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Recharge to Ground Water from the West Nishnabotna River

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Abstract. Surface water budgets, calculated from base-flow discharge data, for several reaches of the West Nishnabotna River in Southwest Iowa, reveal two reaches with anomalously small incremental discharges. These small incremental discharges cannot be accounted for through evapotranspiration at the time of the discharge measurements nor can they be related to losses associated with shallow ground water withdrawals near the river. The small incremental discharges in the two reaches are interpreted as resulting from influent conditions at natural ground water recharge sites within each reach. The southernmost of these two sites is located near a major buried valley which may be conducting the influent river water into the subsurface, away from the river.

The regional hydrogeology of a river basin can be outlined by using a variety of surface and subsurface methods. An integral part of such a study should be the determination of gross surface-subsurface water flow relations. It is obvious, in the case of the perennial rivers of Iowa, that groundwater contributions sustain the base-flow. These contributions can have their source in discharge to the river from consolidated and unconsolidated aquifers. The discharge from unconsolidated aquifers can originate in alluvial material in continuity with the stream channel or can be derived from unconsolidated material of glacio-fluviatile origin. The separation of the base-flow discharge of a river into components derived from one or more of the sources mentioned above is generally difficult. The discharge from unconsolidated aquifers is usually distributed through long reaches of a river and where thick unconsolidated material overlies consolidated rock, the discharge of the consolidated material tends to be masked by the effects of the unconsolidated material. Kunkle (1962) developed a general method whereby the hydrograph of base-flow of a river can be separated into components due to "bank storage" discharge and to "basin storage" discharge. This method is particularly useful for interbasin comparisons and is the best general method at present. Further separation of the components of base-flow must be attempted in light of the detailed hydrogeology of a basin, and will usually involve some correlation of the mineral content of base-flow water and that of ground water sources suspected of contributing to base-flow.

A more subtle aspect of the hydrology of Iowa rivers is that they can discharge to groundwater systems. Obviously these dis-

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charges are exceptional circumstances because few, if any, Iowa rivers dwindle in a downstream direction. It seems that the lengths of influent reaches, therefore, would be short, relative to the total length of effluent river. If an influent reach can be identified, the problem of where the river water goes can be attacked with the local hydrogeology as a guide. Because the influent reach will be of limited length, the discharge to groundwater is somewhat localized and the problem is less imposing than that of separating base-flow components in a longer, effluent reach.

IDEAL METHOD OF STUDY OF RIVER REACH WATER BUDGETS

The ideal data with which to identify and define an influent river reach would consist of base-flow discharge measurements taken every three or four miles on the main stream, and discharge measurements of all tributaries at their confluence with it. These measurements should all be made simultaneously under conditions of minimum evapotranspiration, and of no consumptive use of alluvial ground water or of river water.

With these data, under the specified conditions, simple calculations of the water budget balance in each river reach would permit reaches to be classified as influent or effluent. The calculation would simply be to subtract the upstream river discharge in a given reach, from the downstream river discharge in the reach, and to subtract the sum of discharges of all intervening tributaries from this difference.

$$\triangle Q = Q_{downstream} - Q_{upstream} - \Sigma Q_{tributary} \qquad (1)$$

A positive value of $\triangle Q$ would indicate that the river was gaining water, aside from tributary contributions, in the reach. A negative value of $\triangle Q$ would indicate that water loss in the reach occurred.

This technique would isolate a reach from the cumulative and integrated effects of all the variables affecting river flow upstream of the reach. Likewise, it would strip out the effect of tributary flow contributions within the reach, which may mask gains or losses in the main stream itself.

METHODS FOR PRELIMINARY STUDY OF RIVER REACH WATER BUDGETS

The set of data obtained from instantaneous discharge measurements at all desired measuring sites on a river and its tributaries would be difficult, if not impossible, to secure. Measurements of discharge, taken on rivers and some of their tributaries, within a period of one to two or three days, are available as discharge measurements made at low-flow partial-record stations, and published by the U. S. Geological Survey, Water Resources Division, in Water Resources Data for Iowa, Part 1, Surface Water Records. These measurements are not complete, in that discharges of only the major tributary streams to various rivers are made, hence calculated reach $\triangle$ Q values will be too large by the amount of the sum of discharges of unmeasured tributaries within a river reach. The data, however, should be of value in a preliminary analysis of surface flow.

As stated previously, an incremental river reach discharge ($\triangle$ Q) should be a valid quantity for comparison of reaches. It may, in fact, be necessary to use this quantity with the available data in order to identify influent river reaches. Comparisons are frequently made using station discharge measurements normalized by the drainage area upstream of the respective stations (Q/A, discharge per unit drainage area upstream of the measuring station). Such a comparison for stations, as located in Figure 1, on the West Nishnabotna River is presented in Table 1. The data, from six water years, were analyzed as a randomized block design, considering stations as treatments and water years as blocks. The treatment mean square is significant and blocking is effective, but the only departure from the downstream trend of increasing mean values of Q/A was found to be non-significant. The only conclusion that can be reached from this analysis is that discharge per unit area increases downstream, but this brings us no closer to identifying possible influent reaches. Increasing discharge per unit drainage area in a downstream direction is a fairly normal aspect of alluvial streams in Iowa, and the failure of this type of analysis to discriminate significantly between stations is not surprising be-

Table 1
Discharge per unit Drainage Area*

			Water Year					
Station No.	1960	1960	1961	1964	1965	1966	Mean	Difference between Means
1	0.027	0.094	0.208	0.059	0.109	0.069	0.094	
3	0.055	0.164	0.207	0.080	0.127	0.100	0.122	
4	0.059	0.198	0.196	0.078	0.141	0.112	0.130	0.002 n.s.
6	0.052	0.244	0.192	0.067	0.131	0.082	0.128	
9	0.093	0.266	0.194	0.074	0.142	0.118	0.147	
9.5	0.097	0.271	0.189	0.078	0.145	0.123	0.150	
11	0.110	0.309	0.211	0.079	0.147	0.110	0.161	

$s_{\bar{d}} = 0.0161$

lsd(0.05) = 0.0328

* Cubic feet per second per square mile (csm)

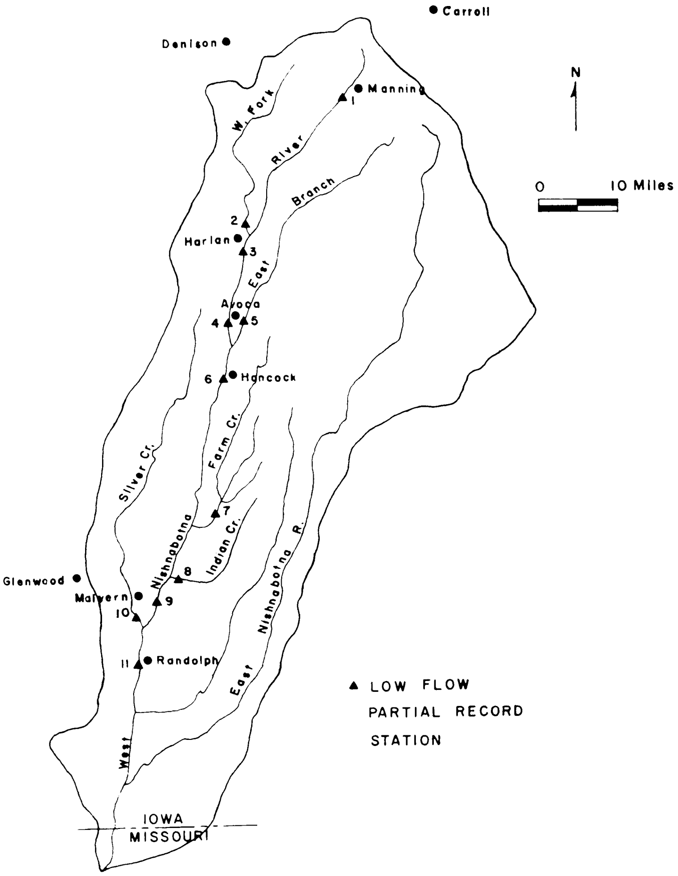

Figure 1. Nishnabotna River Basin showing Low-Flow Partial-Record Discharge Measurement Stations.

cause each discharge measurement, treated by itself, represents an integration of cumulative hydrologic effects in all of the drainage basin upstream of the station.

Two alternative approches to preliminary study of river reach water budgets present themselves. These are to calculate and compare among reaches, mean values of 1) $\triangle Q/\triangle A$, where $\triangle A$ is difference in river drainage area for the reach, and 2) $\triangle Q/A_{ds}$, where A_{ds} is the total river drainage area at the lower end of the studied reach. Any low mean values, relative to corresponding values up and downstream, if significant, would be taken as being indicative of an abnormal condition. This abnormal condition could then be interpreted to be the result of either loss of river water to the subsurface within the reach, a decrease in bank and basin storage discharge to the river in the reach, or a combination of both. An element of uncertainty is necessarily present in the interpretation because of the fact that all tributary discharges are not known (ΔQ is too large).

RESULTS OF A PRELIMINARY STUDY OF SEVERAL REACHES ON THE WEST NISHNABOTNA RIVER

Discharges for six water years from partial-record stations on the West Nishnabotna River and some of its tributaries were used to calculate $\Delta Q/\Delta A$ and $\Delta Q/A_{ds}$ for five reaches on the river. The measurements were made in September, October, or November and in each year were made in a period of one to three days.

The calculated values of $\Delta Q/\Delta A$ and $\Delta Q/A_{ds}$ are tabulated in Tables 2 and 3, respectively. Mean values of $\Delta Q/\Delta A$ and $\Delta Q/A_{ds}$ were calculated for each reach. The data were analyzed as a randomized block design in which reaches were considered as treatments, and water years as blocks. Blocking is effective in both cases and treatment mean squares are highly significant. The indicated differences between means were tested against the least significant difference (lsd).

Comparison of means of $\Delta Q/\Delta A$ (Table 2) reveals a highly

Table 2
Change in Discharge per Unit Change in Drainage Area#

Reach Limit Stations	Water Year						Means	Difference between Means
	1960	1960	1961	1964	1965	1966		
1-3 (Manning-Harlan)	0.029	0.079	0.073	0.039	0.061	0.050	0.055	
3-4 (Harlan-Avoca)	0.097	0.456	0.114	0.068	0.246	0.204	0.197	
4-6 (Avoca-Hancock)	-0.023	0.077	0.056	0.006	0.002	-0.030	0.014	0.107**
6-9 (Hancock-Malvern)	0.120	0.153	0.131	0.062	0.131	0.129	0.121	
9-11 (Malvern-Randolph)	0.044	0.149	0.136	0.025	0.058	-0.017	0.065	0.056* (α=0.15)

$s_{\bar{d}} = 0.0351$
lsd(0.01) = 0.0998
lsd(0.20) = 0.0465

#$\Delta Q/\Delta A$ (csm)

Table 3

Change in Discharge per Unit Drainage Area#

Reach Limit Stations	Water Year							Difference between Means
	1960	1960	1961	1964	1965	1966	Means	
1-3 (Manning-Harlan)	0.023	0.065	0.060	0.032	0.050	0.041	0.045	
								0.023**
3-4 (Harlan-Avoca)	0.011	0.052	0.013	0.007	0.028	0.023	0.022	
								0.016**
4-6 (Avoca-Hancock)	-0.009	0.032	0.023	0.002	0.001	-0.012	0.006	
6-9 (Hancock-Malvern)	0.044	0.056	0.048	0.023	0.048	0.047	0.044	
								0.027**
9-11 (Malvern-Randolph)	0.011	0.039	0.035	0.006	0.015	-0.004	0.017	

$s_{\bar{d}} = 0.0051$

lsd(0.01) = 0.0145

#$\triangle Q/A_{ds}$ (csm), where A_{ds} is total drainage area at downstream end of reach.

significant low value for the Avoca-Hancock reach and low value, significant at the 85% confidence level for the Malvern-Randolph reach. Highly significant low values of means of $\triangle Q/A_{ds}$ for the same two reaches were calculated (Table 3). It should be noted that the incomplete discharge data yielded negative $\triangle Q$ values only in these two reaches.

INTERPRETATION OF RESULTS

The discharge measurements used in the analysis were made near the end of or after the growing season so that the effect of transpiration should be minimal. Evaporation of channel water is likely to affect one reach just about as much as another so that evaporation can be considered a constant through the five reaches.

Ground water withdrawal in moderate quantity from river alluvium occurs at Avoca in the Avoca-Hancock reach. This withdrawal is probably just about equalled by the amount of waste water effluent to the West Nishnabotna River from the Avoca town system. No appreciable ground water withdrawals occur in the Malvern-Randolph reach.

It seems, that by elimination, the significantly low mean values

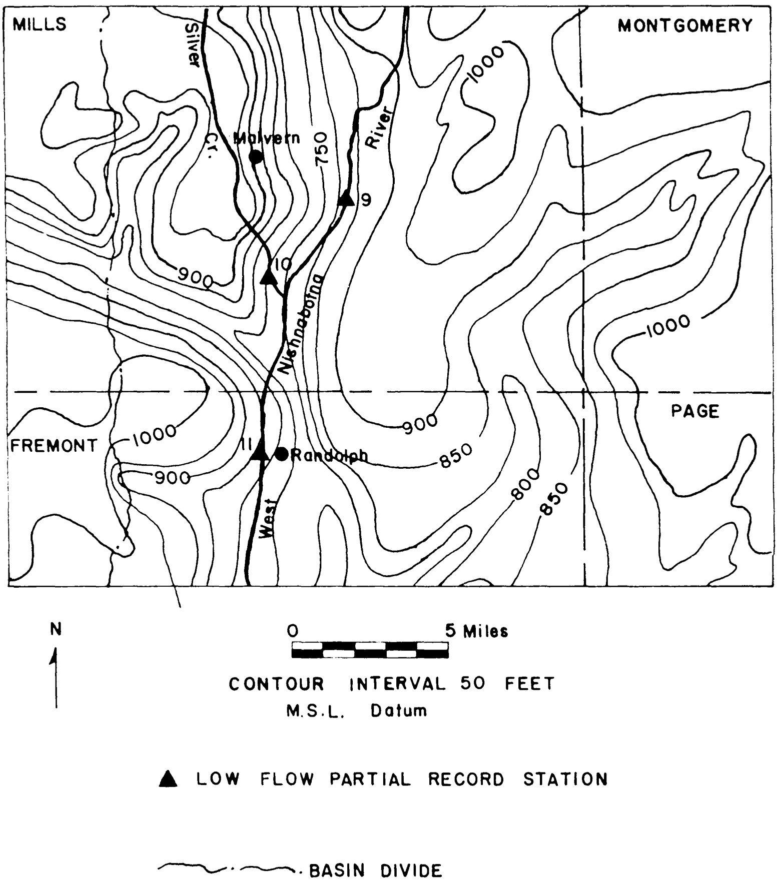

Figure 2. Bedrock Topography in Portions of Mills, Montgomery, Fremont, and Page Counties, Iowa (Modified from Sendlein et al (1968).

of $\triangle Q/\triangle A$ and $\triangle Q/A_{ds}$ for the Avoca-Hancock and Malvern-Randolph reaches can only be explained by losses to the ground water system and/or decreases in the amount of discharge to the river from bank and basin storage. Decreases in the amount of discharge to the river from bank storage seems unlikely because the flood plain and its associated alluvium is wider at both of the reaches in question than upstream from them. Because at least one negative $\triangle Q$ value for each reach was recorded and because each calculated $\triangle Q$ value is really larger than it would be with complete data, it is concluded that the low mean values for the derived discharge quantities in the Avoca-Hancock and Malvern-Randolph reaches are caused by losses of river water to the subsurface.

The Malvern-Randolph reach lies just about astride the junction of a north-south trending buried bedrock valley, referred to as the Fremont Channel, and a tributary bedrock valley which trends to the west-northwest. Figure 2, a portion of a bedrock topographic map modified from Sendlein et al (1968), illustrates this relationship. If the tributary bedrock valley contains coarse, unconsolidated materials (sand and/or gravel), as these valleys often do, and if there is continuity between this material and the river alluvium, it may be that the water lost in the Malvern-Randolph reach of the West Nishnabotna River, makes its way in the subsurface through the tributary bedrock valley towards the west-northwest.

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