A WATER MANAGEMENT MODEL FOR THE GREEN RIVER

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ABSTRACT

WIRSOS and HYDROSS software packages were compared to determine the most practical water management tool to accurately model the Green River Basin in Wyoming. Providing for better handling of water rights diversions and actual permit data, a WIRSOS model was constructed and calibrated with USGS streamgaged values throughout the river basin. The final model yields results within eight percent of measured runoff on an annual basis.

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CHAPTER I

INTRODUCTION

PURPOSE OF MODELING

Before construction of any part of a model, the actual rationale behind it must be fully realized. A model simply constitutes an additional tool for water resource planners and managers (Loucks, 1992). No matter how well the model parallels the actual conditions, it should not replace the judgment of an experienced person. Utilization of such a tool requires a knowledgeable user to detect and disqualify any output that seems unreasonable. A suitable model augments the talents of the individual through its use. "Blind use" can result in decisions based on incorrect data or false assumptions. In the right hands, a model is a powerful instrument, but inappropriate use can result in a disaster.

MODEL APPLICATIONS

Many tasks call upon the use of modeling for a more accurate and informed view of a system. The possibilities for model usage vary as widely as the functions of the water itself. Besides engineers, model operators include such groups as farmers, fish and wildlife managers, economists, and city planners. Although each occupation has specific problems to answer, the general concerns become relatively similar and facilitate grouping into general categories. The main issues discussed in this section include the use of modeling for economic evaluations, determination of engineered systems, and water resource management (NRC, 1982).

Economics encompasses the widest variety of reasons for model implementation. A main consideration for a model involves the necessity to predict a system's performance upon agricultural resources during times of drought or flood conditions. The output can help determine which water diversion permits are to be met. This information transforms into approximations of harvest amounts which directly relates to any economic impact of the area. Models also determine amounts of possible flooding, thereby providing for damage estimation.

Another large economic area entails recreational uses (Peterson, 1986). If model use helps regulate the release of stored water or predicts future water levels, park managers have the ability to alter their operational practices. This ability allows them to maximize the potential of aquatic recreational activities. Further recreational use appears in the employment of water models by wildlife officials. With the determination of possible stream levels, alternative flow regimes can be reviewed influencing the stream's administration. Testing of new instream flow requirements can also be accomplished to establish their actual result. These reasons along with other economic components provide several examples of the significance of modeling for financial investigations.

Engineers also employ models. One of the main purposes of modeling in engineering involves the computation of maximum and minimum values in a body of water such as peak flood flow rates. These limits usually influence the adequacy of engineers' designs. Examples of their use include finding their effects on dams, lined channels, transmission structures, structures within floodplains, and environmental engineering concerns. With appropriate water level values known, the engineer's plan becomes more reliable and safe.

The most widely seen implementation of models, however, involves water resource managers. A system model allows them to continually manipulate the data to ascertain the changes that would occur on the actual system. This enables the testing of new permits before their issue. Also, managers hold the capability of testing new storage facilities or varying storage release amounts throughout the year to ensure that their operations do not affect any other part of the operating system. Another instance where administrators find models useful occurs due to lawsuits. During the proceedings, an accounting of the water through all types of seasons becomes a necessity to show significant need for the amounts of water being specified.

A major concern of water managers pertains to the estimation of resource adequacy. In this area of use, models can determine what permits will not be filled in a given year and the effects on reservoirs. With the proper model, water users receive advance notice of shortages or excessive flooding. Reservoirs can then be adjusted to assist in the shortfall or to take up the surplus water to assist downstream permits. Even though this purpose constitutes a majority of water management model use, all the tasks stated in this section show the essential need of this significant tool.

TYPES OF MODELS

Two primary types of models exist--causal and empirical (NRC, 1982). A causal model describes a system based on the dynamics of the processes; whereas, an empirical model is completely based on observations and relations. In a causal model, analytical methods characterize all the processes in the system with only basic measured values used as inputs (e.g. precipitation and soil properties). To describe a system, empirical models employ observed relationships and observed data like runoff values and evaporation rates. Since all the models that are presented in this paper are empirical, the discussion will be constrained to only this type.

Empirical models have advantages and drawbacks. The main benefit of this type of model relates to the necessary knowledge of the actual mechanisms. Since this type of model is strictly based on observational relationships, the need to understand the actual phenomenon does not exist (NRC, 1982). This results in a short-circuiting of the actual complex causal chains. Without having to fully understand the actual workings, a model's time to completion becomes condensed compared to that of casual models. Unfortunately, since empirical models fit only the set of data upon which it was established, they become simple interpolation formulas and have no justification beyond that collection of measurements (NRC, 1982). Although this is a significant handicap, empirical models do give significant understanding of the systems operation and, in the range of the data, applicable results.

GOAL

The primary goal of this thesis involves the construction of a water management model for the Green River drainage basin in western Wyoming. Since there have been no previous modeling attempts to describe this system in detail, a base model must first be constructed. To ensure that reality is retained, calibration of this model must reduce the differences between what the model predicts and actual measured values below a set guideline. In conjunction with the testing, a model must be fabricated which permits further enhancements as additional output requirements are needed. This basic analysis must also be able to crudely represent the system to permit the examination of large system expansions. In the final analysis of the model, its utility lies in the fact that it should give a basic understanding of how this river system behaves.

Throughout this study, an IBM compatible personal computer forms the basis of the hardware selection. Along with this system, several software packages assisted in the production of the final model. The two main modeling packages are discussed in the next chapter. To help with the formatting of the data, databases were constructed with DBASE III.

Although the origin of this thesis came from a need of the Wyoming Water Development Office and the Wyoming State Engineers' Office for a water accounting model on the Green River. There was no biased place on any software. Each piece of software underwent the same examination and testing to determine its ability to handle the system in question. The best software available that met the needs of the water accounting system for the Green River was used.

CHAPTER II

MODEL COMPARISON

INTRODUCTION

Before any basin data can be developed for input, a model must first be chosen in order to decide what data needs to be obtained. The two models which were selected for investigation are WIRSOS and HYDROSS. WIRSOS (Wyoming Integrated River System Operation Study) was developed by Leonard Rice Consulting Engineers for the State Engineer and Attorney General's Office of Wyoming. HYDROSS (Hydrologic River Operation Study System) was authored by the United States Bureau of Reclamation, Upper Missouri Region. Version 4.0 constituted the generation of HYDROSS that was tested. Both models consist of fortran code and can be run on IBM-PC compatible computers as well as workstations or mainframes. These two models were chosen because they are the two primary models that are suited to handle Wyoming water allocation systems and acceptable to the State Engineer's Office, Bureau of Reclamation and Wyoming Water Development Office.

Each model, however, is slanted toward the main concerns of the organization that operates it. HYDROSS is specifically designed to best evaluate the effects of reservoirs in the model; whereas, WIRSOS is better adapted to handle water rights issues in Wyoming and contains more river management capabilities. These two differences in use manifest themselves throughout every input file required and in the output that they generate.

DIVERSIONS

One of the most important inputs into any water management model is the diversions. These determine how the water is dispersed, what quantities of water are available for storage, and what permits will not be filled. Being central to a management model, the discrepancies in the diversion input files for the two models are noticeable and significant. The differences range from how the priority date is treated to the number of reservoirs on which a single diversion can call.

The priority date encompasses the heart of the priority permit system on which Wyoming water law is based. This date allows every user on the system to be prioritized and allotted water in correct priority. The day that the permit is legally filed results in its priority date in Wyoming; therefore, the date consists of a day, a month, and year. WIRSOS recognizes this format and allows for an eight digit number (mmddyyyy) to be used. HYDROSS, on the other hand, only tolerates a four digit number for the priority date. The four digits can either represent the year of the permit or an independent numbering system assigned to each permit. This distinction forces the modeler to decide between the accuracy of the full date or the efficiency of less input. Both models do allow for multiple diversions with different priority dates at each station. HYDROSS additionally permits a priority date for stored water to be included.

The modeler must also be concerned about the overall efficiency of the diversion. Efficiency in this case means the percentage of the water diverted that is actually consumed. WIRSOS lumps all losses into one value and applies this to the water which will become the return flow. Since WIRSOS only allows one efficiency value, this one percentage is then taken as the efficiency for every month. Although this method is not completely accurate, even this one value is not readily available through the literature or basic flow data on most systems; therefore, it must be evaluated from data near the investigation site, a more intense field study or educated estimate. Efficiencies in HYDROSS require more intricate data for both canal and site losses. HYDROSS also permits the variation of efficiency values throughout the year. This compels the programmer to either devote a large amount of time to the development of the specific conditions at the points of diversion or to estimate significantly more efficiency values than are generally known. This results in a model that is farther from actual conditions in many cases. With both models dictating the use of data which is generally unavailable, the less approximations or estimates that have to be made will assist in the overall simplicity of the model; therefore, in real basin modeling, a lumped value for a diversion efficiency can be considered to be a more acceptable estimation than a more detailed accounting of losses when there is no data to support the larger input requirements.

With the priority and efficiency problems addressed, the focus can be turned to the manner by which the actual amounts of water per diversion are encoded. WIRSOS takes the managerial position and only allows a monthly table. In addition to this method, HYDROSS allows for other types of input. The most useful is a per unit table. The units can either be an irrigation requirement or a per capita value. In conjunction with the number of acres or population, a value can be determined and a demand placed on the system. HYDROSS also employs a maximum annual amount per diversion, a bypass diversion value, and off-channel storage. With both models able to apply basic monthly table inputs, the added ability of HYDROSS is quite attractive; however, there are few times that a model will deviate from the permitted amounts of water.

The last major difference in the diversion file is reservoirs. WIRSOS is limited to call upon only one reservoir for additional water for a diversion. HYDROSS offers the capability to link multiple reservoirs to a single diversion. This feature requires additional input space to be used thus increasing the size of the input files.

RUNOFF

As with all river studies, one of the key components of the data input is the actual amount of water that actually occurs in the system. These values can be found from USGS gauging stations, previous studies, hydrologic analysis or local agencies. These data, however, can be some of the most difficult to obtain and apply. Also, HYDROSS requires pristine channel flow at every station in the model. This involves taking any data that are available and converting them back in time before there were any demands on the system. Not only is this impractical in the amount of time that must be spent altering all the data, the size of the file that results limits HYDROSS to only the running of smaller models due to computer memory allocated.

WIRSOS averts this problem by only requiring data from the basin headwater sources and developing the flow at stations downstream through its algorithms. Along with this feature, WIRSOS allows mid-basin runoff stations to be specified to alter the flow that the model would predict. Runoff data are difficult to collect; yet, having to alter them and determine values at every point in an analysis, as is the case with HYDROSS, is overly complex and an extremely time consuming process.

RESERVOIRS

Reservoirs represent a major contributor to the amount of data in any model. Their complexity and data requirements are enormous compared to that of a diversion, but since they are major structures in a system, the data are usually available. Since most major reservoirs in Wyoming are generally owned and operated by the Bureau of Reclamation, HYDROSS's main concern is reservoirs. Although WIRSOS does account for reservoirs, it treats them in a simple manner, not as the complex systems that they are. The differences in the two models include use of the stored water, the input parameters, the water rights, and pooling.

From a managerial point, the quantity of water that a reservoir has been permitted is as important as that of a diversion. For this reason, priority dates are also given to reservoir rights. A dam operator has limited control over the timing of reservoir filling. If he has a late priority, a downstream user with earlier rights has precedence over the water and therefore a reservoir must pass water in dry years instead of filling. Realizing this fact, WIRSOS assigns each reservoir right its proper priority date and maintains its priority throughout the running of the model. HYDROSS does not. A priority of 9999 is assigned to each reservoir right in the system. This represents the lowest priority of all and can result in a reservoir never filling in dry years regardless of its actual priority date. To circumvent this method, the Bureau of Reclamation suggests treating each reservoir as an "offstream reservoir" supplied by a diversion with the reservoir's actual priority date. Although this becomes an effective tool, it further removes the model from the reality of how the system works. Seeing the necessity of proper modelling of priority dates, HYDROSS contains a definite flaw which is not present in WIRSOS.

The characteristics that are input into the two models for each reservoir are essentially identical. Both include minimum and maximum content, maximum spillway capacity, and area-capacity relationships. The variances in the two models' handling of reservoir parameters exist in HYDROSS's input of absolute maximum content, target content, and the use of tables for relationships. Absolute maximum combines with downstream channel capacities to prevent flooding by filling a reservoir past its maximum content. With table input, the HYDROSS reservoir parameters are those actually measured. WIRSOS, however, uses equations to relate area and capacity. There are five choices of equations in WIRSOS and, depending on the available area and capacity relationship for each reservoir, they can be expressed as:

1. AREA = CF1 + CF2*(VOL**CF3)

2. AREA = CF1 + CF2*(ALOG10(VOL))

3. AREA = CF1*(CF2**(CF3*VOL))

4. AREA = 10**((CF2*ALOG10(VOL)+CF1)

5. AREA = CF1 + (CF2*ALOG(VOL))

where:
CF1,CF2,CF3 = Input Constants
AREA = Reservoir Surface Area (Acres)
VOL = Reservoir Storage Volume (Acre-Feet)

One reservoir can actually utilize all five equations by dividing it into as many as five parts. Even though the equations give a more continuous set of points, a regression must be achieved for each relationship resulting in some degree of error. This error, however, can become negligible with a good regression fitting of the equation(s), but it still adds error to a model who's attempt is to accurately portray the actual river system.

Now that the differences in the reservoir characteristics have been discussed, how the water is actually used can be examined. Although both handle diversion and bypass releases in approximately the same manner, a couple of areas do exist that separate the two programs--power operations and pooling. HYDROSS allows for more detailed power input. Compared to WIRSOS's only inputs of a release goal month and volume, HYDROSS does much more, almost to the extent that it appears to be overdone. It requires a monthly power release table, a priority date for power use, a power plant efficiency, and an optional tailwater elevation table. The efficiency and tailwater information are combined with the upstream head to determine the amount of power being produced each month allowing for more accurate and complete reservoir reports. To further enhance these reports, HYDROSS can also perform pooling of the reservoirs. Pooling involves attempting to keep all reservoirs at their specified target volume by releases from upstream reservoirs which are in excess of their target volumes. This feature can be turned on or off for each reservoir depending on a difference in ownership or to simply prohibit a reservoir from being altered by the routine. With this trait along with the power manipulation and the input of physical properties, HYDROSS exhibits a distinct advantage over WIRSOS in the domain of reservoirs even with its severe priority problem stated earlier.

OUTPUT

As in the case of the input categories, the output deviates between the two models. The main differences in the output also relate to the main purpose of each program. HYDROSS gives detailed information with respect to what is happening to the reservoirs. Unfortunately, it ignores individual diversions and only reports what is happening at each modeling station. Conversely, WIRSOS has specific information on which permits are called out with specific amounts and percents as well as rudimentary reservoir data.

This allows for exact effects to be seen for all users of the system instead of just reservoir owners.

CONCLUSION

With the added input characteristics and simplifications that the Bureau of Reclamation installed in HYDROSS, its intent is obvious. The manipulation of reservoir data constitutes its primary responsibility. This ability is fitting when reservoirs are the only area of interest in the model. For an entire river basin, though, every influence must be analyzed and their results revealed. WIRSOS does demonstrate the aptitude to accomplish this goal, but it comes up lacking in its operation of reservoirs. An ideal model would combine the water rights aspects of WIRSOS and the reservoir attributes of HYDROSS. Since neither model illustrated an overall ability to deal with all inputs in an exemplary manner, some sacrifices have to be made. WIRSOS's definite superiority in diversion input and output in combination with the ability to run reservoirs in a more coarse form offered the best alternative. With this in mind, all the data for the Green River basin was constructed in a WIRSOS format and WIRSOS was used as the model for the basin.

CHAPTER III

GREEN RIVER MODEL INPUT

INTRODUCTION

With WIRSOS as the chosen model, data was then organized into the specified formats. The major problem became what information was available to include as a part of the input files. This branched into which diversions, which streams, which reservoirs, how to delay the return flows, and how to determine runoff. Although some of these questions appear to be simple, the answers directly affect the accuracy of the model; therefore, they all become extremely significant. Fortunately, the State Engineer's Office responded to some of the more vital questions in this regard since they and the Wyoming Water Development Office are the eventual users of the model. With their input and some previous studies in the area, most of the difficulties associated with data development were averted with assumptions based on the goal to provide a general model of the entire basin. This chapter describes the initial data input to the model. During the calibration phase, changes to these data did occur to increase the reliability of the model.

MODEL FORMAT

A determination of which tributary streams to the main stream segments to be included as a part of the model was the first step in the definition of the model format. Although the Green River (Figure 3.1) and its major tributaries are obviously included, judgment is required initially on which smaller streams and stream segments are required in order for the model to produce a satisfactory water accounting.

Each water right diversion was first placed on a set of maps (1:100,000 scale) to see which streams or stream segments could be eliminated due to their lack of water right diversions and/or runoff volume being insignificant to the water balance of the basin as a whole. After eliminating these streams, the locations of gauging stations were charted on the maps. This allowed for the determination of streams with few water rights diversions on them and no headwater runoff data availability to be grouped and a decision made on whether or not to include these streams or stream segments in the model. Those with small drainage areas and small water right diversion amounts were initially deleted. It was assumed that the water right diversion amounts and the amount of runoff from these streams or stream segments canceled each others' effect on the system. Those that were included were typically the streams that had the larger drainage areas and

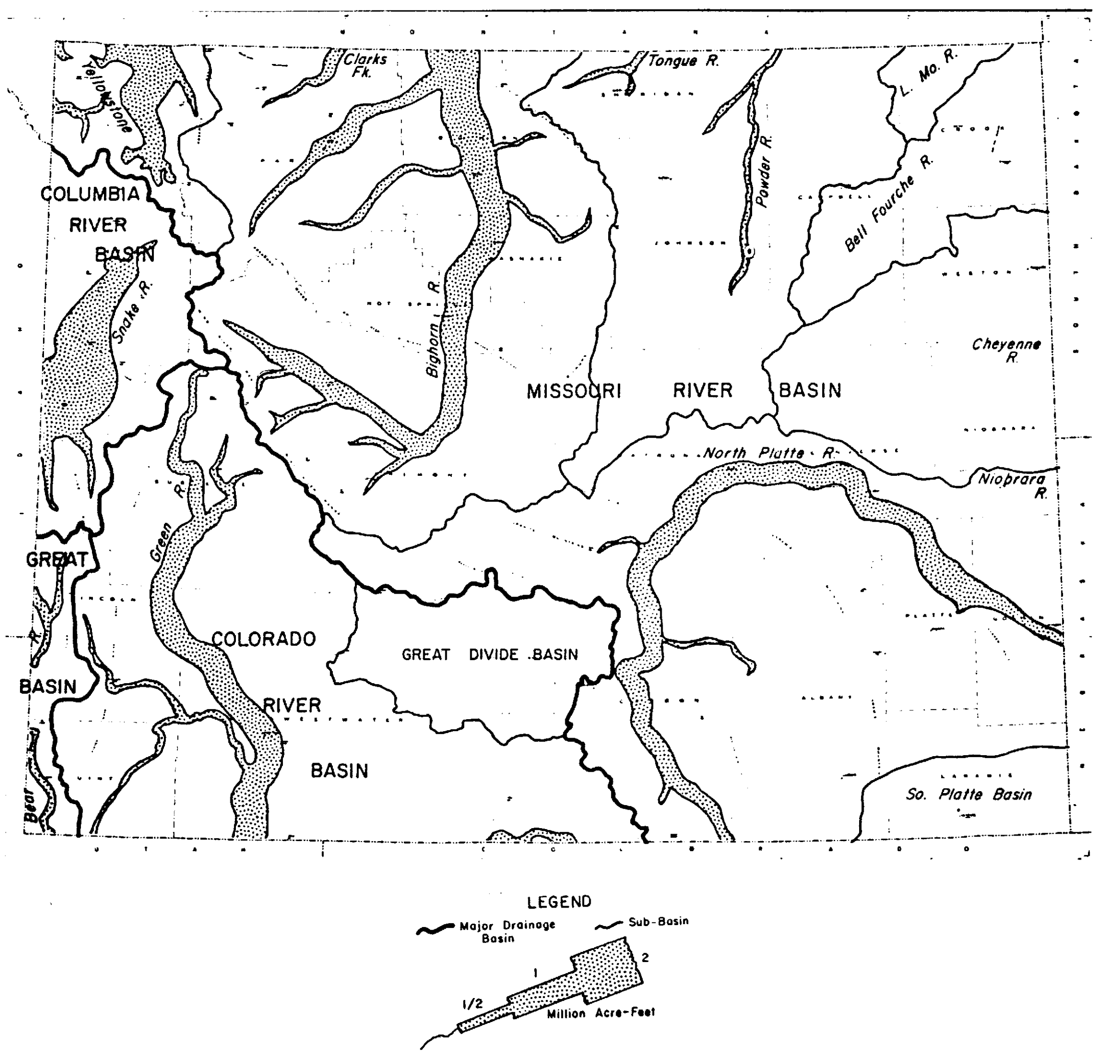

Figure 3.1. Wyoming Map Indicating Green River Basin Boundaries. The speckled areas represent average annual streamflow in million acre-feet.

few or even no diversions. A list of all the streams eliminated from the model appear in Table 3.1. If a larger stream was eliminated, all its tributaries were obviously expunged as well.

Another simplification to the stream system resulted in Middle Piney and South Piney Creeks being combined. Primarily, this was done due to their extreme proximity within the same land sections, throughout most of their reaches, and the fact that water is diverted from one to the other.

Table 3.1 - Streams Not Included in Green River WIRSOS Model. Asterisks (*) denotes streams with diversions.

Salt Wells*	Black Butte	Roaring Fork
East Muddy*	Alkali*	Spring
Wagon*	Tosi	Klondike
Lime	Eagle	Whiskey
Rock	Wagonfeur*	Badger
Big Twin*	Little Twin*	Mud*
Spring*	North Beaver*	Forty Rod*
Muddy*	Muddy*	Dry Piney*
Birch*	Muddy*	Sheep*
Shute	Little Beaver	Sweetwater
Killpecker on Bitter Creek	Little Pacific	Dry Sandy

With the stream pattern developed, stations could be located. The first ones utilized were the headwater stations (Figure 3.2). These stations were located at all the headwaters of the streams and rivers being modeled. The

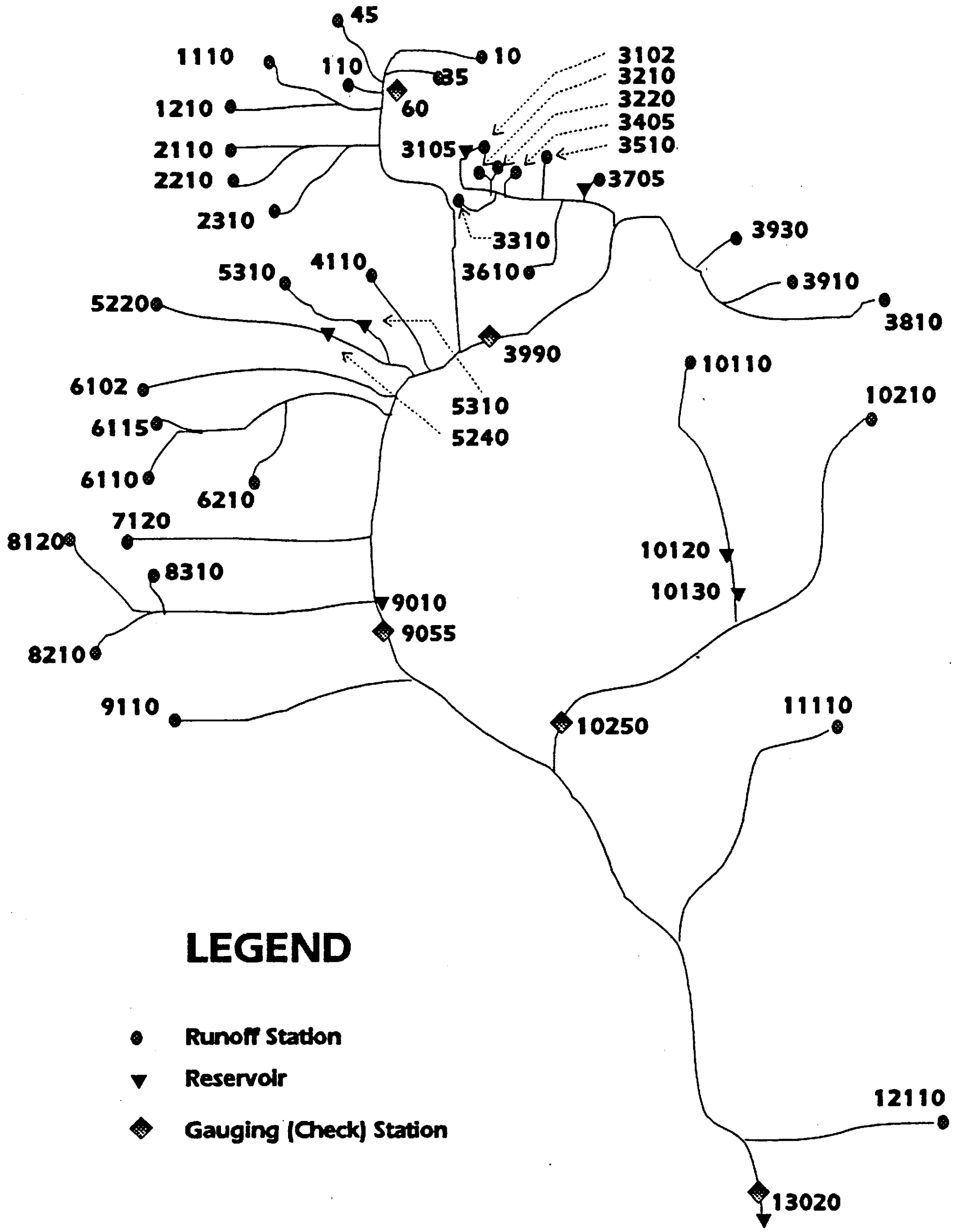

Figure 3.2. Significant Green River WIRSOS Modelling Stations. The numbers represent station numbers assigned to all the main stations in the model.

numbers shown on Figure 3.2 represent the station numbers assigned to all of the main stations used in the model. Although some station numbers were conveniently located next to or at gauging stations, all headwater stations must eventually have runoff assigned to them before the model can be run. The manner in which runoff was assigned to the headwater stations will be discussed further in the runoff section.

The stations below headwater stations were generally at the confluence of one or more streams or at the confluence with one of the major streams draining the Green River basin. Wherever a modeled river, stream, creek, or even wash merged into another body, a station had to exist so that the system could reliably be described in the model. The final stations to be utilized were the stations located to include the diversions. Once again studying a map of the plotted diversion locations, stations were placed for grouping of diversions that were not yet near one of the other types of stations. This allowed for the relating of each diversion to a specific station. With the stations now located and the stream exclusions resolved, the actual details of the model could be decided upon and organized into working formats.

DIVERSIONS

As one of the only two required inputs, the choices made concerning each diversion are keys to the reliability of the model. The most fundamental problem of which diversions to model demanded the attention of the State Engineer's Office. With their guidance, only the diversions having adjudicated status were used in this version of the model. The decision also included the exclusion of the permits for oil and gas production, highway construction, stock water, supplemental supply, and pollution control. This reduced the number of permits on the system from over 2400 to just over 1200. With the type of diversions now defined, the actual information for each one was inserted bringing up several points of concern.

The primary consideration dealt with the efficiency and return flow of each diversion. For this information, a study of the upper New Fork River region was consulted (Wetstein, 1989). This investigation analyzed the diversions' withdrawals from the river and the amounts of water that returned in the form of overland flows and return flows. To encompass varying climatic conditions, a study on return flows on the New Fork River was conducted from 1985 to 1988. These four years contained one dry year. The data from this year were used to approximate a diversion efficiency and to calibrate the delay table for return flows for irrigation permits. For all other permits (municipal and industrial), one hundred percent of the return flow reentered the system the next month based upon short retention times during these uses. All return flows are modeled to reappear at the next downstream station regardless of the type or location. This simplification should make no noticeable difference in the river flow since most return flow occurs in months of reduced irrigation use. These approximations comprised the bulk of the estimations for diversions, and with data backing up most of the numbers, their accuracy was assured to be within reason of the actual values. However, several adjustments did result during the calibration phase.

The last debate over the diversions was on how to distribute their permitted values throughout the year. The industrial and municipal permits were the simplest of all. It was speculated that their withdrawals would remain essentially constant throughout the year. So, their permitted value was allotted year round. The irrigation permits, however, presented problems. Since the water use is seasonal, a distribution had to be evaluated that would give a close approximation of the actual use. For this information, distributions used with the Wind River WIRSOS model were attained and used. The actual distribution that was applied to this model is displayed in Table 3.2. This was the initial distribution used for calibration; however, this does not represent the final distribution used in the model. With all the permits now distributed, the diversion file was completed and other obstacles such as runoff could be addressed.

RUNOFF

Along with the diversion file, the runoff file is

Table 3.2 - Monthly Green River Basin Irrigation Diversion Percentages

Month	Percent of Permit
January	0
February	0
March	0
April	5
May	45
June	100
July	100
August	80
September	40
October	5
November	0
December	0

required and of major importance. The first step in the construction of this file involved looking at the headwater stations and determining which runoff stations could be used. After the available data from these stations were recovered, a judgment was made on what years to include in the study. Only ten years (1961-1970) of data were chosen since they were common among most of the fifteen runoff stations which were available. The runoff stations that had the appropriate data and were included in the model are presented in Table 3.3. The other headwater stations were then ratioed to one of three runoff stations to determine their monthly flows throughout

Table 3.3 - Green River Model Runoff Data Stations.

USGS Station Number	WIRSOS Model Station	Station Location
091895.00	1210	Horse Creek, Sherman Ranger Station
091930.00	3102	New Fork River below New Fork Lake
091965.00	3405	Fremont Creek above Fremont Lake
091985.00	3510	Pole Creek below Half Moon Lake
091995.00	3610	Fall Creek near Pinedale, WY
092030.00	3810	East Fork River near Big Sandy, WY
092040.00	3930	Silver Creek near Big Sandy, WY
092055.00	5220	North Piney Creek near Mason, WY
092125.00	10110	Big Sandy River at Leckie Ranch
092140.00	10210	Little Sandy Creek near Elkhorn, WY

the ten years. The scaling was accomplished by reducing the associated runoff data to a unit value based on one square mile; then, these monthly values were multiplied by the approximated drainage area for each unknown headwater station. Since the streams were only compared with those of similar topography, configuration and elevation, the assumption was made that similar areas will have similar runoffs. This theory also demands that runoff is linearly dependent only on the drainage area for areas of similar elevation (Lowham, 1976). For this reason, the basin was divided into three regions; the north-eastern mountains, the southern slopes, and the north-western slopes. The runoff stations used for each region were respectively: 091965.00, 092055.00, and 091895.00.

The names of these stations are also located in Table 3.3. Tables 3.4 through 3.6 list which headwater stations were included in each region.

Table 3.4 - Headwater Stations Figured from Station 092055.00 (58.00 mi^2) for the Green River Basin Southern Slopes Region.

Model Station	Headwater Station for	Drainage Area (mi^2)
2110	Cottonwood Creek	50.0
2210	Killpecker Creek	16.0
2310	South Cottonwood Creek	45.0
4110	Meadow Canyon Creek	13.0
5310	Above McNinch Res.	18.0
6102	Middle Piney Creek	34.3
6110	South Piney Creek	46.0
6115	Fish Creek	23.0
6210	Beaver Creek	25.5
7120	LaBarge Creek	122.0
8120	Fontenelle Creek	96.0
8210	Roney Creek	11.0
8310	Dutch George Creek	16.0
9110	Slate Creek	34.0
11110	Alkali Creek (factored)	282.0
12110	Bitter Creek (factored)	758.0

One problem did exist with this technique, however. For Bitter Creek and Alkali Creek, the only available data were annual peak flood values. No suitable runoff station existed in the area that would allow for a comparison. Since the type of drainage area differed greatly from that of the other regions, these stations could not be directly compared to any of the other stations in the system. This problem was circumvented by first taking the ratio of annual peak flood values and using this as an added factor in the method described for the other headwater stations. Although this method seems overly simplified, the data for these stations is only being used to account for the large drainage areas that they control. If this method results in erroneous data, the calibration portion of the project will correct it by either adjusting the factor in some manner or eliminating the stations altogether. An adjustment was required through the calibration process.

Table 3.5 - Headwater Stations Figured from Station 091965.00 (75.8 mi^2) for the Green River Basin North-Eastern Mountains Region.

Model Station	Headwater Station for	Drainage Area (mi^2)
10	Green River Lakes	116.0
3210	Willow Creek	41.8
3220	Lake Creek	44.0
3310	Duck Creek	27.0
3705	Boulder Creek	115.0
3910	Cottonwood Creek	30.0

Table 3.6 - Headwater Stations Figured from Station 091895.00 (43.0 mi^2) for the Green River Basin North-Western Slopes Region.

Model Station	Headwater Station for	Drainage Area (mi^2)
110	South Beaver Creek	30.0
1110	South Horse Creek	32.0

RESERVOIRS

A basic question to be answered was which reservoirs to include. Once again, the State Engineer's Office was consulted. It was decided that in this stage of the model only major reservoirs had to be included. This translated into a minimum of one thousand acre-feet storage for a reservoir. With this standard and the additional criterion that they must be permitted and adjudicated, only seven reservoirs qualified for the model. One reservoir, Fremont Lake, met these specified standards but was not included since there was no correct area-capacity relationship and no available data to create one. Table 3.7 lists the seven reservoirs along with some of their physical properties that were employed with the model.

Along with the properties shown in Table 3.7, WIRSOS demanded other characteristics of the reservoirs. The most essential and involved is the area-capacity relationships. These are equations, in chapter 2, that relate the volume in storage to a surface area so an evaporation amount can be calculated. Although any permit for a reservoir must contain the relationship between these two factors, they are commonly in a table or graphic format. This forced a regression to be completed on each reservoir to fit the data to a model curve. As with any curve fitting, some error was introduced. To further embellish this error, all the reservoirs had to be fit

Table 3.7 - Reservoirs in Green River WIRSOS Model.

Reservoir	WIRSOS Model Station	Minimum Storage (acre-ft)	Maximum Storage (acre-ft)
Fontenelle Reservoir	9010	81031.	345397.
Boulder Lake	3705	0.	37800.
New Fork Lake	3105	4000.	25700.
Sixty-Seven Reservoir	5240	0.	7090.
McNinch Reservoir	5310	0.	1620.
Big Sandy Reservoir	10120	1400.	54400.
Eden Reservoir	10130	0.	20209.

to a linear relationship since any form of the logarithmic relation would cause an error in WIRSOS resulting from the fitted curve giving negative values for the reservoir area during times of extremely low volume. The coefficients that were attained for the linear fits are presented in Table 3.8. Along with these numbers, the R-squared value indicates the accuracy of each fit.

A slight dilemma also existed in finding proper values for the monthly evaporation rates. Since none of the

Table 3.8 - Green River Basin Reservoirs' Regression Coefficients.

Reservoir	CF1	CF2	CF3	R-SQUARED
Fontenelle Reservoir	845.	0.023	1.0	.949
Boulder Lake	1511.	0.007	1.0	.994
New Fork Lake	1290.	0.006	1.0	.997
Sixty-Seven Reservoir	128.	0.041	1.0	.918
McNinch Reservoir	74.1	0.028	1.0	.969
Big Sandy Reservoir	131.	0.058	1.0	.972
Eden Reservoir	405.	0.047	1.0	.887

reservoirs contained stations with evaporation data, another station within the basin had to be found. The information needed was found to exist at station number 483170 in Farson, Wyoming. Although this location was not next to any of the reservoirs, it was decided that these values would accurately represent the evaporation at all the reservoirs in the model. Since only one year of evaporation rates are permitted in WIRSOS, average evaporation rates were calculated from the ten year study period. In addition to the averaging, the Farson station only contained data for the months of May, June, July, August, and September. To augment these data, a study on evaporation rates in Wyoming was used to extrapolate the remaining months (Lewis, 1978). For these values, a correlation was made between the evaporation in June and that of the missing months. This completed the data and allowed for a representative year of evaporation to be installed into the model (Table 3.9).

Table 3.9 - Monthly Evaporation Rates and Non-project Release Percentages in Green River Basin (Lewis, 1978).

Month	Evaporation Rate (ft/mo./ft^2)	Non-project releases (% of active storage)
January	0.14	3.0
February	0.13	4.0
March	0.20	6.0
April	0.41	0.0
May	0.64	0.0
June	0.72	0.0
July	0.87	0.0
August	0.73	13.0
September	0.50	12.0
October	0.39	10.0
November	0.20	2.0
December	0.13	5.0

The last consideration with the reservoir file was the non-project releases. Since no diversions were allowed to call upon any reservoir, this is the only way that a reservoir would release water from storage. To accommodate this occurrence, data regarding the amount of storage in Fontenelle Reservoir were reviewed over the ten year study period. A year was chosen in which Fontenelle completely filled and operated properly. The release volumes were then computed from this year's data by the difference in storage amounts from month to month. Since WIRSOS wants the values in percent of active storage that is released, the dispensed amounts were then normalized by the total amount of active storage in Fontenelle reservoir. As with the evaporation rates, these values were also considered to be suitable for the rest of the reservoirs and assigned to them as well.

INSTREAM FLOW

Using the same acceptance criteria as the diversions, the instream flow permits were examined. Only two permits were adjudicated and fell within the basin. These two permits were placed in the proper file utilizing the monthly adjudicated values.

DISCUSSION

Given these assumptions, a model was constructed that provides a representation of the entire river system. The model should not be used for a detailed analysis of any individual portion of the basin. However, it does provide a starting point from which further data can be added to make the model better predict what is actually occurring at different points in the system. In addition, this model renders the means to examine the effects of any large modifications on the existing features of the Green River basin.

CHAPTER IV

CALIBRATION

INTRODUCTION

Calibration of any model begins with defining the acceptable error limits. These values typically depend upon the final intent of the project and the need for accuracy. Since these quantities directly affect the eventual users of the model, a consultation visit with the client must transpire to ensure the end product will meet the expectations of everyone involved. For the Green River model, the State Engineer's Office suggested that the error coincide with that of stream gauging. This results in an accuracy of five percent for a good measurement to eight percent for a poor measurement. The final decision called for all yearly values to be within eight percent of the gauged rate and as many years as possible to fall within the five percent boundary. Although the eight percent may sound excessive, the initial goal must be recalled. The model simply forms a base model on which to build and a method for evaluation of large changes in the basin. With the acceptable limits defined, the actual process of calibration will be reviewed.

Being a large basin, the Green River required zoning into general areas to facilitate the process. Two of the most obvious regions involved large streams that fed into the Green River, the New Fork River system and the Big Sandy River system. Before either of these enter the Green River, a check of the flow occurs to insure that the runoffs in these specific parts represent the actual conditions. The Green River headwaters area was also used as one of these calibration stations. For this purpose, a control point evaluates the initial flow of the river before any notable diversions occur.

Along with these areas, the gauging station below Fontenelle Reservoir became a major verification point. This permits the entire basin to be effectively halved as well as helping with the evaluation of Fontenelle Reservoir. The final location of a calibration station demanded placement at the inlet to Flaming Gorge Reservoir. This allows the evaluation of the model over the entire river system.

The necessary changes that follow to the initial input requires their description as it pertains to their downstream calibration station. The following sections describe these changes in such a manner along with a few general changes. Final calibration percentages are presented in Appendix A.

GENERAL CHANGES

The only change, on the entire system, involved the multiplication of the June and July diversion amounts by an additional 30 percent. This action attempts to simulate the "2 cfs" policy of the state which gives permits prior to 1945 an additional one cfs for every seventy acres of irrigated land. Only the agricultural permits fell into this category. The process was further assisted by reducing high flows for the whole system throughout the period of runoff data. The original concept for this procedure came through a suggestion by the State Engineers' Office; therefore, this assumption relies upon the experience of the state modelers. After the model was calibrated, however, various other values were simulated in an attempt to lower the error. This resulted in larger errors than with the initial increase.

GREEN RIVER AT WARREN BRIDGE (091885.00)

The Warren Bridge gauging station encompasses the headwater region of the Green River. In the model, the flows at station 60 represent the amounts that would pass the gauge. The actual USGS location number for the bridge is 091885.00. The initial inputs resulted in the runoff appearing to be approximately half the real values. For this reason, some of the creeks initially not considered were installed into the modelling effort in their appropriate places. The first ones to be inserted contained the drainage area south of the Green

River Lakes area. For simplicity, all the streams in this small basin became lumped into one station, model number 35. This position drains approximately 67 square miles of forested catchment through Jim and Gypsum Creeks. The determination of runoff at this station involved the same area comparison technique suggested in Chapter II. With its proximity and similar topography, model station 3405 (USGS 091965.00) enhanced the comparison runoff.

Other changes involved the addition of several small streams in the northwestern part of the Green River basin. The creeks added into the model include Tosi, Wagon, Rock, Klondike, and Lime Creeks. The combined drainage area totaled nearly 98 square miles. Since few diversions occurred in any part of this area, all the creeks resulted in another lumped station to interject the cumulative runoff. The area comparison technique was again used in this situation since none of the creeks had runoff data associated with them. Station 5220 (USGS 092055.00) served as the base runoff.

NEW FORK RIVER NEAR BIG PINEY, WYOMING (092050.00)

The New Fork River gauge contains one of the most sensitive branches of the entire Green River system. The New Fork River contains four major reservoirs or lakes. The landscape varies from high mountain to low prairie terrain. A significant amount of diversion exists; and, extreme amounts of stream branching become almost entangled messes. All of this culminates in the necessity for an accurate portrayal in the model for the rest of the basin to properly balance. For this reason, a modeling station located at 3990 (USGS 092050.00) helps to balance the New Fork River before it enters the Green River.

The New Fork River provides large runoff which allows for an opportunity for significant errors to occur; however, the model only needed a few alterations from the initial values to comply with the error limits. The major adjustment in calibration was the reapportionment of several streams. This involved converting the associated streams that served to define their original runoff. The set of streams that required this adjustment included Duck, Cottonwood, Willow, and Boulder Creeks. The conversion removed the streams' reliance on Fremont Creek (USGS 091965.00) and replaced it with the East Fork River (USGS 092030.00) gauge. This transformation resulted from a more in-depth survey of the actual area that the streams drained. Being at lower elevations and gentler grades, the East Fork River drainage better represents them. Along with this change, the drainage area of Cottonwood Creek increased to 35 square miles by moving the headwater station down the creek.

The other area demanding alterations concerned the modeled reservoirs, New Fork Lake and Boulder Reservoir. Upon initial input, the release schedules revolved around Fontenelle Reservoir's releases. After consulting with people familiar with the operation in question, new schedules were developed (Table 4.1). The largest substitution pertained to the non-project releases. Minor changes in the overall values assisted in the calibration of this portion of the model.

GREEN RIVER BELOW FONTENELLE RESERVOIR (092119.00)

Of all the difficulties encountered, the Green River Below Fontenelle Reservoir gauge (USGS 092119.00) represented the largest single calibration problem. Located right below Fontenelle Reservoir at modeling node 9055, this gauge station did not have recorded flows until after the completion of the reservoir in 1964. This caused the first three years of the model to be undefined at this point. The event that resulted in the most turmoil, however, was the filling of the reservoir. Since WIRSOS does not allow for reservoirs to begin operation in the middle of a run, the runoff data demanded division into two parts. The first portion contained the seven years before the dam actually started filling, 1961-1967. The second part was composed of the years 1968 through 1970. This action resulted in errors in the New Fork River system since return flows occur over yearly boundaries and are lost at the end of the actual completion of the program over the defined years. To alleviate this problem, the starting reservoir values in the second part were increased by approximately twenty-five percent of their final values in the earlier portion. To further force the second part to calibrate, the release schedule of Fontenelle Reservoir needed revision. The current values appear in Table 4.1.

BIG SANDY RIVER (CREEK) BELOW EDEN, WYOMING (092160.00)

Of all the branches that required calibration, the Big Sandy system possessed the most hidden problems. The Big Sandy River Below Eden, Wyoming gauge (USGS 092160.00) fell just upstream of the confluence with the Green River allowing the river to be isolated. Unfortunately, the largest problem resulted from the operations of the Green River above the Big Sandy River. Since Big Sandy Reservoir is operated by the

Table 4.1 - Final Release Schedules of Fontenelle Reservoir, Boulder Reservoir, and New Fork Lake in Green River WIRSOS Model. All values are in percent of storage.

Month	New Fork Lake and Boulder Reservoir	Fontenelle Reservoir
January	0	10
February	0	10
March	0	10
April	0	0
May	0	0
June	30	0
July	40	0
August	10	30
September	0	30
October	0	25
November	0	25
December	0	20

Bureau of Reclamation along with Fontenelle Reservoir, a hypothesis followed that it was used as a way of augmenting the Green River's flow during the years of Fontenelle's filling. This produced a severe error in the Big Sandy portion of the model from 1966 to 1969. As the only countermeasure available, varying sets of input evolved that solved the predicament. Appendix B indicates the run files used. For the first five years, diversion file INP4.1 contains the proper diversions normally operating on the system. For the next several years, an additional diversion had to be added which will be described later. INP4.2 gives these appropriate diversions for years six through nine including the break in data due to Fontenelle. With the Big Sandy Reservoir returning to normal operations midway through 1970, a third set of data, INP4.3, resulted that contains the remnants of the added diversion and the rest of the normally operating diversions. For any year beyond 1970, INP4.1 is the appropriate diversion file.

The other dominant problem existed in the efficiencies or consumption rates in the Big Sandy River basin. During normal years, the model predicted almost twice the amount of water that actually appeared in the measured data at the gauging station. Due to this fact, an assumption arose that the efficiencies in this area would vary significantly compared to the rest of the Green River Basin because of the existing environmental conditions. The Big Sandy River has a significant portion of its drainage area within an arid, non-forested region in contrast to the forested density territory that initially established the runoff for this drainage. The main irrigation takes place on this arid area. With this knowledge and discussions with experienced engineers with understanding of this particular area, the efficiency rate for the area was increased from 48 percent to approximately seventy percent. Even though this change reduced the error, it still did not account for a large portion of the excess water.

The final answer to this mystery rested in the operation of Big Sandy Reservoir itself. During a site investigation, the outflow from the dam appeared to be totally diverted into a canal that did not reenter the river bed. Treating this as a large diversion with a slight increase in its diversion efficiency (73 percent), the discrepancies disappeared. In the years of filling Fontenelle Reservoir, a bypass diversion called upon a portion of this diverted water. This allowed the water to circumvent the diversion without being assessed the high efficiency loss. The addition of these two factors allowed for the complete calibration of the Big Sandy River basin.

GREEN RIVER NEAR GREEN RIVER, WYOMING (092170.00)

The Green River near Green River, Wyoming (USGS 09217.00) gauge, being the last gauge in the modelled system, was effected by every change discussed so far in this chapter. The USGS station identification number for this gauge is 092170.00 with modeling number 13020. The location of the measurement occurs before the inlet to Flaming Gorge Reservoir and after the city of Green River, Wyoming. This allows for the inflow into Flaming Gorge Reservoir due to the Green River to be easily identified in the model. The only correction occurring in the initial model that influences this station alone pertained to the elimination of Alkali Creek as a factor in modeling and a runoff change on Bitter Creek. Originally these two entities were believed to contribute significant amounts of water to the system. Approximations for the initial runoff values came from paralleling peak annual flows for Bitter Creek and another stream. This method produced extremely large values that could not be substantiated due to a lack of runoff data for any stream in the immediate area of either Alkali or Bitter Creek during the period of investigation. Finally, some data emerged that contained runoff data in the late seventies and early eighties for Bitter Creek at a gauging station below Rock Springs, Wyoming. These values range from 2,000 to 10,000 acre-feet per year. Since no other means presented itself for the determination of these flows, a typical year, 1977, portrays the flow throughout the study in Bitter Creek. Since Alkali Creek equated to a very small fraction of the Bitter Creek flow, it was eliminated from the model.

One other matter presented a dilemma. In year one, the flow at the Green River station is approximately 20 percent high. In looking at the check stations above this point, the sum of their waters is greater than at the end without inclusion of all the streams in between. This leads to the theory that this model does not accurately approximate extreme low flow years such as year one of the model. However, the rest of the check stations do show compliance in year one indicating that any portion of the model above a valid check station executes the model's goals within the established standards for year one.

REVIEW AND RUNNING

With all the fragmentation that occurred as a result of Fontenelle Reservoir, the level of sophistication in the running of this model increased significantly. The files that constitute a particular run depend on the specific year of data. Appendix B outlines what files comprise the input for which years. Appendix B also contains a segment on what files to run if the assumptions of regular operation over the entire runoff data set were to be developed. Disks containing all the input and resulting output can be obtained from the Wyoming Water Resources Center.

Student t tests were used to confirm the accuracy of the model. For a confidence level of 99 percent, all check stations' t values were less than the standard limiting t value for the corresponding degrees of freedom. The means, standard deviations, and computed t values for all the data appear in Appendix A with their corresponding check stations.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY

The primary focus of this research has been the construction of an applicable water management model for the Green River. The main function of the thesis was to develop a base model which would allow further adaptation as seen necessary. Along with this responsibility, the capacity to emulate large scale changes in the river system was also accomplished.

Before any information was obtained, however, a model had to be chosen. After examining the two major pieces of software available for modeling the Green River basin by the interested parties (State Engineers' Office and Wyoming Water Development Office), the decision was made to use the Wyoming State Engineers' Office's version of WIRSOS. The choice of this model was based on its ability to handle a large amount of data in the form of water right diversion inputs as well as its more precise handling of them. Unfortunately, the treatment of reservoirs is rudimentary in WIRSOS compared to the Bureau of Reclamation's model, HYDROSS.

After the decision to use WIRSOS, the development of the necessary data for the model occurred. Throughout the data input stage, assumptions based upon the opinions of experienced individuals and actual studies involving parts of the system assisted in the resolution of several key problems. An initial model was then developed that permitted further refinement. Starting with this basic model, parts of the individual model were altered to permit the calibration of the system. The changes in the model varied from simply altering derived runoff data to adding efficiency diversions and deleting non-contributing runoff areas from the system. One of the largest changes, however, occurred in the reservoir operations. Since the percentages of water released and stored differed throughout the entire run-time of the model, few of the values could act as constants. This resulted in several different input files that forced the necessity of separate runs and then compilation of their output. Even with these measures, one year of data required deletion from the model due to inaccurate yields based on the eight percent error rule.

CONCLUSIONS

Although this model does provide for an accurate interpretation of the river system, years that have a Flaming

Gorge Reservoir inlet runoff below 800,000 acre-feet tend to be overestimated. This results from large conveyance losses in the river system that do not follow the general trends used in the model for other years without adversely affecting these years with flows greater than 800,000 acre-feet. For this reason, year one of the model should not be used to predict or test any results for the entire basin. In contrast, most individual areas of the model accurately simulate low flow years for their separate regions. These localities can be determined by looking at the check stations in Appendix A and determining when the percentage error for year one meet the calibration requirements established.

The only other major issue in this model pertains to the description of the reservoir parameters. Even though the basic physical data represents those of record, the operating methods forced the making of some extreme assumptions involving release schedules and related diversions since no data was available to properly determine these quantities. With no exact solutions to these parameters, they became tools to assist in the calibration of the stream segments that they affected. This resulted in the parameters differing in respect to which check stations that relied upon them.

FURTHER RESEARCH

As for the software itself, the way that reservoirs are handled in WIRSOS must be altered. More of the processes that occur need to be represented to eliminate some of the assumptions that were made to allow for calibration. Other than this fact, WIRSOS provides an excellent foundation for water management models to be established in Wyoming.

Continued construction of this model should result from the specific uses that can be incorporated into it. The specific topics that need to be addressed include the addition of more runoff data, more diversion permits, and further definition of the reservoirs. As the range of these inputs increases, the more appropriately it should define the actual status of the Green River.

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APPENDIX A

FINAL VALUES AND ERROR PERCENTAGES FOR ALL CALIBRATION STATIONS

Modelling Station 60, USGS 091885.00
Green River at Warren Bridge

Year	Gauged acre-feet	Modeled acre-feet	Error Percentage	Difference acre-feet
1961	267054	266180	0	-874
1962	419823	416086	-1	-3737
1963	352062	353025	0	963
1964	390929	361660	-7	-29869
1965	498647	522703	5	24056
1966	289575	286261	-1	-3314
1967	439596	436685	-1	-2911
1968	377357	394033	4	16676
1969	376407	386853	3	10446
1970	334419	352760	5	18341

Mean of gauged data = 374,587 acre-feet

Standard deviation of gauged data = 69,003 acre-feet

Mean of modeled data = 377,625 acre-feet

Student t = -0.13

$t_{.01,9}$ = 2.821

Modelling Station 3990, USGS 092050.00
New Fork River near Big Piney, Wyoming

Year	Gauged acre-feet	Modeled acre-feet	Error Percentage	Difference acre-feet
1961	294737	299505	2	4768
1962	597666	582524	-3	-15142
1963	448014	465223	4	17209
1964	501022	494217	-1	-6805
1965	801251	799112	0	-2139
1966	356813	357347	0	534
1967	662488	670018	1	7530
1968	610521	569951	-7	-40570
1969	644459	628170	-3	-16289
1970	395543	422283	7	26740

Mean of gauged data = 531,251 acre-feet

Standard deviation of gauged data = 158,556 acre-feet

Mean of modeled data = 528,835 acre-feet

Student t = -0.05

$t_{.01,9}$ = 2.821

Modelling Station 9055, USGS 092112.00
Green River below Fontenelle Reservoir

Year	Gauged acre-feet	Modeled acre-feet	Error Percentage	Difference acre-feet
1961	*****	*****	*****	*****
1962	*****	*****	*****	*****
1963	*****	*****	*****	*****
1964	1103125	1153621	5	50496
1965	1894102	1807455	-5	-86647
1966	801702	844364	5	42662
1967	1407303	1444839	3	37536
1968	936416	943687	1	7271
1969	1271128	1258248	-1	-12880
1970	922102	983714	7	61612

***** - Data not available

Mean of gauged data = 1,190,840 acre-feet

Standard deviation of gauged data = 375,045 acre-feet

Mean of modeled data = 1,205,133 acre-feet

Student t = 0.09

$t_{.01,6}$ = 3.143

Modelling Station 10250, USGS 092160.00
Big Sandy River (Creek) below Eden, Wyoming

Year	Gauged acre-feet	Modeled acre-feet	Error Percentage	Difference acre-feet
1961	8684	8379	-4	-305
1962	28171	28919	3	748
1963	17251	18431	7	1180
1964	19902	18289	-8	-1613
1965	37256	36444	-2	-812
1966	38219	36021	-6	-2198
1967	50774	47332	-7	-3442
1968	39200	42919	9	3719
1969	60551	56234	-7	-4317
1970	21440	21304	-1	-136

Mean of gauged data = 32,145 acre-feet

Standard deviation of gauged data = 16,053 acre-feet

Mean of modeled data = 31,427 acre-feet

Student t = -0.13

$t_{.01,9}$ = 2.821

Modelling Station 13020, USGS 092170.00
Green River near Green River, Wyoming

Year	Gauged acre-feet	Modeled acre-feet	Error Percentage	Difference acre-feet
1961	558780	688130	23	129350
1962	1452836	1355994	-7	-96842
1963	1001659	1074258	7	72599
1964	1136290	1173654	3	37364
1965	1963030	1855541	-5	-107489
1966	910871	874435	-4	-36436
1967	1522791	1495397	-2	-27394
1968	974886	983439	1	8553
1969	1361736	1309698	-4	-52038
1970	932592	1004596	8	72004

Mean of gauged data = 1,181,547 acre-feet

Standard deviation of gauged data = 399,086 acre-feet

Mean of modeled data = 1,181,514 acre-feet

Student t = -0.00

$t_{.01,9}$ = 2.821

APPENDIX B

WIRSOS FILE COMBINATIONS FOR YEARS ONE (1961) THROUGH TEN (1970)

YEARS ONE THROUGH FIVE FILES

INP1

INP2.A

INP3

INP4.1

INP7

INP14

INP15.A

INP16

INP17

YEARS SIX AND SEVEN FILES

INP1

INP2.A

INP3

INP4.2

INP7

INP14

INP15.A

INP16

INP17

YEARS EIGHT AND NINE FILES

INP1

INP2.B

INP3

INP4.2

INP7

INP14

INP15.B

INP16

INP17

YEAR TEN FILES

INP1

INP2.B

INP3

INP4.3

INP7

INP14

INP15.B

INP16

INP17

ASSUMING STANDARD OPERATION

OF ALL RESERVOIRS

INP1

INP2

INP3

INP4.1

INP7

INP14

INP15.B

INP16

INP17