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Simple Hydrologic Models for Use in Floodplain Research

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Ecological researchers working in floodplain environments commonly need accurate and short-interval (e.g., daily) data on surface- and ground-water fluctuations at multiple sampling sites, for the purpose of establishing linkages between hydrologic variation and biotic fluctuations. However, the cost of automated water level recorders frequently prohibits their installation at each site or plot to be monitored. On the other hand, the cost of shallow ground-water well installation is seldom prohibitive, using techniques described below. The time and personnel needed to obtain manual field measurements then becomes the primary obstacle to obtaining daily water level measurements or estimates. We have developed a modeling approach, using inexpensive data collection equipment, infrequent (e.g., weekly to monthly) field measurements, and simple stepwise regression techniques, to enable researchers to estimate (i.e., model) daily water level conditions during interludes between field measurements.

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Our modeling approach is based upon the understanding that fluctuations in surface water and ground water in floodplain environments often are strongly driven by streamflow and river stage fluctuations (Piper et al. 1939, Suter 1947, Meyer and Turcan 1955, Bell and Johnson 1974, Grannemann and Sharp 1979, Hurr 1981, Kondolf et al. 1987, Rheinhardt and Hershner 1992, Stanford and Ward 1993, Triska et al. 1993). Streamflow measurements or estimates therefore drive our three-step modeling process (see Figure 1):

Step 1. Streamflow Models: If streamflow data at the research site(s) are unavailable, or of inadequate measurement frequency, we begin by collecting streamflow data at the research site(s). We then obtain U.S. Geological Survey (USGS) stream-gauging data from other locations within the same watershed or region, and use this off-site streamflow data as the independent variable(s) to predict streamflow at the research site.

Step 2. River Stage Models: We then use streamflow, measured or estimated in Step 1, as the independent variable to predict river stage (surface-water level).

Step 3. Water Table Models: We use river stage measurements or estimates from Step 2 as the independent variable to predict ground-water levels at each well (located in the plot/transect of interest).

As illustrated by Figure 1, these three types of hydrologic (regression) models are developed using on-site measurements of streamflow, river stage, and ground water data (collected at each plot or transect of interest). Each sequential modeling step illustrated in Figure 1 has a built-in feedback loop, driven by model testing. As each of the three types of models is developed, its adequacy is assessed based upon the model errors resulting from the model development process, or by comparison with additional field measurements collected for the purpose of model validation. If model errors are greater than acceptable for the ecological research, then additional data, or more frequent data, or different types of data must be collected as illustrated in Figure 1. For example, if surface-water levels alone are inadequate to predict ground-water levels with the desired accuracy, then precipitation or evapotranspiration data can be used as additional

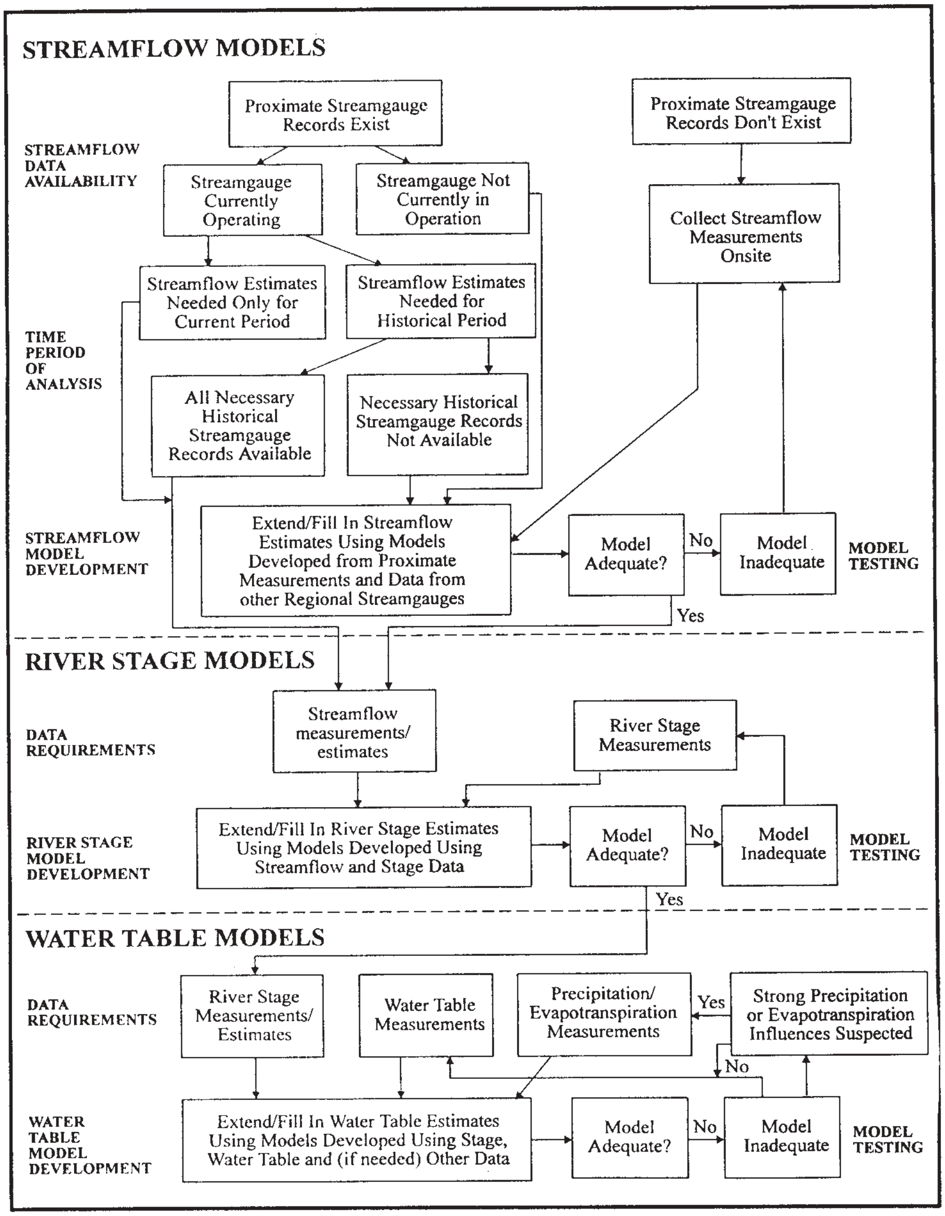

Figure 1. Flow chart illustrating adaptive hydrologic modeling process.

independent variables in stepwise regression to improve the models.

The temporal resolution of these three types of predictive models is ultimately dependent upon the frequency at which streamflow measurements or estimates are available. If hourly streamflow values are available, hourly estimates of surface water or ground water could be developed from the respective models. More commonly, we have used this modeling approach to synthesize daily hydrologic estimates, using readily available daily mean streamflow data from the USGS. The strength and accuracy of streamflow regression models commonly depend upon: (a) the proximity of predictor stream gauge(s) to the river segment of interest; (b) the availability of more than one predictor gauge, for use in stepwise regression modeling; (c) the position of the predictor gauge(s) in the watershed, relative to the segment of interest—gauges located on the same stream or river, rather than on an upstream tributary or on a downstream, higher order channel, will generally work best; (d) the presence of intervening tributary inflows, flow diversions, and other human influences between the independent and dependent sites; and (e) the range of flow variation and length of record measured at the predictor site(s).

We have begun testing this modeling approach on a number of field sites, including the Yampa River near Hayden, Colorado (Figure 2). Ecological research on the Yampa is focused on predicting riparian vegetation changes that would be expected as a result of proposed water development activities in the watershed. Nine monitoring transects that span the width of the Yampa floodplain (perpendicular to the river) have been established for use in vegetation and hydrologic sampling (Figure 2). During 1993, the river stage (surface-water level) was temporarily marked at the edge of water on each transect (using surveyors' stakes), on four to seven different dates as river flows receded from a high stage in late May to a low stage in late July. The water level markers were subsequently surveyed using standard rod-and-level techniques to obtain their elevations.

Sixteen shallow ground-water observation wells were installed during 1992, at depths of 1.7 to 3.2 m below the floodplain surface, depending upon the depth needed to penetrate the expected low water table level by at least 0.5 m. Well installation and monitoring methods followed those described in The Nature Conservancy's "Hydrologic Monitoring Manual" (The Nature Conservancy 1996; available from the authors). Total costs for well materials amounted to less than $1,000.

Model results are presented in Tables 1, 2, and 3, and illustrated in Figure 3. Model validation revealed that we were able to explain from 81% to nearly 100% of the variation in ground-water levels at 14 of the 16 wells based upon river stage alone, with mean errors ranging from 0.09 to 0.30 m at the 14 wells. Thus, mean errors generally were less than 10% of the range of water table fluctuation. At the remaining two wells, confounding influences from a nearby irrigation ditch (Well 4AP) and from an adjacent, flood-irrigated agricultural field (Well 9AS) weakened the ground-water models. As depicted in Ta-

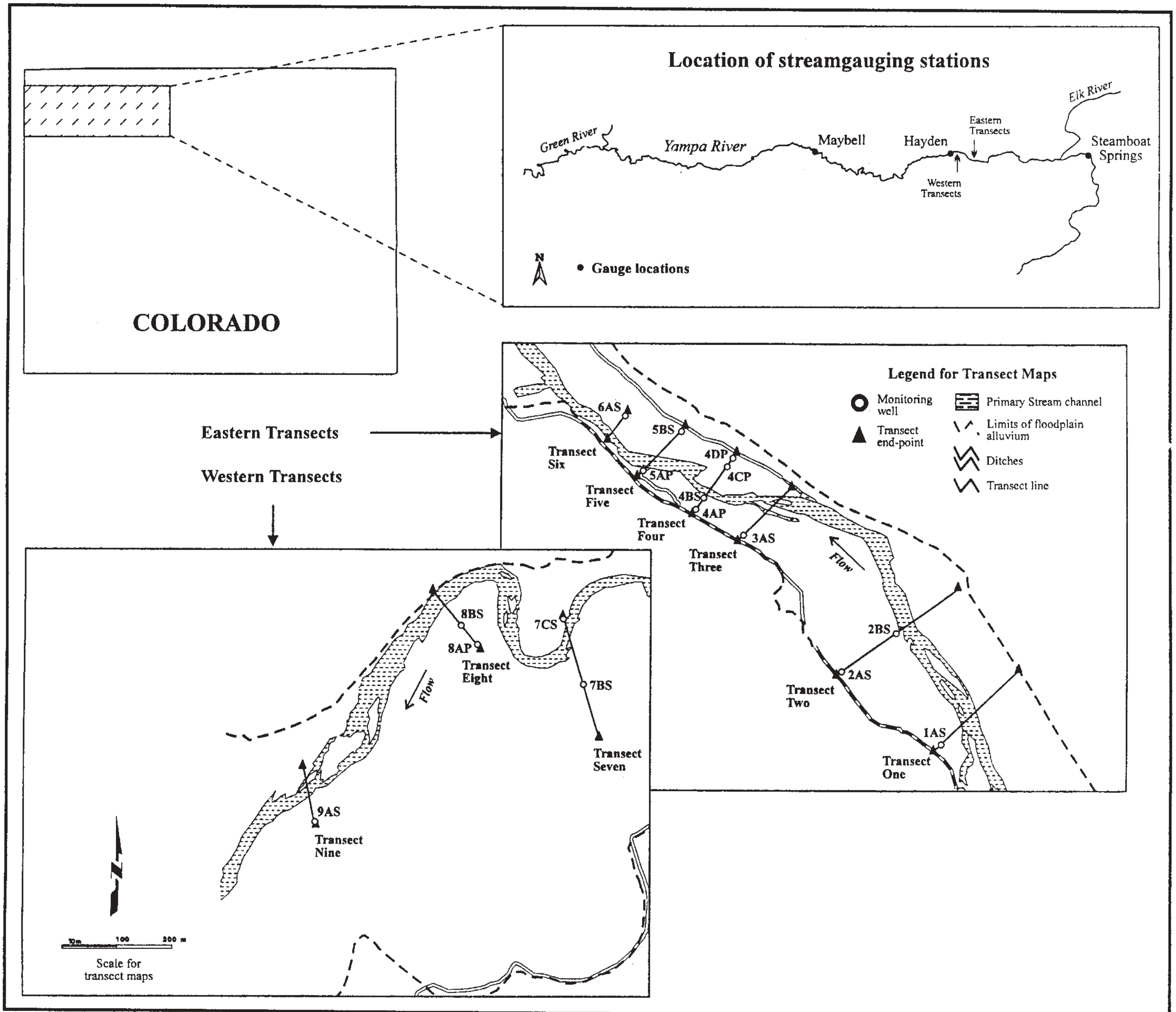

Figure 2. Study area location and distribution of monitoring transects and streamgauge sites.

ble 3, many of the ground-water models were based upon same-day river stage alone; however, the stepwise addition of time-lagged river stage values from 1 to 3 days prior to the ground-water measurement substantially improved some of the models. The importance of time-lagged river stage values can be explained by the time required for water (or more accurately, "head") in the river to reach the ground-water well. In coarse, highly conductive sediments, ground-water levels appear to respond almost instantaneously to chang-

Table 1. River flow modeling results. SHAY=estimated flow for Yampa River at Hayden; SMAY=measured flow for Yampa River at Maybell; SSTEAM=measured flow for Yampa River at Steamboat (all values are square roots of streamflow in cubic feet per second, cfs; see Figure 2 for streamgauge locations). MEE=mean error of estimation (model development); MEP=mean error of prediction (model testing).

River Flow Model				
r^2	p	n	MEE (cfs)	MEP (cfs)
.986	< 0.001	4018	292	224

Equation: SHAY = - 0.93+(0.417*SMAY)+(0.759*SSTEAM) es in river stage on the Yampa. In finer, less-conductive sediments, this translation of head may be delayed by one or more days.

More detailed discussion of these approaches and results appears in an unpublished report available from the authors.

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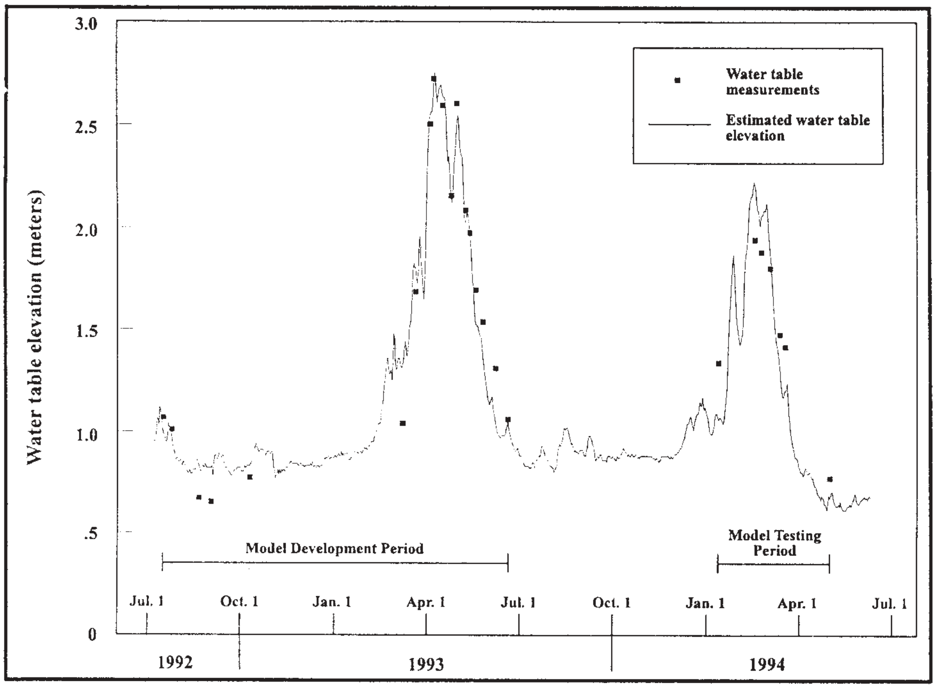

Figure 3. Estimated and observed values of water table level for well 7BS for the period of water table measurements (1992–1994).

Table 2. River stage modeling results. For each research transect, a model was developed to relate river stage to streamflow. LSTAGE = river stage at the transect, in units of log (base-10) meters; LCFS = streamflow, in units of log cubic feet per second (cfs). MEE = mean error of estimation (model development).

River Stage Models

	Equation	r^2	p	n	MEE (meters)
Transect 1	LSTAGE=-0.748+(0.298*LCFS)	.998	< 0.001	5	.017
Transect 2	LSTAGE=-0.898+(0.34*LCFS)	.991	< 0.001	6	.044
Transect 3	LSTAGE=-1.252+(0.404*LCFS)	.971	< 0.001	6	.066
Transect 4	LSTAGE=-0.723+(0.307*LCFS)	.960	< 0.001	5	.066
Transect 5	LSTAGE=-0.904+(0.352*LCFS)	.993	< 0.001	5	.044
Transect 6	LSTAGE=-0.568+(0.264*LCFS)	.980	< 0.001	4	.043
Transect 7	LSTAGE=-1.199+(0.434*LCFS)	.978	< 0.001	7	.116
Transect 8	LSTAGE=-0.785+(0.313*LCFS)	.979	< 0.001	6	.071
Transect 9	LSTAGE=-0.693+(0.3*LCFS)	.983	< 0.001	7	.082

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Table 3. Water table modeling results. Two models were developed for each well: the first model listed is based upon same-day river stage alone; the second model included time-lagged river stage values. If the same-day river stage model was the best overall model, only that model is listed. RS, RS-1, RS-2, and RS-3 represent river stage values on 0– days preceding water table measurements, respectively. MEE = mean estimation error (model development); MEP = mean prediction error (model testing). Well numbers ending with "S" indicate steel (well point) wells; numbers ending with "P" indicate plastic wells.

Well No.	Distance from River (m)	Intercept	Coefficients Used in Regression Equations: RS	RS-1	RS-2	RS-3	r^2	p	n	MEE (m)	MEP (m)
1AS	50.4	.327	.69				.86	< 0.001	19	0.18	0.24
1AS		.34	4.12	-3.42			.93	< 0.001	19	0.14	0.27
2AS	249.9	.74	.44				.71	< 0.001	16	0.20	0.26
2AS		3.03	.48				.95	< 0.001	16	0.07	0.09
2BS	43.6	.254	.81				.98	< 0.001	17	0.08	0.25
3AS	146.9	.31	.78				.87	< 0.001	22	0.16	0.17
3AS		.264				.82	.88	< 0.001	22	0.15	0.15
4AP	77.7	2.27	.108				.51	< 0.001	24	0.07	0.10
4AP		2.25				.118	.53	< 0.001	24	0.07	0.11
4BS	48.2	.23	.865				.96	< 0.001	19	0.13	0.29
4BS		.17			.89		.97	< 0.001	19	0.11	0.31
4CP	71.0	1.15	.45				.81	< 0.001	21	0.14	0.20
4DP	107.6	.84	.84				.92	< 0.001	18	0.16	0.26
4DP		.68				.91	.95	< 0.001	18	0.13	0.28
5AP	58.2	.37	.85				.95	< 0.001	22	0.14	0.33
5AP		0.44	1.68			-0.87	.97	< 0.001	22	0.09	0.30
5BS	93.3	.63	.92				.96	< 0.001	18	0.15	0.15
6AS	98.1	.05	1.04				.98	< 0.001	18	0.09	0.11
7BS	191.4	.36	.80				.96	< 0.001	17	0.14	0.20
7CS	86.3	.29	.78				.98	< 0.001	14	0.08	0.11
8AP	161.8	1.17	.68				.87	< 0.001	16	0.16	0.23
8AP		1.1			.71		.88	< 0.001	16	0.16	0.25
8BS	97.8	.58	.83				.95	< 0.001	17	0.13	0.16
9AS	95.1	.965	.59				.51	0.003	15	0.42	0.63
9AS		.82				.66	.59	0.01	15	0.40	0.65