to trans-basin diversions and/or to reservoirs from which water can be withdrawn to supply the water requirements not met by natural flows. The operation of diversions and storage are performed as follows.

1. Natural streamflows are allocated to diversion and storage water rights by priority.
2. Water allocated to storage for a given reservoir ownership is placed in the upstream reservoirs provided that space in the upstream reservoirs and streamflows for storage is available.
3. Trans-basin diversion, if specified for any diversion or storage water rights, is made to meet water shortages.
4. Reservoir releases are made to meet water shortages for direct diversion and run-of-the-river water rights. If releases from multiple reservoirs are necessary to meet the downstream water requirements, the amount of release from each reservoir is determined in such a way that water storage among the reservoirs is balanced in accordance with target storage levels defined by the user.

g. Water Quality Simulations

The model incorporates a water quality simulation component. The main features of the water quality simulation are:

- simulation of the advection and dispersion of water quality constituents in groundwater, and
- transformation of water quality constituents in the soil zone.

An example is presented in the Montgomery Watson IGSM Manual for nitrogen. The processes modeled for nitrogen are denitrification, plant uptake, mineralization, immobilization, adsorption and desorption. The water quality routines used for most constituents are based on the Agricultural Runoff Management model developed by the U.S. Environmental Protection Agency.

2.2.2. Data requirements.

The IGSW model requires prior knowledge of diverse data characterizing the modeled area. Some of these data pertain to the discretization of the modeled area into finite elements. The others describe time invariant (e.g., geography and stratigraphy) and time dependent properties and aspects of the area. The data necessary to run the IGSW model are summarized in the following paragraphs. The terminology used to describe them is similar to the one adopted in the Montgomery Watson IGSW user's manual. Most of the characteristics of the modeled area must be specified for each node of the finite element mesh. If these data are not available, the model incorporates some routines to estimate them. The user can specify the characteristics of the estimation procedures.

Element Configuration Data

The configuration for the finite element mesh is obtained by specifying the nodes that connect to make a finite element. An element can be 4-sided or 3-sided.

Groundwater Nodal Coordinates

The model requires the knowledge of the number of nodes in the finite element mesh of the model network, the node number, and the x and y coordinates of each node from a reference origin.

Stratigraphic Data

The stratigraphic information necessary to run the model are:

- the number of layers (aquifers) present in the modeled area (based on independent hydrogeologic investigations),

and for each node:

- the ground surface elevation,
- the thickness of the aquiclude overlying aquifer layer I (top layer),
- the thickness of the aquifer layer I, and
- the aquiclude and aquifer thickness' for each layer in successive order, if any.

Stream Geometry Data

The stream geometry data are all the time-invariant geographic and hydrogeologic information regarding the streams to be modeled. The streams are modeled as one dimensional line elements which are always co-linear with an edge of a two dimensional finite element as specified in the model. Stream elements are characterized by a set of 'stream nodes' which are different from, but assigned to 'ground water nodes'.

The stream geometry data are:

- the number of stream reaches modeled,

  and for each stream reach:

  - the reach sequence number, the upstream and downstream stream node numbers for that reach, and the upstream node number of the stream reach to which the reach drains (i.e., the outflow node for this reach),
  - the corresponding ground water nodes and the subregion to which the stream belongs, and
  - the number of points that specify the stream rating curves.

  and for each point that specify the stream rating curves:

    - the stream node number,
    - the elevation of the stream bottom, and
    - the hydraulic head, wetted perimeter and corresponding flow rate.

Lake Data

The lake data necessary to run the model are the lake location and surface area within each element.

Reservoir Operations Data

The reservoir operation data necessary to run the model are:

- the number and identification of the stream nodes with a specified minimum flow requirement,
- the minimum flow requirements at these stream nodes for each month of the year,
- the number of reservoirs in the system,

and for each reservoir:

- the stream node that represents the reservoir,
- the rainfall and evaporation stations that should be used to characterize the reservoir,
- the reservoir capacity, the reservoir dead storage, the maximum flood control storage for each month of the year, an elevation-surface-area storage curve,

and for all reservoirs:

- a list of target storage (used so that the water releases from each reservoir will maintain a water balance among the reservoirs in accordance with the target storage).

Reservoir operation data must also specify the diversion priorities (date of the water right) for each diversion, trans-basin diversions, reservoir ownership's and water release policy constraints.

Well Data

The well data necessary to run the model are:

- the number of wells in the model area, and
- the x-y coordinates of the well, the diameter of the well (inches), the well pumping capacity (gallons per minute), the depth to top and bottom of well perforations.

Optional information on well depth and state well number can also be entered in this file for reference.

Element Characteristics

Characteristics of each element for the groundwater component, including hydrologic and geographic information, consist of:

- the associated rainfall station number,
- the rainfall factor for each element (note: this factor is multiplied by the precipitation at the corresponding station to obtain the effective rainfall at the element),

- the stream node to which surface water runoff from the element drains,
- the subregion number to which the element belongs,
- the element group number to which the element belongs (note: the element group numbers are only used to generate water budget information by group), and
- a weighted soil factor for hydrologic soil group (based on the US Soil Conservation Service classification for runoff potentials).

Parameters

Parameters refer to all the hydrologic, geologic, and water use properties and conditions essential for the model calibration and verification procedures. The hydrogeologic parameters for groundwater flow (e.g., conductivity, specific storage) can be specified in one of two ways:

- assignment of values at every model node (for aquifer parameters) and every model element (for unsaturated zone parameters), or

- assignment of values at some nodes defined by a parametric grid (note: when this second option is used, the model estimates and assigns values to each node or element using an interpolation scheme, the parameters needed for the interpolation process are specified by the user).

Parameters needs concerning the aquifer include:

- hydraulic conductivity, specific storage, specific yield, effective porosity, and aquitard and aquifer vertical conductivities for each groundwater element.

Parameters needs concerning the unsaturated zone include:

- thickness of the unsaturated layer,
- soil moisture and hydrologic parameters (such as field capacity, soil infiltration parameter, SCS curve numbers) for each land use type by subregion,
- parameters characterizing the small stream watersheds which are outside the model boundaries, but close enough to contribute to the streamflow and baseflow of the groundwater basin (note: these parameters are the rainfall station number associated with the small watersheds, the field capacity, the root depth of natural vegetation, a percolation parameter (ft/day), a curve number, a threshold value above which groundwater storage contributes to surface runoff, a recession coefficient for surface outflow and a recession coefficient for subsurface outflow),
- streambed properties, including hydraulic conductivity and thickness of the streambed specified for each stream node (note: an optional data item for each stream node is the date (year and month) after which the channel is lined, and the stream-aquifer interaction is halted),
- lake bed characteristics (lake element, hydraulic conductivity of lake bed, thickness of lake bed, lake bottom elevation, initial lake surface elevation),

- bedrock leakage parameter (1/day),
- water use parameters for each region to account for the agricultural and urban return flow (note: these parameters are the fraction of pervious area for urban area, the fraction of total irrigation that becomes field runoff, the fraction of total urban water that becomes field runoff, and the fraction of urban water used indoors),
- specification of the destination of urban wastewater for each subregion (e.g., stream, groundwater recharge), and
- root zone depth for each agricultural crop, urban lawn, native and riparian vegetation.

Boundary Conditions

The boundary conditions must be specified for each model layer. Five types of boundary conditions can be specified at any node of the model grid:

- prescribed flux (same as specified flux),
- specified head (same as constant head),
- rating tables/mixed head,
- general head, or
- small watershed inflow.

Diversion Specifications Data

These data specify how to proportion surface water diversions and their components, such as losses and seepage, to different elements and/or subregions of the model. These data are:

- number of surface water diversions,

and for each diversion:

- the stream node from where the diversion takes place,
- the amount of recoverable loss,
- the percentage of the recoverable loss usable as recharge,
- the number and identification of the subregions to which diverted water is delivered, and
- the proportion of the diverted amount that is delivered in each subregion.

Initial Conditions

The initial conditions are:

- the groundwater head at the starting time point at each node for each layer, and
- the initial soil moisture for each land use type and subregion of the model.

Land Use Data

The land use data describe the land use distribution in each element of the model grid as a percentage of the element area. The land use data can be given for any number of years as available. The land use categories are agriculture, urban, native vegetation, and riparian vegetation.

Crop Acreage Data

The crop acreage data necessary to run the model are the annual crop acreage, by crop type and by model subregion, and the acreage of urban areas, native and riparian vegetation. Information should be provided for more than one year if available.

Precipitation Data

Precipitation data necessary to run the model are the monthly rainfall at each gaging station that is used in the model.

Evapotranspiration Data

The evapotranspiration (ET) data necessary to run the model are the monthly ET rates listed by crop/land use and subregion. These values are considered to be constant from year to year.

Groundwater Pumping Data

The pumping data necessary to run the model are the monthly values of groundwater pumping for each subregion of the model or for each well.

Surface Water Diversions Data

The surface water diversions data necessary to run the model are the number of surface water diversion sites, the maximum diversion capacities per diversion and the diversion amounts during the simulation period.

Agricultural Supply Data

The agricultural supply data necessary to run the model are the historical or estimated monthly and total demand for each subregion.

Urban Water Demand Data

The urban water demand data necessary to run the model are the total urban water demand by subregion for the entire period of simulation.

Stream Inflow Data

The stream inflow data necessary to run the model are a list of the stream nodes numbers where inflow to the modeled area occur, and the monthly stream inflows at each of these stream nodes.

Crop Demand Parameters

The crop demand parameters necessary to run the model are the minimum soil moisture requirements and the crop irrigation efficiency factors for each month and for each crop type in each subregion.

Measured Water Levels in Wells

Measured water levels for individual wells are used during calibration for comparison with model results.

Reservoir Evaporation Data

The reservoir evaporation data necessary to run the model are the monthly evaporation (inches) for each reservoir.

Pump Specification Data

The pump specification data specify the number of wells or number of elements over which a known regional pumpage can be distributed.

* * * * * * * *

The following sections describe the data necessary to run the water quality simulation routine. These data must be specified for each constituent of interest.

Constituent Specific Parameters

The constituent parameters necessary to run the model include:

- chemical decay rate for non-conservative constituents,
- soil chemical reaction parameters (in the case of nitrogen, these parameters quantify immobilization, ad/de sorption, leaching, denitrification and plant uptake), and
- aquifer diffusion (transverse and longitudinal) characteristics and retardation factors.

Constituent Boundary conditions

The constituent boundary conditions are specified as a set of constant concentrations or flux variant concentrations for each aquifer layer.

Constituent Initial Conditions

The initial concentrations are:

- the solute groundwater concentration at each node, and
- the solute, organic (if relevant), adsorbed (if relevant) concentrations in the soil zone at each node.

A single number can be used for each of these values which will set the initial concentrations constant throughout the model area. For soil zone initial conditions (solute concentrations, organic concentrations, and adsorbed concentrations) the initial condition values can also be set by sub-region.

Mass Input Control Data

The mass input control data necessary to run the model are:

- the mass flux entering each layer (by element),
- the mass input to soil (by sub-region and land use), and
- the monthly amount of constituent (e.g., fertilizer) applied to the soil (by region and land-use).

Flux Concentration Data

The flux concentration data necessary to run the model are the constituent concentrations in the water entering the model boundary area by the following pathways:

- injection wells,
- groundwater sinks,
- lakes,
- bedrock leakage,
- surface water diversions,
- groundwater inflows,
- small stream inflows, and
- large stream inflows.

2.3. The MODSIM Model

2.3.1. Background

MODSIM is a water budget model that simulates the behavior of a river system. In Modsim the physical river system is represented by a series of nodes and links that form a network whose characteristics are defined by the user. Nodes represent both storage and non-storage aspects of a river system such as reservoirs, demand/diversion structures, inflow locations, and stream gage locations. Links represent stream reaches, canals, tunnels, ground-water interchange and other methods of water conveyance.

MODSIM is also a water rights planning model. The types of water rights that can be simulated are:

- direct flow rights,
- instream flow rights,
- reservoir storage rights,
- reservoir system operations, and
- exchanges and operational priorities (e.g., augmentation, subordination).

To allocate water to each of these rights, MODSIM creates a 'mass balance' or 'accountancy' network, superimposed on the physical network, invisible to the user, composed of 'accountancy' links and nodes. Each water right corresponds to a node and is assigned a 'accountancy' link. Each 'accountancy' link is characterized by a 'unit cost'. The 'unit cost' of a link corresponds to the product of the 'link cost' and the flow in that link during the current time interval. The 'link cost' is calculated as a function of the priority of the water right. It is not related to monetary cost. The older the water right, the higher the priority and the lower the 'link cost'. While distributing the available water, MODSIM seeks to minimize the total 'unit cost' associated with supplying a right with water. In other words, water is first delivered to the oldest water rights. The algorithms of cost minimization were first developed for economic models, explaining the terminology adopted.

The biggest asset of MODSIM is the graphical user interface. This interface allows the user to draw a specific network; model elements (nodes and links) are created within the interface using the mouse to activate the appropriate icons and place the model elements where needed. Simultaneously, the user can access different spreadsheets indicating and organizing the data necessary to run the model. The interface also contains pull down menus to define run-time parameters (e.g., length of run, user/model generated lag factors,), save a network, load a network, and display graphical output of model variables.

2.3.2. Data requirements

The data necessary to run MODSIM can be classified according to the type of element they describe. The types of elements considered in MODSIM are the storage nodes (reservoirs), the non-storage nodes (confluence nodes, return flow nodes, etc.), the demand nodes and the links. The following paragraphs, based on the MODSIM information available on the Internet (http://palisades.pn.usbr.gov/manuals/modsim/modsim.html), describe the data requirements for each type of element.

Reservoir Node Data Requirements

The reservoir data necessary to run the model include the following:

- Data describing the reservoir itself:
    - node name (8 characters node identification),
    - node description (30 characters),
    - maximum volume (maximum physical capacity of the reservoir),
    - minimum volume (note: this might be the bottom of active reservoir capacity or a minimum pool level),
    - initial volume,
    - priorities numbers (note: these numbers are used to determine which reservoirs will physically release water to meet downstream storage right demand),
    - identification of the link used by the network to bypass nonstorable flow through the reservoir, and
    - target storage (maximum physical content of a reservoir for a given time period),
- Data describing the water import into the reservoir:
    - annual volume of water imported and distribution percentages to distribute the annual import into monthly volumes, and
    - time series import data (if the annual volume imported varies from year to year),
- Data describing interactions with the ground water:
    - pumping capacity (maximum volume of water available for pumping at the depletion node for the time scale of the model),
    - pumping costs (note: these costs compete directly with the costs associated with reservoirs),
    - specific yield,
    - transmissivity,
    - average distance between the depletion node and the river, and
    - seepage return,
- Data describing the efficiency of the reservoir power plant (if existing):
    - table presenting the power plant efficiency as a function of heads based on reservoir content and the range of flows the power plant can operate within,

    - power plant maximum power,
    - elevation of the power plant turbines,
    - maximum hours of power plant generation for each time period,

- Table presenting a list of corresponding reservoir surfaces, capacities, elevations and outlet hydraulic capacities (note: the reservoir surface is used to compute the evaporation, the elevation is used to compute the power generated by the power plant, the hydraulic capacity of the outlet is used to constrain reservoir releases).

Non-Storage Node Data Requirements

The non-storage node data necessary to run the model are:

- node name (8 characters node identification),
- node description (30 characters),
- constant annual import at the node and distribution percentages to distribute the annual import into monthly volumes, and
- inflow time series at the node (if the annual inflow is not constant).

Demand Node Data Requirements

The demand node data necessary to run the model are the following:

- Data identifying the demand node itself:

    - node name (8 characters node identification),
    - node description (30 characters node description),
    - annual volume imported at the node and distribution percentages to distribute the annual import into monthly volumes,
    - time series data (if the import varies from year to year),
    - identification of the downstream node to which water returns (flowthru nodes) and specification of the fraction (0 - 1) of the flow distributed to the corresponding flowthru node,
    - direct flow reservoir node (note: this node must be specified when water is diverted directly from the reservoir; in this case the demand is represented as an offstream demand node of the node downstream of the reservoir),
    - total annual demand for each hydrologic state and distribution percentages used to distribute the total annual demand on a monthly basis (note: a set of monthly percentages should be specified for each hydrologic stage), and
    - priority number (note: priority number used to compute the cost (link cost =10*priority-1000)).

- Data describing interaction with the ground water:
    - infiltration rate = fraction of the demand that returns to the system,
    - pump capacity (maximum volume of water available for pumping at the depletion node for the time scale of the model),
    - pump cost ,
    - monthly lag factor for the infiltrated water to reach the aquifer,
    - specific yield,
    - transmissivity, and
    - average distance between the depletion node and the river.

Link Data Requirements

MODSIM differentiates two basic types of links. The first type presents methods of physical conveyance (stream channels, pipelines, canals, tunnels, and stream reaches). The second refers to exchange/accounting links. Exchange/accounting links include natural flow, storage ownership, and reservoir accrual links. These links are used to transfer water from the river to demands sites or to storage reservoirs by competing for flow on the basis of the assigned link costs. Some link data needed in the model are specific to the type of link being defined.

For each link, the data necessary to run the model are:

- link name (8 characters link identification),
- link description (30 characters used to describe the link),
- the water rights date associated with the link,
- maximum capacity / storage ownership (note: these data define:
    - the upper bound on links representing physical conveyance of water
    - the capacity of the ownership in the case of a storage ownership link),
- minimum capacity / previous storage (note: these data define:
    - the lower bound on links representing physical conveyance of water.
    - the initial volume of the storage ownership accrued at the beginning of the study in the case of accounting links),
- cost associated with supplying water to the demand,
- channel loss coefficient (fraction of the supplied demand lost to groundwater),
- return node (node to which channel loss accumulates),
- seasonal capacity (cumulative annual volume of water that can pass through the link),
- parent link number (note: this field has three meanings:
    - for ownership links, the parent link number is the accrual link number that represents the storage priority that the ownership is assigned to,
    - for reservoir outflow links representing the normal dam outlet or account release, the parent link

number is the negative of the outflow link number,
  - for lastfill links, the parent link number is set numerically to the lastfill link number),
- accrual debit link number (link number that will accrue this link's flow as part of the seasonal accrual that is limited by a seasonal capacity),
- variable capacity (link upper bound for each month if the link capacity changes throughout the season),
- monthly lag factor for the infiltrated water to reach the aquifer,
- water rights rank,
- exchange limit flow (amount of flow added to an exchange limit link as the constraint for the link with the exchange limit),
- rent pool limits (rent pool limit values for each hydrologic state (dry - average wet). If positive, the amount is the maximum amount of an ownership link that will be contributed to the rent pool; if negative, it represents the amount desired from the rent pool.

2.4. The WEAP Model

2.4.1. Background

Like MODSIM, WEAP is a surface water simulation model. In WEAP the system is represented by a network of nodes (demand nodes, storage nodes, supply nodes) and links. The links transfer water from one node to another. WEAP also contains a graphical user interface that allows the user to create his network, define run-time parameters, save a network, load a network, etc. The equations governing WEAP rely on the mass balance principle. Contrary to MODSIM, WEAP includes some crude contaminant transport equations and allows the user to introduce cost data and perform economic analyses.

2.4.2. Data requirements

The data necessary to run the WEAP model are:

- Data Describing the Demand:
  - land use data (crop, acres, type of irrigation),
  - annual crop needs,
  - monthly variation coefficients (note: these coefficients are used to compute the monthly needs of crops based on their annual need),
  - water needed by each demand site, projected growth coefficient (growth rate or drivers and elasticities for population and sectors of activity), and
  - pollution generation data (by demand site, if necessary).
- Data Describing the Links between Supply and Demand:
  - distribution capacity of the link (canal),
  - wastewater routing (given as percentages of supplied flow),
  - losses (canal evaporation and seepage coefficients, given as percentages of supplied flow), and
  - reuse coefficients from one irrigation district to another (given as percentages of supplied flow).

- Data Describing the Wastewater Treatment Plants:

    - plant capacity (volume/day),
    - average and maximum inflows,
    - decay in route factor for the wastewater (%),
    - plant treatment efficiencies (%), and
    - returns of treated effluent (for every destination, given as a percentage of inflow).

    (Data relative to the cost of the wastewater treatment plant, such as total cost, real escalation rate, amortization rate, amortization period and annual cost, can be introduced.)

- Data Describing the Supply:

    1. *For local reservoirs (not linked to a river)*:

        - monthly inflow (ignoring the return from treatment plant and demand sites), and
        - yearly and monthly hydrologic fluctuations.

    2. *For groundwater sources:*

        - monthly pumping capacity,
        - maximum accessible storage,
        - initial accessible storage,
        - natural annual recharge , and
        - lag time.

    3. *For each river (reach) and main tributaries*:

        - monthly headwater flows (inflow to the first node for an average year or historical inflow),
        - monthly flow at some confluence nodes,
        - monthly outflows at the diversion node (expressed as percentages of the flows passing that node),
        - monthly minimum downstream requirements (minimum values acceptable below a node on the river),
        - monthly instream requirements (note: for each reach of the river one can specify the minimum flows for recreation, water quality, etc.), and
        - monthly values of surface evaporation and groundwater seepage (given as a percentage of river flow).

4. *For river reservoirs:*

- initial storage, total storage, monthly evaporation, a volume - surface area - elevation function,
- monthly values (in cubic meters) for the tops of the conservation pool, the buffer pool, and the inactive pool (note: it is assumed that the reservoir can not be emptied below the top of the inactive pool),
- buffer zone coefficient (note: this coefficient, expressed as a percentage, is used to regulate release when water is taken from the buffer zone), and
- reservoir requirements for fish and wildlife.

If the reservoir is used to generate power:

  - minimum and maximum turbine flow,
  - tailwater elevation,
  - monthly plant factor (monthly use time of the turbines expressed as a percentage), and
  - monthly efficiency (in percent).

2.5. The Snowmelt and Runoff Model developed by Dr. KIM

The model reviewed in this section was developed by Dr. Sung Kim, student at University of Idaho (1987). For his doctoral research, Dr. Kim developed an hydrologic model that he applied to the Snake River basin above Heise. This model is capable of predicting the spring snowmelt and estimating the daily natural flow in the Snake River caused by the snowmelt. The following sections detail these two features of the model.

2.5.1. Background

a. Snowmelt model

Snowmelt models can be classified in long-term and short-term models according to the time period they relate to. Long-term models can predict the seasonal volume that will be discharged in a river. Long-term models are often empirical and based on multiple regression. In contrast, short-term models, like Kim's model, can predict daily runoff. As a general rule, the shorter the time period of runoff prediction, the more complex the model is. Most short-term models are conceptual and often rely on a solution of energy balance equations which require numerous parameters. Kim's approach is different and original in its simplicity. It can be described and summarized as follows.

- Snowmelt

The amount of snow that melts daily (Melt) is computed as a function of the degree-day:

$$\text{Melt} = a \times \rho_s/\rho_w \times T$$

Melt	Amount of snow melted (in inches)
T	Degree-day
ρ_s	snow density
ρ_w	water density
a	empirical degree-day factor (value found by calibration)

The degree-day is defined by the difference, if positive, between the daily temperature and a 'base temperature' whose value is close to 32° F. If this difference is negative, then the degree day is 0.

The daily amount of liquid water (snow melt + rain) present in the snowpack will contribute to runoff after the 'prime requirements' for runoff are met. The 'prime requirements' concern the snow cold content and its liquid water deficiency.

- Cold content

When the snowpack temperature is lower than 32^0 F, no liquid water is present in the snowpack. Any liquid added to a snowpack that is below freezing will freeze. Therefore, it is necessary to raise the snowpack temperature to 32^0 F in order to have snowmelt. This heat deficiency is called the cold content. The cold content can be expressed in terms of its equivalent depth of liquid water at 32^0 F produced by rain or melt which, upon refreezing within the pack releases its latent heat of fusion raising the snowpack's temperature to 32^0 F.

The initial cold content (cold content characterizing the snowpack at the beginning of the simulation) is defined as a function of the temperature and the cloud cover during the three days preceding the initial date. It is updated daily as a function of snowmelt, rain and the new cold content resulting from the night frost.

- Liquid water deficiency

When the temperature of the snowpack equals or exceeds 32^0 F at any point, liquid water may exist within the pack. However, this water will not become runoff and leave the snowpack while the liquid water content of the pack is smaller than its liquid water holding capacity. The liquid water deficiency is defined as the amount of water necessary to raise the liquid water content of the pack to its holding capacity. The initial liquid deficiency is computed by an empirical function of the actual and maximum snowpack density.

- Runoff

The amount of water 'freed' by the snowpack is defined by the difference between the 'snowmelt + rain and the amount of water necessary to eliminate the cold content and the liquid water deficiency of the snowpack. The amount of water contributing to runoff is defined by the product of the 'freed' water and a runoff coefficient. The runoff coefficient is: 1) set to 0.13 for water released from a temporary snowpack or a snow free, or 2) obtained by calibration for water released from an old snowpack or from a rainfall runoff event.

b. **Runoff model**

Kim's model estimates the daily natural discharge of the river as a function of the runoff caused by snowmelt in the basin. Kim's model relies on the assumption that the hydrograph shows an instantaneous increase to the maximum flow (instantaneous rising limb) followed by 3 successive recession stages characterized by different lengths and recession coefficients. The existence of these three stages in the recession can be explained by the fact that the water participating in the discharge is coming from different types of storage. The first recession is characterized by a very steep change in discharge and corresponds to the recession of the surface runoff. It is followed by a period of more moderate changes in discharge corresponding to the interflow recession. Finally, the third period, whose length is theoretically infinite, is characterized by a very slow change in discharge corresponding to baseflow. When a runoff event occurs while the recession from a previous event is in progress, the results of the two recessions are superimposed.

Kim also assumes that the basin recession response to runoff varies with basin conditions. As a result, the three recession coefficients are not only dependent on the basin characteristics but also on flows in the river. Because Kim's model distinguishes three phases in the recession and the three recession coefficients depend on the flow, it is classified as a non-linear multiple recession coefficient model. The recession coefficients are estimated from previous recession hydrographs.

In contrast with the IGSM, MODSIM and WEAP models, the documentation evaluated for the Kim's Snowmelt and Runoff Model (Ph. D. thesis) contains some examples and results obtained with the model. Based on these examples, one can observe the following.

- The model contains numerous relationships to characterize the changes of weather with altitude (e.g., precipitation *vs* altitude, temperature *vs* altitude, Snow water equivalent *vs* altitude). A lot of work must be performed on the original weather data in order to establish these relationships. It is likely that they will have to be modified if the model is applied to another basin.

- Prior to running the model, Kim carefully studied hydrographs of the studied area to determine the relationships that identify the recession coefficients. These relationships probably vary from basin to basin. The way it is written, the model does not allow these relationships to be modified. The model would have to be partially rewritten if applied to different basins.

- The results presented by Kim only concern the periods for which the model has been calibrated. No results are shown concerning the model validation. In other words, the model has not been used to simulate periods it has not been calibrated with.

2.5.2. Data requirements

The data necessary to run the model can be divided into: 1) permanent basin characteristics, 2) characteristics of the entire simulated period, and 3) daily weather data during the simulated period. More specifically, these data are:

- Permanent basin characteristics:
  - area of the basin (square miles),
  - lowest and highest elevations, and elevations corresponding to every 5% increment of the total area,
  - elevation of the highest snow observation station,
  - base temperature for the computation of the degree-day,
  - prime snow density,
  - length of the first recession period,
  - length of the second recession period,
  - elevation of the index station (station whose temperature measurements are used in the model),
  - coefficient characterizing the degree-day factor used to compute the daily amount of snow melt,
  - runoff coefficient for water released from an old snowpack or a rainfall event, and
  - runoff coefficient for water released from the temporary snowpack in a snow free area.

- Data characterizing the entire simulated period:
  - slope and ordinate at the origin of the regression line between Snow Water Equivalent and elevation,
  - Initial [1] average snow density,
  - average maximum temperature in March at the index station,
  - average minimum temperature in March at the index station,
  - last runoff prior to the beginning of the simulation (on March 31), and
  - last runoff contribution from the third recession period prior to the beginning of the simulation.

- Daily weather data:
  - precipitation at the index station (this precipitation is assumed to be characteristic of the entire area),
  - minimum elevation of snow,
  - new snow density,
  - maximum temperature at index station, and
  - minimum temperature at index station.

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[1] In his work, Kim always chose April 1 as the initial date, assuming that snowmelt could start from this date on.

Chapter 3. Availability of hydrologic data

3.1. Introduction

The existence and availability of measured data are crucial elements affecting the success of a modeling effort. Data are necessary during every step of the modeling process.

- First of all, data are used as model inputs. The characteristics of the available data (e.g., variable measured and density of measurement) limit and orient the choice of possible models. The effect of a change in land use on the peak flow of a stream, for instance, cannot be identified if the flows are only measured monthly.

- Data are also indispensable to model calibration. When a model is applied to some conditions (e.g., type of soil, type of climate) it was never exposed to, it is likely that the value of some of its parameters will have to be modified so that the model gives reliable results. The process is called the model calibration. In calibration, the values of the parameters are adjusted so that the model outputs agree with the data they are supposed to reproduce.

- Finally, observed values are essential to checking the reliability of a calibrated model. During this operation, called validation, the model output are simply compared with the equivalent observed data, data that have not been use for the model calibration.

The U.S. Geological Survey (USGS) is the major source of hydrologic information concerning the Teton basin. Other sources include the Idaho Division of Environmental Quality, the Idaho Department of Water Resources - District 01, Targhee National Forest and Idaho Department of Fish and Game. In 1991 the USGS initiated an intensive sampling program aimed at assessing the Water Quality in America. This program, named 'National Water Quality Assessment Program' is currently being applied to 20 watersheds nationwide; one of them is the upper Snake River basin. The data collected during this program and other related data (e.g., climate, land use, ecoregion) are or will be compiled in spatially organized data bases accessible to the public.

Tables 3.1. to 3.6. identify and describe the major hydrologic data sets characterizing the lower Teton River basin. The availability of other type of data that would be useful in an integrated model is not within the scope of this project.

3.2. Data characterizing water quantity

Table 3.1. Water quantity data sets - Surface water

Measurements	Density of measurements		Source	Media
	In space	In time		
Discharge of sewage treatment plant	1 location (Rexburg)	1/month	Idaho Division of Environmental Quality	paper
Discharge of natural streams	22 streams in Teton basin	1/ 3 to 5 years	Idaho Division of Environmental Quality - BURP project[1]	Paper
	Teton Canyon, Canyon and Milk Creeks	1 year - 13 samples	Idaho Department of Environmental Quality	Paper
	≈6 streams in the Teton River basin	at least one time	Targhee National Forest	Paper
	4 gaging stations on the lower Teton River	1/ day	U.S. Geological Survey	Paper / Internet[2]
Canal diversion	every canal in the lower Teton River basin	1/ day	Idaho Department of Water Resources - District 01	Paper / Internet[3]
Location of the Dried bed stream	Every Teton River tributary	One time (fall 1994)	Idaho Department of Fish and Game	Paper

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[1] The Beneficial Use Reconnaissance Project (BURP Project) started in 1994. The main goal of the project is to characterize the strean integrity and water quality by integrating biological and chemical monitoring with physical habitat assessment. So far, all the stream have not been sampled yet. The objective is to sample each stream every 3 to 5 years.

[2] Current and historical discharge information are available at the following address: 'http://waterdata.usgs.gov/nwis-w/id/'

[3] Current and historical discharge information are available at the following address: 'www.idwr.state.id.us/idwr/info/dist01/main.htm"

Table 3.2. Water quantity data sets - Groundwater

Measurement	Density of measurements		Source	Media
	in space	in time		
Water table levels	≈ 10 observation wells in the lower Teton River basin	≈ 6/ year	U.S. Geological Survey	Paper/ Internet[1]
Groundwater pumpage permit	for every groundwater well (planned)	one time	Idaho Department of Water Resources	Paper
Water table contour maps - wells specific capacity	≈ 50 wells in the lower Teton River basin	One time	U.S. Bureau of Reclamation	Paper

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[1] Current and historical water level information are available at the following address: 'http://idaho.usgs.gov/public/gwdata.html'

3.3. Data characterizing water quality

Table 3.3. Water quality data sets - Chemical characterization

Source of water	Measurement	Density of measurements		Source	Media
		In space	In time		
Surface water outflow from sewage treatment plant	(a)	1 location (Rexburg)	1/ month	Idaho Division of Environmental Quality	paper
natural stream	(b)	Teton Canyon, Canyon and Milk Creeks	1 year - 13 samples	Idaho Division of Environmental Quality	paper
	(c)	Gage #15055000 (Teton River in St. Anthony)	April to September 5 samples/ month	U.S. Geological Survey	paper/ Internet
	(d)	Gage #15055000 (Teton River in St. Anthony)	April to September 1 sample/ month	U.S. Geological Survey	paper/ Internet
Groundwater	(e)	7 wells in Lower Teton basin	1/ year	U.S. Geological Survey	paper/ Internet
	(f)	Community of Rexburg, Sugar City, Newdale, Teton	1/ 3 year	Idaho Division of Environmental quality	paper

a) The parameters measured are: pH and residual chlorine.

(b) The parameters measured are: nitrate, nitrite, ammonia, total nitrogen, total phosphorus, dissolved ortho-phosphate and total ortho-phosphate.

(c) The analyses are: pH, specific conductance, oxygen dissolved, total hardness, calcium dissolved, magnesium dissolved, sodium dissolved, copper dissolved, potassium dissolved, alkalinity, carbonate, bicarbonate, chloride, sulfate dissolved, fluoride, chlorine, silica dissolved, solids dissolved, nitrite, nitrate, ammonia, ammonia + organic nitrogen (dissolved and total), total phosphorus, dissolved phosphorus, dissolved ortho-phosphorus, dissolved iron, dissolved manganese, organic carbon and suspended sediment.

(d) The analyses are: arsenic dissolved, barium dissolved, cadmium dissolved, chromium dissolved, copper dissolved, iron dissolved, lead dissolved, mercury dissolved, selenium dissolved, silver dissolved and zinc dissolved.

(e) The analyses are: pH, specific conductance, total hardness, calcium dissolved, magnesium dissolved, copper dissolved, potassium dissolved, alkalinity, carbonate, sulfate, fluoride, chlorine, silica dissolved, nitrate, ammonia, orthophosphate, arsenic, cadmium and chromium.

(f) The quality of the public drinking water supply of the communities pre-listed is assessed by the following parameters: inorganic chemicals concentrations, synthetic chemicals (every 3 to 9 years), volatile organic chemicals and radiological analyses for gross alpha particles (every 4 years).

Table 3.4. Water quality data sets - . Physical characterization

Source of water	Measurement	Density of measurements		Source	Media
		in space	in time		
Surface water					
outflow from sewage treatment plan	temperature	1 location (Rexburg)	1/ month	Idaho Division of Environmental Quality	paper
natural stream	suspended solids	Teton Canyon, Canyon and Milk Creeks	1 year - 13 samples	Idaho Division of Environmental Quality	paper
	temperature, presence of large debris	≃ 20 streams in Teton River basin	1/ 3 to 5 years	Idaho Division of Environmental Quality - Burp project	paper
	temperature, suspended sediment, percentage of sediments finer than 0.062 mm	Gage #15055000 (Teton River near St. Anthony)	April to September 1 to 5 samples/ month	U.S. Geological Survey	paper/ Internet
Groundwater	temperature	5 wells in lower Teton River basin	1/ year	U.S. Geological Survey	paper/ Internet

Table 3.5. Water quality data sets - Biological characterization

Source of water	Measurements	Density of measurements		Source	Media
		in space	in time		
Surface water					
outflow from sewage treatment plant	BOD5, coliform fecal	1 location (Rexburg)	1/ month	Idaho Division of Environmental Quality	paper
natural stream	coliform fecal, streptococcus fecal	Teton Canyon, Canyon and Milk Creeks	1 year - 13 samples	Idaho Division of Environmental Quality	paper
		Gage #15055000 (Teton River near St. Anthony	April to September 1/ month	U.S. Geological Survey	paper/ Internet
Groundwater	coliform fecal	5 wells in lower Teton River basin	1/ year		

3.4. Data characterizing fish populations, substrate and aquatic habitat

Table 3.6. Data sets characterizing fish populations, substrate and aquatic habitat

Parameters	Density of measurements		Source	Media
	in space	in time		
(a)	22 streams in Teton River basin	1/ 3 to 5 years	Idaho Division of Environmental Quality - Burp project	paper
(b)	≈ 6 streams in Teton River basin	at least once	Targhee National Forest	paper
(c)	Teton River	four times (summer 87, 91, 94 and 95)	Idaho Department of Fish and Game	paper/ Dbase 3+
	Every tributary but Bitch Creek 1 location/creek	One or two times	Idaho Department of Fish and Game	paper/ Dbase 3+
	Moody creek from old dam to mouth	One time	Idaho Department of Fish and Game	paper/ Dbase 3+
(d)	Gage #15055000 (Teton River near St. Anthony)	1/ year since 1993	U.S. Geological Survey (with Division of Environmental Quality)	paper*/ later on Internet
	Gage # (Teton River in Driggs)	One time (summer 1992)	U.S. Geological Survey (with Division of Environmental Quality)	paper*/ later on Internet
	Bitch Creek	One time (summer 1993)	U.S. Geological Survey (with Division of Environmental Quality)	paper*/ later on Internet

* The report concerning the first five years of the "National Water Quality Assessment Program" (1991-96) is currently being prepared.

(a) The analyses concern: width and depth of the reach, shade, bank stability, substrate characteristics (pebble counts for estimation of the percentages of fines, gravel, cobble and boulder), habitat type (classified in riffle, run, glide and pools), pool complexity (physical characterization of a pool), stream channel classification (longitude, latitude, elevation, slope, stream order, valley type, aspect, lithology, Rosgen stream type), habitat assessment, photopoints (pictures from the sample sites), GPS (accurate location of the sample site), macroinvertebatres counts and identifications and fish count.
Note: the length of the sample site is defined by 20 X the wetted width or a minimum or 100 m in length.

(b) The analyses concern: fish species composition and count, characterization of the stream profile and quality of substrate (use of a quality index).

(c) The analyses concern: fish species composition, fish density, relative abundance of species, fish length, reach length, stream width, depth and width, bank condition assessment (slope, grazing evaluation), riparian vegetation survey (plant species, relative abundance), substrate composition (visual estimation of pebble size and abundance).

(d) The analyses concern: macroinvertebrates (species composition and count), fish community (species composition and count), algae (species composition chlorophyll and biomass), habitat visual assessment, fish and insect tissue sampling for traces of contaminants, physical substrate characterization.