CHARACTERIZATION OF HYDROLOGIC CONDITIONS TO SUPPORT PLATTE RIVER SPECIES RECOVERY EFFORTS[1]

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ABSTRACT: Efforts are under way to recover habitat for several threatened and endangered species in and along the Platte River in central Nebraska. A proposed recovery program for these species requires a means of characterizing "wet" versus "normal" versus "dry" hydrologic conditions in order to set corresponding Platte River instream flow targets. Methods of characterizing hydrologic conditions in real time were investigated for this purpose. Initially, 10 watershed variables were identified as potentially valuable indicators of hydrologic conditions. Ultimately, six multiple linear regression equations were developed for six periods of the year using a subset of these variables expressed as frequencies of nonexceedence. The adequacy of these equations for characterizing conditions was assessed by evaluating their historic correlation to subsequent flow in the central Platte River (1947-1994). These equations explained 54 to 82 percent of variability in the observed flow exceedences in the validation datasets, depending upon the period of year evaluated. These equations will provide initial criteria for setting applicable flow targets to determine, in real time, whether water regulation projects associated with the species recovery effort can divert or store flows without conflicting with recovery objectives.
(KEY TERMS: river management; hydrologic variability; water policy; water allocation; instream flow; decision making.)

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INTRODUCTION

A 140 km reach of the Platte River in central Nebraska is the focus of a concerted effort to recover riverine and nearby habitat for three endangered and threatened migratory bird species. This section of the river, often referred to as the Big Bend reach, begins near Lexington, Nebraska, and ends near the town of Chapman, Nebraska (Figure 1). This paper addresses the development of tools to characterize hydrologic conditions for this reach of the Platte River in support of ongoing habitat recovery efforts.

In 1997, a cooperative agreement was signed between the states of Nebraska, Wyoming, and Colorado and the U.S. Department of the Interior to develop a basin wide Platte River Recovery Implementation Program (Program) to improve and maintain the habitats associated with three federally listed species: the whooping crane (*Grus americana*), interior least tern (*Sterna antillarum*), and piping plover (*Charadrius melodus*). The endangered pallid sturgeon (*Scaphirhynchus albus*), a fish that uses the lower reaches of the Platte River in eastern Nebraska, is also associated with this recovery effort.

One long term objective is to provide sufficient water to and through the central Platte River to benefit these target species and their associated habitats. To achieve this objective, program participants have agreed to implement, among other measures, practices to reduce shortages to instream species recovery "target flows" for the central Platte River, initially using U.S. Fish and Wildlife Service (USFWS) definitions (Bowman, 1994; Bowman and Carlson, 1994;

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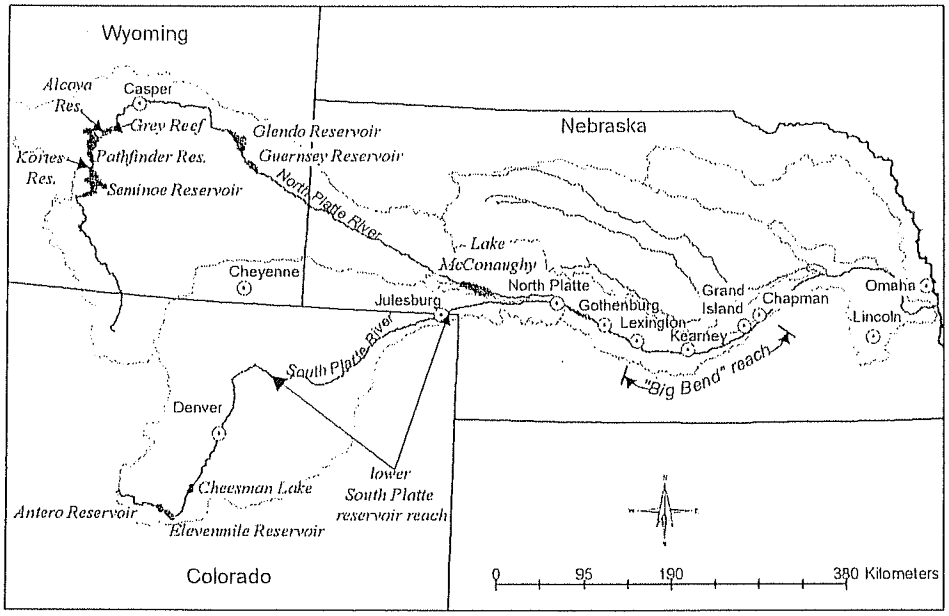

Figure 1. Platte River Basin and Subbasins in Wyoming, Colorado, and Nebraska.

USFWS, 2003). Recognizing that river flows naturally vary from year to year and that variability in flow provides important biological benefits (e.g., Richter *et al.*, 1997), many of these targets vary depending upon whether hydrologic conditions are deemed "wet," "normal," or "dry."

Program efforts to protect target flows when they are met and to increase river flows during periods when they fall short of targets therefore require a means of determining in real time which hydrologic condition applies. This paper discusses the development of initial methodologies for making these real-time determinations for this program.

Physical Setting and Description

The Platte River upstream of Grand Island, Nebraska, drains an area of 149,000 km^2 in three states. In Nebraska, it flows eastward until it joins the Missouri River south of Omaha. The river corridor along the Big Bend reach is generally characterized by a broad, shallow, sand bed river channel with adjacent areas of cultivated farmland, meadows, grasslands, backwaters, and woody riparian vegetation. Adjacent areas also include occasional homesites, roadways, urbanized zones, and sand excavation pits and ponds.

The Platte River system originates on the eastern slopes of the Rocky Mountains and flows across the Great Plains. The upper river system consists of two major tributaries: the North Platte River, which drains part of north-central Colorado, much of southeast Wyoming, and the Nebraska panhandle; and the South Platte River, which primarily drains northeastern Colorado. These tributaries merge near the town of North Platte, Nebraska. The highest elevation in the basin, at the continental divide in Colorado, is more than 4,300 m above mean sea level. Where the Platte River joins the Missouri River, its elevation is less than 300 m.

Climate varies greatly across the basin. Precipitation is highest in the western mountains, where, in some locations, annual averages exceed 150 cm. These averages decline rapidly with loss of elevation and reach a minimum of around 30 cm on the eastern plains of Wyoming and Colorado. As one progresses eastward, precipitation gradually increases to an annual average of more than 75 cm at the Missouri River confluence.

Most precipitation at the higher elevations in the Rocky Mountains falls as snow, which accumulates during late fall, winter, and early spring. This accumulated snowpack provides runoff during the snowmelt season of late spring and summer. Historically, this resulted in a relatively consistent seasonal flow pattern in the central Platte River, characterized by a substantial spring rise that peaked, typically, in May or June. Following this snowmelt driven peak, flow typically receded to the lowest levels of the year during the summer and fall. Nevertheless, locally intense thunderstorm activity is common during the summer season, and this can produce significant high flow events in the central Platte River, including annual peaks.

Today, Platte River flow is highly regulated and heavily used. Total reservoir storage capacity in the river system upstream of Grand Island is about 9.3 billion m^3 (7.5 million acre feet) (Eisel and Aiken, 1997), roughly five times the average annual flow in the river at Grand Island from 1940 through 1999. Water throughout the basin is used to meet consumptive demands, which include about 770,000 ha (1.9 million acres) of surface water irrigated agricultural land and a population of about 3.5 million. Platte Basin flows are also used to generate hundreds of megawatts of hydroelectric and steam fired power.

A century and a half of surface and ground water development in the basin has resulted in substantial changes to central Platte River flow quantities and timing, channel characteristics, and riparian conditions (Simons and Associates, Inc., 2000; Murphy *et al.,* 2004). Most of the Big Bend reach, for example, has narrowed, deepened, undergone vegetative encroachment, and changed from a braided to an anastomosed channel planform within the past century (Williams, 1978; Currier, 1996; Johnson, 1997; Chen *et al.,* 1999; Simons and Associates, Inc., 2000), resulting in degraded habitat conditions for the target species (USDOI, 2003; NRC, 2005). In part because of these changes, in 2003 the American Rivers Conservation Organization identified the Platte River as one of the "ten most endangered rivers" in the United States.

Objectives of this Specific Investigation

The first 13-year increment of the proposed Platte River Recovery Program aims to reduce shortages to central Platte River target flows by 130,000 to 150,000 acre feet (160 million to 185 million m^3) in the average year. As the program is currently envisioned, this primarily will be achieved through a combination of retiming flows in the river from periods of excesses to target flows (typically, during winter months) to periods when targets are not met (typically, spring through fall) and voluntarily reducing the consumptive use of water through program purchases or leases.

The USFWS recommendations (Bowman, 1994; Bowman and Carlson, 1994) establish an initial basis for the Platte instream "target flows." The full suite of flow recommendations is too complex to address here and remains subject to review and modification; relevant to this discussion is the fact that target flows for the central Platte River exist for every day of the year and are based on whether conditions are considered dry, normal, or wet.

Implementation of some program associated activities will have immediate effects on flows in the central Platte River by altering the quantity and/or timing of flow diversions and/or storage. For example, the state of Colorado proposes regulating South Platte River flows near the Nebraska state line such that they will be diverted to shallow alluvial aquifers adjacent to the river during periods when flows exceed targets and will gradually be returned to the Platte River from these alluvial zones during periods when flows are characteristically deficient (State of Colorado, 2003).

Real time operation of this Colorado project and other proposed program activities requires that the target flow for the central Platte River at Grand Island be defined year-round such that operations do not conflict with desired flows. Because targets vary according to conditions and because conditions can change over short periods, program participants agreed to develop criteria to determine, for any given day, whether hydrologic conditions should be characterized as wet, normal, or dry.

By consensus for this recovery effort, "wet" conditions correspond to the wettest one-third of flows, "dry" conditions to the driest one-quarter, and "normal" to all remaining conditions (Bowman, 1994).

Current Monitoring of Basin Conditions and Characterization of River Flows

Water supply conditions in the Platte Basin, including basin snowpack and reservoir contents, are watched closely, as this water is crucial for agriculture, municipal supplies, power production, and industrial activity.

While general hydrologic conditions in the basin are attentively monitored, few efforts have been made to relate basin conditions to central Platte River flows. Several monthly streamflow models have been developed for the river system, including a model for the North Platte River above Lake McConaughy (USBR, 1997), for the South Platte River in Colorado (Hydrosphere, 2001), and for the central Platte River in Nebraska (Platte River EIS Office, 2002). However, the general purpose of these models is to evaluate the likely impacts of various management alternatives. None of these models was designed nor intended to serve as a real time river management tool.

Thus the investigations described here represent new efforts to objectively characterize hydrologic conditions in the river basin for periods of one to three months.

MODELING APPROACH

Numerous models have been developed to express future streamflow probabilities as a function of watershed and/or meteorological conditions (e.g., Chow *et al.*, 1983; Day, 1985; Schaake *et al.*, 2001). These in turn are applied to management needs such as reservoir optimization (e.g., Yeh, 1985; Faber and Stedinger, 2001). The efforts described herein differ in that they focus simply on developing an objective and unbiased method for classifying basin conditions as "wet," "normal," or "dry" based on historic river behavior. There is no intent to forecast streamflow *per se*.

For the Platte River, a statistical rather than a physically-based modeling approach offered several advantages. First, program stakeholders were comfortable with a statistical approach because it could be easily implemented in a short time frame while providing a bias free classification scheme. Also, statistical concepts underlying this approach are more easily explained to a wide spectrum of interests than are models simulating complex hydrologic processes. Development of a dynamic, process-based hydrologic model would have been costly, time consuming, and, for this particular application, of questionable additional practical value.

Water year classification schemes based on weighted input parameters rather than dynamic hydrologic models are used to support water management in several major river basins in the United States. The Sacramento and San Joaquin River basins in California, for example, are annually assigned a classification of "wet," "above normal," "below normal," "dry," or "critical" by the State Water Resources Control Board (SWRCB) based on three weighted basin variables (SWRCB, 2005). Similarly, the Susquehanna River Basin Commission in the northeastern United States annually compares four hydrometeorological parameters and two water supply variables to threshold values to determine whether one of three drought conditions should be declared for basin subregions (Kibler *et al.*, 1987).

It does not appear that the California or Susquehanna Basin water year classification scheme was derived through a systematic statistical analysis of historic basin conditions and river flows, although later efforts by Kibler *et al.* (1987) did systematically evaluate the validity of the Susquehanna drought indicators and proposed improvements. Development of a multivariate statistical model to estimate central Idaho stream temperatures, as described by Donato (2002), may represent a methodology more comparable to ours. There, statistical relationships were derived between landscape, climate, vegetation, stream channel characteristics, and corresponding stream temperatures. The model used variables known to have a bearing on stream heat exchange (for example, site elevation, stream width, and riparian canopy coverage) without simulating specific energy exchange processes. The approach described herein is analogous: variables known to historically affect Platte River flows were assessed, but no attempt was made to simulate the specific processes and management decisions that regulate streamflow.

METHODOLOGY

Characterization Goals and Potential Characterization Variables

Throughout Program negotiations, the standard period of record used to evaluate the likely effects of water management alternatives has been 1947 through 1994, as this period encompasses a wide range of basin climatic conditions including droughts and unusually wet periods. Of these 48 years, 16 (one-third) correspond, by definition, to wet conditions, 12 (one-quarter) to dry conditions, and the remaining 20 to normal conditions.

The USFWS worked closely with a team of Program stakeholders from Nebraska, Colorado, and Wyoming to identify variables that historically might have been useful predictors of streamflow in the central Platte River in following months. For evaluation purposes, data relating to these variables had to be available for all or nearly all of the 1947 through 1994 period and for purposes of future program use, also had to continue to be available in real time.

The menu of variables the team identified and their potential relationship to subsequent Platte River flow conditions are summarized in Table 1.

A few words about Table 1 variables in the context of Platte basin hydrology may be useful. Ultimately, Platte River flows are largely determined by snow accumulation in headwater areas. Under natural, uncontrolled conditions, reasonable predictions of spring and summer flows likely could be derived from snow accumulation data alone (e.g., using Variables 8, 9, and 10 in Table 1). Under present-day conditions, reservoirs (Variables 4, 5, 6, and 7) store the bulk of upper basin runoff, releasing it downstream primarily in response to irrigation demands (reflected in part by Variable 3) and for power generation. Precipitation at lower elevations (also reflected in Variable 3) is a less significant contributor to Platte streamflow on an annual basis, although it can have profound effects on daily flows, as plains precipitation produces roughly 10 percent of the per unit area water yield of zones

TABLE 1. Variables Considered for Characterizing Platte Basin Hydrologic Conditions.

Potential Characterization Variable	Abbreviation	Potential Relevance as a Characterization Variable
1. Streamflow in the Platte River at Grand Island, Nebraska	Q @ GI	Some persistence in central Platte River flows is expected (e.g., high flow months tend to be followed by high flow months).
2. Streamflow in the South Platte River at Julesburg, Colorado	Q @ Jules	Flow conditions in the South Platte River directly affect flows in the central Platte, especially during the nonirrigation season, as there are no on-channel reservoirs between Julesburg and Grand Island. Some persistence in flow conditions is expected.
3. Palmer Drought Severity Index (averaged for four districts in western Nebraska, northeastern Colorado, and southeastern Wyoming)	PDSI	PDSI models the effects of weather on the soil water balance (Palmer, 1965). PDSI may correlate to subsequent central Platte flows as an indicator of (1) regional water table and base flow conditions, (2) opportunities to saturate soil and generate surface runoff when precipitation occurs, and (3) likely irrigation demand (or lack thereof) on available surface water.
4. Lake McConaughy Reservoir content as percent of available capacity	Mac	Releases from Lake McConaughy (2.4 x 10^9 m^3 maximum storage) have a large impact on central Platte water deliveries to meet power generation and agricultural irrigation needs. In turn, the magnitude of releases in any given year are related to available storage.
5. Upper North Platte Reservoir content	NPlatte Res	Storage contents in North Platte River reservoirs upstream of Lake McConaughy partly determine the volume and timing of water releases for downstream users.
6. Lower South Platte Reservoir content	Lower SPlatte Res	High spring reservoir contents result in less need to divert spring flows out of the South Platte River. They may also correspond to higher water deliveries for uses downstream.
7. Upper South Platte Reservoir content	Upper SPlatte Res	Higher reservoir releases and/or reservoir spills are more likely in years of above-normal reservoir content.
8. North Platte Basin (Wyoming) April 1 snowpack	NPlatte WY Snow	Snowmelt season in the higher elevation zones of this basin typically begins in April. Greater April snowpack leads to larger late spring and summer inflows to basin tributaries and reservoirs.
9. North Platte Basin (Colorado) April 1 snowpack	NPlatte CO Snow	Same as above.
10. South Platte Basin (Colorado) April 1 snowpack	SPlatte CO Snow	Same as above.

above 1,800 meters (Simons and Associates, Inc., 2000). Lagged return flows from various water uses throughout the basin can substantially influence fall and winter base flows and to a large extent may be detectable in the tendency for persistence in stream discharge during these months (Variables 1 and 2).

Characterization Periods

For the application discussed here, the primary hazard associated with characterizing conditions to be wetter than they really are is that flow targets will be set higher than they "should" be. That is, certain Program associated water operations may be prohibited from diverting or storing Platte flows that they otherwise would be allowed to use. The converse risk, characterizing conditions as being unrealistically dry, would result in inappropriately low instream flow targets, allowing operations to divert flow that otherwise could provide habitat benefits. Ideally, both errors can be avoided, protecting the interests of water users as well as the target species.

Through an iterative process of subdividing the year into shorter characterization periods and evaluating the results, the stakeholder working group determined that seven periods for each year struck the appropriate balance between reliability and ease of implementation. These periods are: December-January-February; March-April; May; June; July; August-September; and October-November.

These one-month to three-month periods for characterizing conditions are shorter than the annual characterizations typical of many other river basins such as the Sacramento, San Joaquin, and Susquehanna examples already noted. These shorter intervals provide additional opportunities to adapt to changing basin conditions.

The above periods also logically group months in terms of regional climate and hydrology. The grouped months of December, January, and February collectively comprise a period in which there is no agricultural irrigation, negligible basin snowmelt, and relatively little precipitation at lower basin elevations. Streamflows in March-April, May, and June historically have exhibited distinctive responses to basin snowmelt, first from the lower elevations (late February through early April) and then from higher elevation source areas (primarily late April through June). The July and the August-September periods are strongly influenced by irrigation deliveries from upstream reservoirs and by local precipitation. October-November is typically a period of streamflow recovery from summer minimums as irrigation diversions cease, riparian evapotranspiration declines, and return flows from earlier water deliveries contribute to river gains.

Lag times were not a concern for this analysis, as water releases from upper basin reservoirs (i.e., in Colorado and Wyoming) typically reach the lower basin (Nebraska) in considerably less than 30 days. Even when water is not physically being delivered from the upper to the lower basin, the status of upper basin reservoirs has an immediate effect on downstream water management by influencing expectations of future water deliveries and/or available streamflow.

Equations Development

Step 1: Compilation of Data. Monthly data covering 48 years (1947 through 1994) were compiled for each variable identified in Table 1. All monthly values for all years and all variables were available, with the exception of "lower South Platte reservoir storage" for the years 1947 through 1950 and certain months in other years. To develop a complete dataset for this variable, monthly values for the first four years were estimated by developing simple 1951 through 1994 regression relationships to storage conditions in other basin reservoirs. Remaining missing months were estimated as linear interpolations between known values.

Data compiled under this step included monthly streamflow for the Platte River near Grand Island, Nebraska (U.S. Geological Survey Stream Gage No. 06770500). These values were used as the dependent variable against which to test the equations' predictive skill (see Step 3).

Step 2: Normalization of Variables. Monthly values for all variables were normalized by converting them into a frequency of nonexceedence (1947 through 1994) between 0 and 1. For example, the highest average May streamflow in the Platte River near Grand Island during this 48-year period was 345 cubic meters per second (cms) in 1984 and the lowest, 4.2 cms, in 1955. For subsequent analysis, this May 1984 variable was treated as the value 1 - (1/(48+1)), or 0.980 frequency of nonexceedence, and this May 1955 variable as 1 - (48/(48+1)), or 0.020.

Values were normalized as described so they could be compared in a consistent and dimensionless manner. The 10 variables are measured in diverse and often incongruous units and have dissimilar statistical distributions. Normalization minimized these potentially confounding disparities and simplified interpretation of each variable's significance in the regression analysis.

Step 3: Elimination of Least Significant Variables. The "test" for each of these 10 variables was to see how well it historically would have forecast streamflow at Grand Island over the following one-month to three-month period. Correlation coefficients were calculated between each of these individual variables and the corresponding streamflow in the Platte River near Grand Island over the period of record, along with the F statistic to determine the level of significance of these correlations. Using these statistics, variables were eliminated that did not individually demonstrate predictive skill at the 99 percent level of significance.

Step 4: Censoring of Periods Heavily Affected by Local Events. A concern surfaced that unusually large local precipitation events could skew attempts to derive equations based on measured basin conditions only, especially during times of the year when local convective storm events can greatly increase central Platte River flows. That is, the effect of central Nebraska storms on contemporaneous river flows is essentially a random variable with little or no relation to antecedent basin conditions. A review of historic data indicated that in a certain proportion of years, May through July streamflows would be in the "normal" to "wet" range regardless of upstream conditions, due solely to this random local effect. To remove this confounding effect from the derivation of equations, unusually high local precipitation periods between 1947 and 1994 were identified and, where appropriate, removed from the evaluated datasets. Subsequently, in setting classification thresholds, the thresholds were adjusted to reflect the expectation that a corresponding percentage of years will have flows corresponding to "normal" or "wet" conditions regardless of basin conditions reflected in the equation.

Monthly precipitation records from the Gothenburg and Kearney weather stations in Nebraska (Figure 1) were used. These two sites are respectively located about 50 km upstream of and about one-third of the way through the Big Bend reach. Precipitation from these two weather stations was averaged for each of the characterization periods. Years in which these periods exhibited "unusually high local precipitation" were defined as those in which precipitation exceeded the 48-year average plus one standard deviation. For each period, between four and nine years fell into this category.

These unusually high local precipitation periods were then compared to the corresponding rank of streamflow in the Platte River at Grand Island during the same period to determine whether these periods clearly corresponded to higher contemporaneous streamflow, regardless of upstream conditions (Table 2). Based on this comparison, eight, seven, and nine months for May, June, and July, respectively, were excluded from the evaluated datasets. For the remaining periods, all the data were retained, as high local precipitation did not exhibit the same contemporaneous effect on flows.

The stronger correspondence in May, June, and July is consistent with the fact that storm events in central Nebraska tend to be most extreme in these months, and normally none of this precipitation falls as snow. Local storm events in these months can drastically alter river flows in a matter of hours.

Step 5: Sorting Data into Calibration and Validation Subsets. The remaining "uncensored" dataset (39 to 48 years of data, depending upon the period of year evaluated) was sorted from highest to lowest total streamflow at Grand Island. Half of these years (or half plus one) were grouped as the "calibration years" and the remainder as "validation years." An example of how these years were sorted and calibration versus validation years identified to ensure an equal weighting of wet/normal/dry conditions is illustrated in Table 3.

Step 6: Derivation of Equations for Characterizing Conditions. Using the calibration dataset, best-fit multiple linear regression equations were derived using each of the predictive variables (expressed as frequency of nonexceedence) to test how well they historically correlated to streamflow in the Platte River at Grand Island in the following one to three months (also expressed as frequency of nonexceedence). These equations were developed in a stepwise fashion, successively dropping independent variables that had either (1) negative coefficients when used with the other variables (here, a negative coefficient for any variable was counter intuitive, suggesting that the information contained in this variable was duplicated by some combination of the other variables); or (2) correlation coefficients that were very small relative to the other remaining variables (in such cases, the value of retaining the variable for future program purposes was highly questionable).

On this basis, equations to characterize hydrologic conditions based on two to five of the variables were developed for six of the predictive periods. At this time, satisfactory equations for the August-September period are still under development.

RESULTS AND DISCUSSION

"Hydrologic condition equations" satisfying the working group of stakeholders were developed for each of the characterization periods except August-September along with corresponding numeric

TABLE 2. Comparison of Locally High Precipitation Periods With Corresponding Streamflow Conditions in the Platte River at Grand Island, Nebraska.

Period	Number of Periods, 1947-1994, With "Unusually High Local Precipitation" (greater than one standard deviation above mean)	Corresponding Streamflow Conditions at Grand Island in These Months		
		Wet	Normal	Dry
December-January-February	4	0	4	0
March-April	6	3	1	2
May	8	3	5	0
June	7	4	3	0
July	9	4	5	0
October-November	6	3	2	1

TABLE 3. Mean Flow in the Platte River Near Grand Island, December Through February, 1947-1994, Sorted From Highest to Lowest.

Water Year)	Mean Flow, Platte River Near Grand Island December-January-February (m^3/sec)
1983*	145.9
1973	112.1
1984	105.9
1985*	78.2
1986*	72.9
1951	69.5
1982	67.6
1987*	65.2
1972*	64.9
1979	62.1
1971	58.5
1969*	56.1
1965*	54.7
1970	50.2
1993	46.5
1975*	45.4
1950*	44.9
1947	44.6
1952	42.8
1988*	42.1
1989*	40.8
1962	40.5
1981	40.5
1961*	39.5
1967*	38.2
1994	38.2
1949	37.6
1953*	36.8
1991*	36.4
1957	36.0
1968	35.4
1992*	35.3
1948*	34.3
1959	34.2
1974	32.7
1980*	32.2
1966*	***31.7***
1976	***29.8***
1960	***29.3***
1990*	***28.2***
1958	***26.9***
1977	***25.8***
1964*	***25.6***
1978*	***25.4***
1954	***24.7***
1955	***23.1***
1956*	***10.8***

Note: Asterisk years indicate years used to develop the type of conditions equation (the "calibration dataset"). Nonasterisk years denote those periods used for the validation dataset. **Bold type** denotes 16 periods defined as "wet;" ***bold italics*** denote 12 periods defined as "dry."

thresholds for distinguishing "dry" from "normal" and/or "wet" conditions (Table 4).

Antecedent streamflow in the Platte River at Grand Island, Nebraska, proved to be the most broadly relevant indicator of hydrologic conditions, serving as a variable for classifying all six periods; for four of these periods, it is the most heavily weighted variable. The Palmer Drought Severity Index was the next most commonly retained variable (relevant for four of the six periods), followed by the contents of Lake McConaughy and of the North Platte River reservoirs (each relevant for three periods of the year). Less broadly useful, but still relevant for two periods each, were snowpack in the North Platte basin, reservoir contents in the upper South Platte River basin, and antecedent streamflow in the South Platte River at Julesburg.

The reliability of these equations was evaluated by calculating the least squares fit coefficients of determination (R^2) of the estimated streamflows versus the actual streamflows at Grand Island, expressed as frequencies of non-exceedence. For the calibration datasets, R^2 ranged from 0.66 (March-April) to 0.91 (December-January-February). For the validation datasets, R^2 ranged from 0.54 (June) to 0.82 (May). These relationships are illustrated in Figure 2. Error matrices (Table 5) provide a better sense of how this methodology would have performed in terms of "correctly" classifying subsequent streamflow conditions. Overall (that is, considering all 48 years, including those "censored" from the calibration and validation exercise), 81 percent of the periods would have been correctly classified from 1947 through 1994. Calibration years fared only marginally better (84 percent) than the validation years (81 percent), although censored periods are excluded from these percentages. Overall, the March-April conditions were most accurately characterized (94 percent correct for the dry/nondry classifications), while October-November fared the worst (73 percent correct for the dry/normal/wet classifications).

Not surprisingly, equations for all these periods tend to be most reliable for the wettest of the wet years and the driest of the dry years. Most classification errors are associated with intermediate conditions.

Reasonableness of the Characterization Variables

Of the 10 variables considered for determining hydrologic conditions, seven were ultimately retained as useful characterization variables for one or more periods of the year. The following discusses each of these variables in terms of their relationship to

TABLE 4. Variables and Linear Equation Coefficients to Characterize the Hydrologic Condition for the Central Platte River.

Characterization Period	Variables and Coefficients*								Thresholds**	
	Q@GI	PDSI	Mac	NPlatte Res	SPlatte Res	Q@Jules	NPlatte Snow	Constant Adjustment	"Normal" Condition	"Wet" Condition
Dec-Jan-Feb	0.579		0.138	0.317	0.236			-0.129	0.25	N/A
Mar-Apr	0.120	0.662		0.198				-0.011	0.25	N/A
May	0.601		0.271		0.031		0.252	-0.065	0.30	0.70
June	0.648	0.121				0.023	0.082	+0.097	0.30	0.70
July	0.237	0.441	0.109	0.105		0.218		-0.071	0.31	N/A
Aug-Sep	Equation still under development									
Oct-Nov	0.658	0.342						-0.048	0.25	0.67

*Descriptions for these abbreviations are provided in Table 1. These coefficients are applied to these variables expressed as frequency of nonexceedence values between 0 and 1. The frequency of nonexceedence is based on the 1947-1994 period of record for the Platte Basin.
**Threshold values of the linear equation above which the corresponding hydrologic condition is defined.

Note: N/A indicates not applicable (i.e., USFWS target flows do not include a "wet" category as distinguished from "normal" for these periods).

subsequent conditions in the Platte River near Grand Island.

Streamflow in the Platte River at Grand Island. This variable was retained in the equations for all six periods. Its value for characterizing conditions reflects a tendency for serial correlation (persistence) in monthly streamflow at Grand Island. That is, higher flow (or lower flow) months tend to be followed by higher flow (lower flow) periods.

Palmer Drought Severity Index (PDSI). This variable was retained in the equations for four of the six periods. February PDSI was the strongest single determinant for characterizing March and April conditions, and June PDSI was the strongest determinant for July. The PDSI reflects recent precipitation and the soil moisture balance. In February, most High Plains precipitation falls as snow, and this commonly contributes runoff to the Platte River in March and April as the snow melts and the ground thaws. Thus the PDSI relationship to March-April streamflow is not surprising. Some correspondence between regional PDSI, water tables, and streamflow seems reasonable at almost any time of the year – especially during summer months (such as July), as the PDSI is closely related to consumptive irrigation demands and potential stormwater runoff.

Content of Lake McConaughy Reservoir. Except when this 2.4 billion m^3 reservoir is full and spilling, virtually all North Platte River flow into Lake McConaughy is captured and released at a time and rate determined by the Central Nebraska Public Power and Irrigation District. As a general operational practice, greater releases tend to be made (for power generation and agricultural use) when storage is high. Thus some relationship between McConaughy storage and subsequent streamflow in the Platte River downstream at Grand Island was expected. This variable appears to be a useful indicator of hydrologic conditions for three periods of the year corresponding to five months (December through February, May, and July).

Content of Other North Platte Reservoirs. Most North Platte River flow upstream of Lake McConaughy is captured by these reservoirs in most years. As the contents of these reservoirs increase, they are typically managed to deliver more water to downstream users and/or are more likely to spill.

Content of South Platte Reservoirs Upstream of Denver, Colorado. This variable was retained to characterize December-February and May conditions. As with the North Platte reservoirs, higher releases and/or spills from these facilities are more likely in years of above normal reservoir content. However, it seems counter intuitive that this was a better indicator of subsequent central Platte streamflow than was the content of lower South Platte River reservoirs, as the latter are much nearer to the central Platte. We speculate that much of the predictive information associated with lower South Platte reservoir contents is duplicated by this and/or other variables and that additional information – perhaps related to moisture conditions at higher elevations – contributes to the

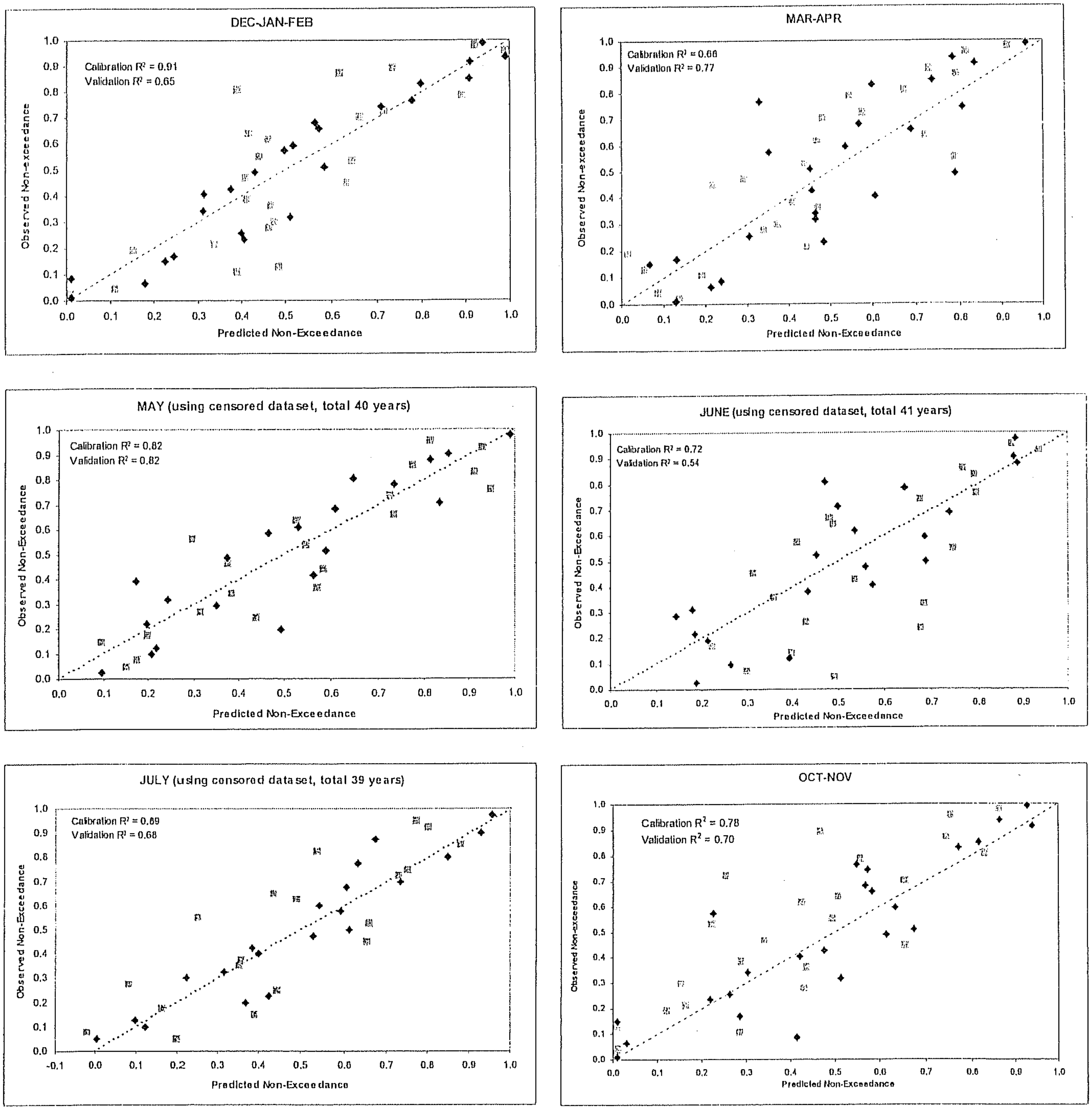

Figure 2. Predicted Versus Observed Streamflow Conditions in the Platte River at Grand Island, Nebraska, 1947-1994, Using the Linear Equations Derived for Characterizing Basin Conditions at Different Times of the Year. Dark diamonds correspond to the calibration data points, pale squares to the validation data. Dotted line represents a perfect 1:1 relationship.

upper South Platte reservoirs' stronger value as an indicator of basin conditions.

Streamflow in the South Platte River at Julesburg, Colorado. This variable was retained to help classify basin hydrologic conditions in June and July. No on-channel reservoirs exist between Julesburg and Grand Island, Nebraska. Thus some correlation between streamflow here and at Grand Island about eight days later (the approximate mean travel time) is not unexpected. Because flow conditions tend to persist for days or weeks at Julesburg during these

TABLE 5. Characterized Versus Observed Streamflow Conditions, Platte River at Grand Island, Nebraska, 1947-1994, as Hits and Misses Relative to Relevant Threshold Conditions.

		Calibration Years (observed conditions)			Validation Years (observed conditions)			All Years (observed conditions)		
		Dry	Not Dry		Dry	Not Dry		Dry	Not Dry	
Dec-Jan-Feb	Dry	5	0		3	0		8	0	
Characterized Conditions	Not Dry	1	18		3	18		4	36	
		Dry	Not Dry		Dry	Not Dry		Dry	Not Dry	
Mar-Apr	Dry	5	0		5	1		10	1	
Characterized Conditions	Not Dry	1	18		1	17		2	35	
		Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
May	Dry	4	2	0	4	1	0	8	6	1
Characterized Conditions	Normal	2	5	2	2	6	0	4	13	3
	Wet	0	0	5	0	1	6	0	1	12
		Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
June	Dry	5	1	0	2	0	0	7	1	0
Characterized Conditions	Normal	1	7	3	4	6	2	5	17	6
	Wet	0	1	3	0	1	5	0	2	10
		Dry	Not Dry		Dry	Not Dry		Dry	Not Dry	
July	Dry	4	0		4	0		8	4	
Characterized Conditions	Not Dry	2	14		2	13		4	32	
		Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
Oct-Nov	Dry	4	2	0	5	2	1	9	4	1
Characterized Conditions	Normal	1	9	3	1	8	3	2	17	6
	Wet	0	0	5	0	0	4	0	0	9

Note: **Bold figures** denote "hits," where the forecast condition matches the observed condition. Only two hydrologic conditions, "dry" or "not dry," are required to set target flows in certain periods of the year. Hence some of these matrices are 2x2, others 3x3.

months, this contributes to this variable's value for defining basin conditions.

North Platte Basin Wyoming Snowpack Conditions, April 1. This variable proved useful for defining May and June hydrologic conditions. Its relevance for these periods is not unexpected, given that the water yield from mountainous areas is disproportionately high and typically peaks in May or June.

Performance, 1995-2004

The performance of these methods was also examined for the years subsequent to the 1947 through 1994 record used for their derivation (Table 6). Generally, the characterized conditions showed a good correspondence to observed flow near Grand Island (80 percent to 90 percent accuracy) for all periods except May (60 percent). The onset of unambiguous drought conditions throughout most of the Platte basin in winter of 2001-2002 is accurately reflected by these equations.

Limitations of the Technique

Even the most diligent efforts to characterize Platte basin hydrologic conditions will be imperfect. Interrelationships among river system components are complex, variable, and incompletely understood, and basin data are sparse and of varying accuracy. Furthermore, water resource use and management in the Platte continuously evolve, and this could compromise the original basis for some of these equations over time. Indeed, one specific objective of the recovery effort is to retime Platte River flows.

In addition, the implicit assumption that 1947 through 1994 is reasonably representative of future conditions in the Platte basin could prove inaccurate. Paleoclimatic studies suggest that droughts in this region in the twentieth century were not representative of the full range of drought variability that has occurred over the past 2,000 years (Woodhouse and Overpeck, 1998). As of this writing, drought persists in much of the Platte River basin, and its ultimate duration is unknown. Further, researchers cite evidence that there is a regional warming trend in nighttime temperatures "consistent with theories of climate warming" (Pielke *et al.*, 2002).

TABLE 6. Characterization ("Char") Versus Observed Conditions ("Obs") for Flows in the Platte River Near Grand Island, Nebraska, 1995-2003.

Year	Mar-Apr Char	Mar-Apr Obs	May Char	May Obs	June Char	June Obs	July Char	July Obs	Oct-Nov Char	Oct-Nov Obs	Dec-Jan-Feb Char	Dec-Jan-Feb Obs
1995	Not Dry	Dry	Dry	Wet	Wet	Wet	Not Dry	Not Dry	Wet	Wet	Not Dry	Not Dry
1996	Not Dry	Not Dry	Normal	Normal	Normal	Wet	Not Dry	Not Dry	Wet	Wet	Not Dry	Not Dry
1997	Not Dry	Not Dry	Wet	Normal	Normal	Wet	Not Dry	Not Dry	Wet	Wet	Not Dry	Not Dry
1998	Not Dry	Not Dry	Wet	Wet	Wet	Wet	Not Dry	Not Dry	Normal	Wet	Not Dry	Not Dry
1999	Not Dry	Not Dry	Wet	Wet	Wet	Wet	Not Dry	Not Dry	Wet	Wet	Not Dry	Not Dry
2000	Not Dry	Not Dry	Wet	Normal	Normal	Normal	Dry	Not Dry	Normal	Normal	Not Dry	Dry
2001	Not Dry	Not Dry	Normal	Normal	Normal	Normal	Dry	Not Dry	Normal	Normal	Not Dry	Dry
2002	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
2003	Dry	Dry	Dry	Normal	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
2004	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Accuracy	9 of 10 or 90%		6 of 10 or 60%		8 of 10 or 80%		8 of 10 or 80%		9 of 10 or 90%		8 of 10 or 80%	

Implementation and Ongoing Research

The procedures described here for defining hydrologic conditions have been adopted as initial guidelines subject to modification during the first 13-year increment of the recovery program.

The limitations cited above suggest several potentially productive areas of followup research. This may include identifying and investigating additional variables having lagged effects on streamflow, such as irrigation water deliveries.

Also, some of the variables could be further refined. For example, April 1 snowpack in the North Platte basin has proven to be a useful indicator of basin conditions, but this variable is based on just seven Snotel and snow course survey sites in Wyoming. Alternative sites in both Wyoming and Colorado may prove more useful.

Finally, it would be of interest to investigate the value (if any) of incorporating long term climate outlooks – for example, forecasts disseminated by the National Oceanographic and Atmospheric Administration (NOAA) Climate Prediction Center. In cases where forecasts suggest a high likelihood of wetter than normal or drier than normal conditions, this information could be used to strengthen water management decision making (e.g., Carbone and Dow, 2005).

Interest in defining the real time hydrologic status of river basins is likely to expand as more efforts are implemented worldwide to restore the ecological integrity of deteriorated river systems. In recent years, the importance of flow variability has gained considerable attention as a key component of ecologically sound river management (e.g., Poff *et al.*, 1997; Richter *et al.*, 1997, 2003). Achieving desired year-to-year variability in heavily managed river systems often will require an objective means of characterizing current conditions as a basis for real time water management decisions. The methodology described here may serve as a useful model for such efforts.

CONCLUSIONS

Six multiple regression equations were developed for six periods of the year to determine hydrologic conditions affecting the central Platte River, using seven watershed variables. The adequacy of using these equations as a method for setting real time target flows for the central Platte River was assessed by evaluating their historic correlation to subsequent streamflow in the Platte River at Grand Island, Nebraska. While it is likely that these methods could be improved, the magnitude of errors associated with these equations (applied to the 1947 through 1994 period) and the apparent lack of systematic bias led a stakeholder working group to accept these as satisfactory initial criteria for guiding program related operations. Ongoing evaluations of and possible improvements to these methods will occur during the 13-year first increment of the Platte River Recovery Implementation Program.

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