EFFECTS OF HUMAN-INDUCED CHANGES ON HYDROLOGIC SYSTEMS
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Effect of a Beaver Pond on Groundwater Elevation and Temperatures in a Recovering Stream System

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ABSTRACT: This study was designed and implemented to observe the spatial and temporal dynamics of groundwater levels and temperatures adjacent to a beaver pond on a gullied riparian area in semi-arid central Oregon. The study site is located on the eastern boundary of Painted Hills National Monument along Bridge Creek, a tributary to the John Day River. Groundwater levels and groundwater temperature were monitored in 64 wells from June, 1991 to June, 1992. Groundwater elevations varied seasonally and were generally positively correlated with streamflow. Groundwater levels throughout the study site averaged a 0.31 m gain as streamflow increased two-fold from August to November 1991. To varying degrees, all wells at the study site responded to changes in streamflow, and thus appeared to be hydraulically connected to the stream. In addition, beaver dam-building activity appeared to increase aquifer recharge near the beaver pond in comparison to downstream areas. Based on hydraulic gradients, the movement of water from the stream to subsurface recharge of riparian areas appeared to be greater near the pond than at downstream locations. The results of this study support the conclusion commonly expressed in the literature, but seldom quantified, that elevated water tables do occur adjacent to beaver ponds. Groundwater temperatures closely followed stream temperatures in wells next to the stream, indicating that stream temperatures readily influence groundwater temperatures. The temperatures in wells located a few meters from the beaver pond were nearly in phase with stream temperature. A downstream well adjacent to the stream had a lag time of about three months. Wells located relatively far out on the floodplain (i.e. 50 meters) but opposite to the beaver pond had about a two month response lag behind stream temperature.

KEY TERMS: Beaver; bank storage; groundwater; groundwater temperature.

INTRODUCTION

Beaver (*Castor canadensis*) have had a significant effect on many streams in semi-arid environments throughout the western United States. Beaver dams and ponds interact with stream and groundwater hydrology in complex ways not yet fully understood. Beaver activity in certain areas may enhance the quality of riparian habitat by creating more favorable conditions for plant growth. Conversely, in other areas beaver may negatively affect riparian habitat through the destruction of riparian plants. Increased interest in riparian area restoration has increased interest in using beaver management to help restore degraded streams (Apple, 1983; Apple, 1985). Beaver ponds provide a number of important ecological functions, such as impounding surface water and trapping sediment. This may lead to additional changes in the ground- and surface-water hydrology of riparian areas and could result in more favorable conditions for riparian vegetation.

Observational evidence suggests water table elevations are elevated adjacent to beaver ponds. Upland plants, which do poorly in wet environments, will eventually recede from the streamside in these areas. Hence, obligate hydrophytic plants which require high levels of soil moisture may increase. However, very little research has been undertaken to examine changes in riparian area hydrology that can occur in areas affected by beaver. Knowledge of hydrologic changes that occur in these areas may provide a better determination of their relative importance for altering stream and ecosystem processes, as well as the merit of using beaver to help restore degraded stream systems.

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PURPOSE AND OBJECTIVES

This study provides information on the spatiotemporal dynamics of groundwater elevations and groundwater temperatures adjacent to beaver (*Castor canadensis*) dams in a downcut stream system. Surface water stored behind these dams may increase the rate of water exchange with stream banks and provide a mechanism for increased subsurface storage and lateral spreading of groundwater. Shallow water tables adjacent to beaver ponds, may over time, show substantial and measurable differences in surface elevations from that of similar un-dammed upstream and downstream reaches. This study was designed to gain an understanding of the relationship between bank storage, stream discharge, groundwater temperature and pond level, and to develop an improved understanding of the interaction of these variables. Efforts were also made to characterize the alluvial aquifer near the pond to provide information on the ability of bank materials to transmit groundwater (Lowry, 1992).

BEAVER AFFECTS IN RIPARIAN AREAS

Beaver were once abundant along waterways in a large part of North America. At the time of the first explorations of the continent by Europeans beaver populations were estimated to be at least 60 million individuals over an area of 15.5 million km^2 (Jenkins and Busher, 1979); this equates to an average density of about 4 beaver/km^2. While nowhere near their former numbers, where present beaver continue to have a significant influence on stream ecosystems. Beaver ponds directly affect surface water and sediment storage, the quality and quantity of fish and wildlife habitat, nutrient storage, and the water table adjacent to ponds (Allred, 1980; Apple, 1985). Several authors (Apple, 1983; Parker et al., 1985; DeBano and Heede, 1987; Skinner et al., 1988; Gebhardt et al., 1989) suggest that beaver ponds may contribute to the local elevation of the adjacent water table. Effective groundwater recharge alongside the stream creates saturated conditions in the soil mass and elevates the free water surface near the stream. The elevated water surface sub-irrigates streamside vegetation on low terraces adjacent to the stream. Plant communities on these terraces may shift from more xeric upland species to obligate riparian species as subsurface water reaches their root zones (Elmore and Beschta, 1987). In addition, bank and streambed subsurface water storage associated with small in-stream structures such as beaver dams may contribute to baseflow by the slow release of stored water during periods of low stream flow (Baurne, 1984).

Soil moisture in streambanks is dependent on ground water energy gradients, capillarity, stream channel morphology, bank and floodplain interaction, and water storage capacity. Groundwater storage in streambanks and in the alluvial aquifer under and adjacent to the stream is an important factor affecting the permanence and magnitude of surface flow (Stabler 1985; Kondolf et al., 1987) and for maintaining riparian vegetation. By increasing the total biomass and relative permanence of streamside vegetation, stream channels may aggrade (Elmore and Beschta, 1987) and streamside water tables may rise, especially along low-gradient streams. As vegetation becomes well established, the vegetation encourages the trapping of sediment and increases the infiltration capacity and moisture retention of soils. In contrast, channel incision lowers a streambed through a process of riparian vegetation destruction and fluvial erosion. Once channel incision occurs, it may be followed by a period of channel instability, with the potential for additional bank erosion, dewatering of riparian zones, downstream transport of sediment and destruction of streamside aquatic habitat (Schumm et al., 1984).

Stream and Soil Temperatures

During summer months and to a limited extent in the winter, the soil surface is heated during the day predominantly by incoming solar radiation. This heat is subsequently lost by convection to the surrounding air, evapotranspiration, longwave radiation, or is transmitted into the ground by conduction. During the winter, the reverse occurs, causing soils to cool (Taylor, 1969). At some depth, usually well below the surface but not deep enough to be affected by the geothermal gradient, the mean annual soil temperature remains virtually constant throughout the year (Carter and Ciolcosz, 1980). Above this depth the balance of heat inflow and outflow causes annual soil temperatures to fluctuate as a nearly perfect sine curve. Seasonal and diurnal variations in soil temperatures are generally restricted to the upper three meters of soil and subsoil (Freeze and Cherry, 1979). Shallow groundwater may also be affected by seasonal and diurnal temperature changes in the soil profile due to convective or conductive heat transfer.

STUDY AREA

The study area is located in the eastern portion of Wheeler County in north-central Oregon, approximately ten kilometers northwest of the town of Mitchell (Figure 1). The site comprises 3.1 ha on the west bank of Bridge Creek along the eastern boundary of Painted Hills National Monument. Bridge Creek drains a 345 km² watershed above the study area. The stream drains the Ochoco Mountains, and is a tributary to the John Day River. The upper basin is mostly forested with mixed conifers, with sagebrush, juniper woodlands, and a few alfalfa fields in the lower basin. The climate of the study site is characterized as semi-arid.

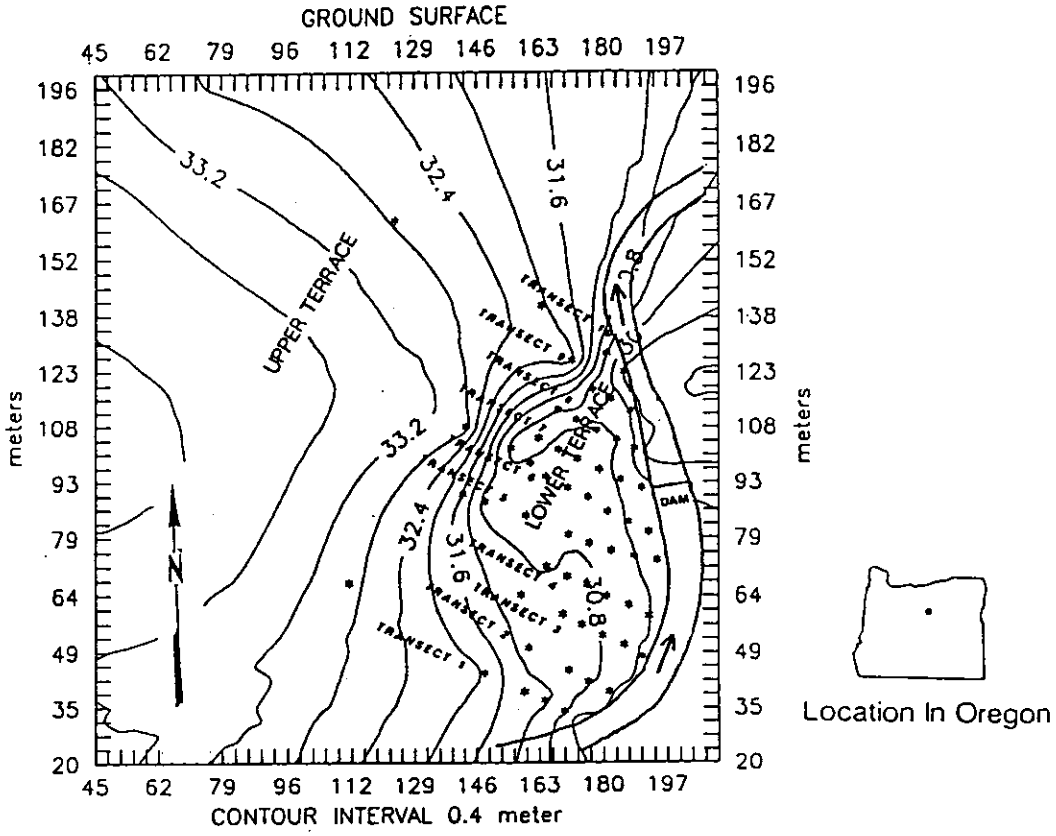

Figure 1. Location map and study site topography. Well locations are indicated by asterisks.

The study area is underlain by the easterly dipping John Day formation, composed predominantly of tuffaceous claystones with some intercalated vitric tuffs. Valley floor deposits are underlain by Quaternary alluvium, and consist of thinly bedded layers of clay, sand, and gravel. For much of its length Bridge Creek is deeply incised into extensive alluvial deposits. Two distinct stream terraces dominated the wellfield morphology. The relatively flat upper terrace was about three meters above the lower, streamside terrace. While hydrophytic plant species are commonly found on the lower terrace, no willows or cottonwoods appear on the upper terrace.

METHODS AND STUDY DESIGN

In order to meet the study objectives, water levels and groundwater temperatures were measured monthly from June 1991 to June 1992 in 64 small diameter observation wells (Figure 1). Daily water levels were also monitored in six wells and in the beaver pond with pressure transducers and were recorded with a data logger. Wells were made of various lengths of 1.9 cm inside diameter schedule 40 steel pipe screened for the lower 91 cm, and were driven into place. The alluvial aquifer was composed predominantly of sandy silt to small gravel, allowing the use of a perforated pipe well screen. Streamflow, stream stage, and pond level were also measured at monthly intervals. Daily total rainfall for the entire year was obtained from a remote NOAA weather station located 5 km from the site and at a similar elevation. Also, soil bulk density and soil characteristics were determined for the study site. Aquifer hydraulic properties were determined by using a slug test developed by Bouwer and Rice (1976) for unconfined aquifers. Determination of *in situ* Hydraulic Conductivities (*K*) of streamside alluvium were desired to help determine the likely lateral extent of elevated groundwater levels. If *K* is relatively high, increased lateral spreading of elevated water tables would be expected. Conversely, if *K* is relatively low, lateral spreading of high water tables would be limited. Lateral extension of bank storage effects may also be constrained or accentuated by heterogeneity of bank sediments. Each well's elevation and horizontal distance relative to a datum was established using standard surveying techniques. Thus exact elevations of the free water surface could be obtained, as well as the elevation of the ground surface. Well transects were located perpendicular to the dominant downvalley trend of the stream. Contour maps were created from ground surface and groundwater elevation information using SURFER©.

RESULTS AND DISCUSSION

Aquifer Characteristics

Saturated hydraulic conductivity (*K*) values for selected wells ranged over three orders of magnitude, from 10^{-2} to 10^{-5} cm/sec (Table 1). Large spatial variability in *K*-values is present. However, *K*-values generally tend to be higher near the stream. Hydraulic conductivity in wells farthest away from the stream had some of the lowest values measured, but this pattern is not consistent.

Table 1. Saturated hydraulic conductivities for selected wells at the Bridge Creek study site. Well transects 1-10 are located up- and downstream respectively. Well A is closest to the stream, with lower alphabetical orders away from the stream.

WELL	K (cm/sec)	WELL	K (cm/sec)	WELL	K (cm/sec)	WELL	K (cm/sec)
1A	2.9E-02	4D	1.2E-02	6D	2.6E-03	8C	4.1E-04
1B	2.1E-02	4E	1.6E-03	6E	1.2E-02	8D	1.2E-04
1C	3.6E-03	4F	6.1E-03	6F	5.6E-03	8E	1.4E-03
2A	6.6E-03	5A	4.6E-02	6G	1.3E-04	9A	7.5E-04
2B	4.5E-02	5C	1.9E-03	6H	1.3E-03	9B	6.3E-03
3A	3.5E-02	5D	1.2E-02	7B	6.8E-03	9C	1.4E-02
3D	2.4E-03	5E	6.0E-05	7C	2.4E-02	10B	4.0E-03
3E	9.4E-03	5F	1.4E-04	7D	2.9E-03	10C	9.0E-05
3F	1.9E-02	5G	2.6E-03	7E	3.2E-03		
4A	3.8E-02	6A	1.7E-03	7F	2.2E-04		
4B	2.3E-02	6C	6.0E-05	8B	4.2E-02		

Since alluvial deposits are seldom homogenous, spatial variability of *K*-values was not unexpected. Considerable variation in particle size and soil types have been observed in gullied stream cross-sections in this area. Often, within a few meters the alluvium deposits changed composition from silty clay to fine gravel. Fluvial depositional processes such as lateral accretion deposits and stream bars are highly complex, and tend to create a heterogenous mixture of sediments.

Rainfall and Streamflow

Figure 2 shows a relationship between stage at the beaver pond, precipitation at the Meyer's Canyon weather station, and well 6B, located 7 meters from the pond. Although precipitation may affect groundwater recharge, well response more closely corresponds with beaver pond stage. Streamflow was very low for the months of August through September, ranging from about 0.04 to 0.15 m^3/sec. Groundwater levels were at their lowest during low flow periods. A two-fold increase in stream discharge occurred in November, with a corresponding overall general rise in groundwater level and a rise in beaver pond stage. The most likely factor affecting changes in groundwater storage for different time periods appears to be beaver pond stage, which is generally tied to changes in streamflow. Increased streamflow generally increased the pond stage, and increases the hydraulic gradient between the stream and its banks up- and downstream of the pond. A similar mechanism for subsurface water recharge was observed by Kondolf (1987) along the Carmel River of California, where alluvial bank material was recharged during periods of high streamflow and increased channel water depths, and stored groundwater drained back to the channel during low-flow, low water level periods.

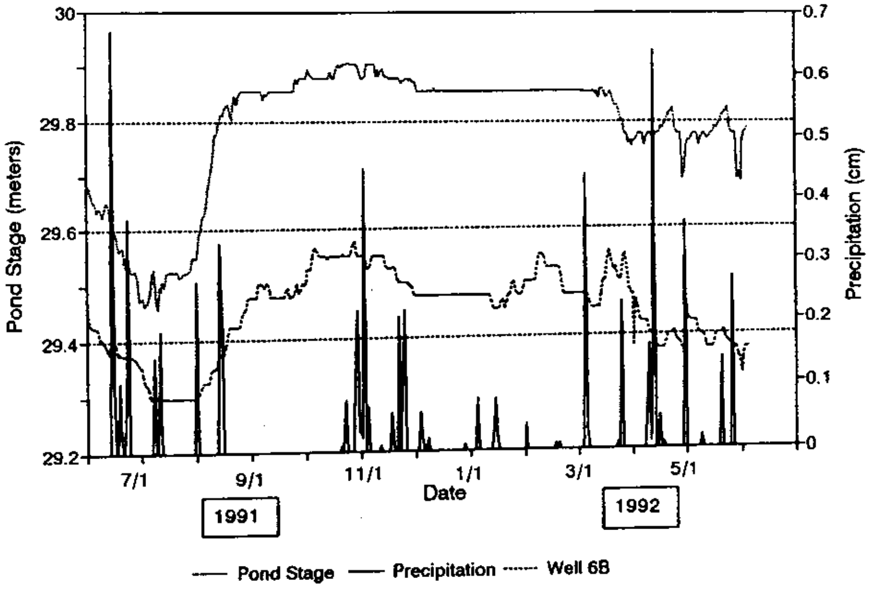

Figure 2. Relationship between beaver pond stage, precipitation, and water level in well 6B, June 1991 to June 1992.

Groundwater levels

Temporal Patterns

Contour maps of the differences in water levels for the well-field were evaluated and average values for water level change were calculated. The differences indicate a net gain or loss of groundwater storage in the well field (Table 2). The greatest differences occurred between August and November 1991. During this time increased flow in the stream resulting from late October precipitation, lack of water withdrawals for irrigation and beaver dam building activity increased the stage in the beaver pond from about 29.6 m to 29.9 m. Increases were not uniform throughout the well-field. For instance, the groundwater elevation of a well located near the pond rose 0.35 m between August and November 1991, while the beaver pond stage increased by 0.30 m. Groundwater elevations at another well located downstream of the dam increased by only 0.17 m during this period with a corresponding increase in stream stage of 0.05 m. Wells adjacent to the pond responded to increasing stage in the pond, while wells downstream of the dam and further out from the stream did not.

Table 2. Estimated groundwater level differences and differences in beaver pond stage for selected periods between August 1991 and June 1992 in the wellfield.

Time Period	Difference in Well Level (m)	Change in Pond Stage (m)
Aug. 1991- Nov. 1991	+0.31	+0.30
Nov. 1991- Jan. 1992	+0.02	0
Jan. 1992- Apr. 1992	+0.02	-0.06
Apr. 1992- Jun.1992	-0.14	-0.06

Spatial Patterns

Elevation of the groundwater surface next to the pond represents a dynamic water storage volume. This volume appears to change from month to month, and depends on several factors. Storage is dynamic since groundwater is apparently actively moving through the system at a rate based on the relative hydraulic conductivity of the aquifer and the hydraulic gradient. Yet, in plan view, the shape or topographic pattern of the equipotential surface is similar from month to month. What appears to undergo the most change is the relative elevation of the groundwater surface.

Four time periods were used for comparing groundwater levels because they represent general patterns of variation. These periods included August 21, 1991; November 4, 1991; April 9, 1992; and June 11, 1992 (Figure 3). Plan views provided by topographic maps of the equipotential surfaces of each measurement period indicate little change in the plan view (i.e. horizontal) dimensions of the water table. However, free water surface elevations changed markedly with increases in streamflow, and associated stream stage. Although groundwater elevations varied considerably over time, in plan view, the "topographic pattern" of relative highs and lows remained essentially unchanged. The free water surface does not resemble a "water table," but appears to be spatially controlled by several factors including variations in aquifer hydraulic conductivity, streamflow and stream stage, and hydraulic gradient.

For November, as for all other months, the south-central area of the map (Figure 3) depicts the highest groundwater levels. The stream upstream of the pond is probably actively recharging the groundwater in this area. Groundwater recharge appears to be actively occurring adjacent to the pond. The pond also appears to be creating a large zone of groundwater storage with groundwater surface elevations that are relatively higher than in adjacent areas and which extend into the floodplain and slightly downstream of the dam.

Figure 4 shows a groundwater-level transect along well Transect 8 and stream levels for November and April. The transect is located about 8 m downstream of the dam. For the high streamflow winter and spring months, water levels in the wells were consistently higher than the stream, hence creating a local hydraulic gradient *toward the stream.* Groundwater "pooling" was observed adjacent to the stream. Thus during these periods groundwater flows from the aquifer directly to the stream immediately downstream of the dam. Numerous small seeps were observed emanating from the streambanks near well 8A during these time periods. This relationship may be particularly important in the late spring and summer when stream temperatures approach or exceed those lethal for salmonids while groundwater seeps draining to the stream are much cooler.

Groundwater Temperatures

Time-series plots were used to illustrate relative response times of water temperatures for two wells (Figure 5). Well

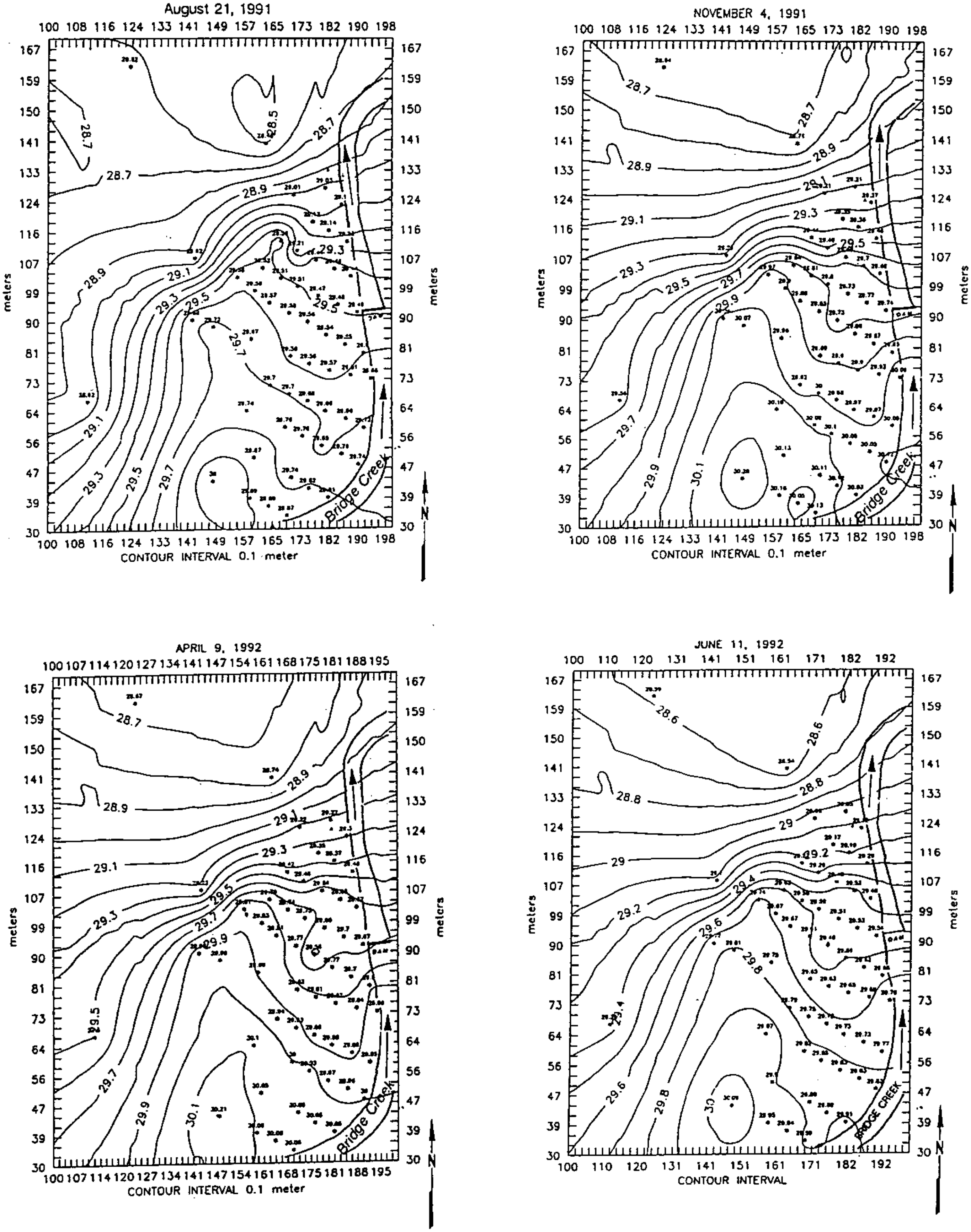

Figure 3. Contour maps of groundwater levels for August 21 and November 4, 1991; and April 9 and June 11, 1992. Groundwater levels in areas of the map with few monitoring wells were estimated by contouring program.

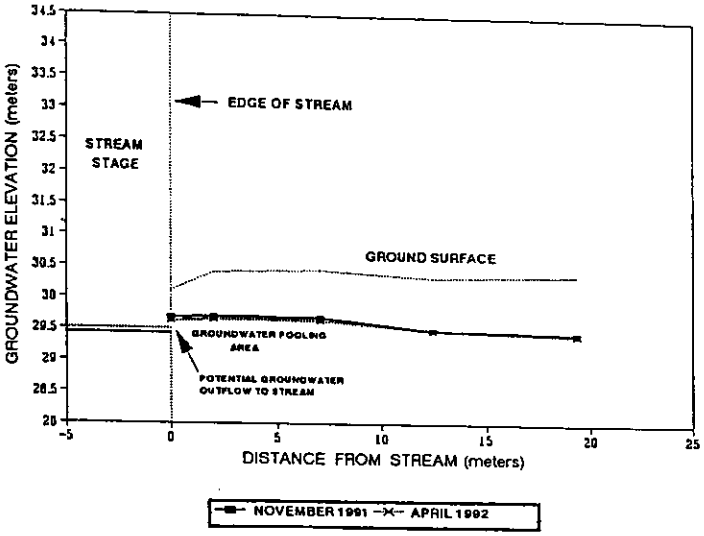

Figure 4. Groundwater levels, stream stage, and ground profile along well transect 8, located 8 m downstream of the beaver pond for November, 1991 and April 1992.

5A, located 21 m upstream of the dam and 1 m from the pond, showed about a one month lag behind stream temperature during the fall, and closely matched stream temperature during the springtime warming. The lowest well temperature was approximately 2°C higher than the lowest stream temperature. This relationship implies that the well temperature response is buffered from low winter temperatures, yet responds relatively quickly to stream temperatures during cooling or warming periods. Well 10B is located about 32 m downstream of the dam, and about 7 m from the stream. Since the lag of well temperature behind stream temperature is about 3 months, this well appears to be less sensitive to temperature changes in the stream.

Spatial Patterns

Groundwater temperatures were compared for August, October, December, January, and April for well transect 6 and 9 (Figures 6 and 7). Spatial variation in groundwater temperatures may provide qualitative information regarding water exchange between the stream and the aquifer. Well transect 6 (figure 6), located adjacent to the pond, more closely reflects the temperature in the pond. Well transect 9 (figure 7), downstream of the pond, shows less variability over time in wells nearest the stream. For both transects, August values typify warmer groundwater conditions, with higher temperatures near the stream and cooler temperatures away from the stream, under the floodplain. January groundwater temperatures were much cooler near the stream and warmer under the floodplain, and near-stream well temperatures were lowest adjacent to the pond. It appears that the stream influence on groundwater temperatures near the pond was greater than at downstream areas. Wells located near the pond showed the highest temperature variability over time, suggesting that the stream is more effective at recharging the streambanks alongside the pond. This is consistent with the observation that the hydraulic gradient tended to be away from the stream channel near the pond, and toward the stream channel downstream of the pond.

SUMMARY AND CONCLUSIONS

Depth to groundwater is an important variable for the establishment and survivability of riparian plant species. Although groundwater elevations varied by up to about 0.3 m over time, in plan view the "topographic pattern" of relative highs and lows remained essentially unchanged. Groundwater elevations generally positively correlated with water surface elevations in the stream channel. Beaver dam-building activity appeared to increase aquifer recharge near the beaver pond in

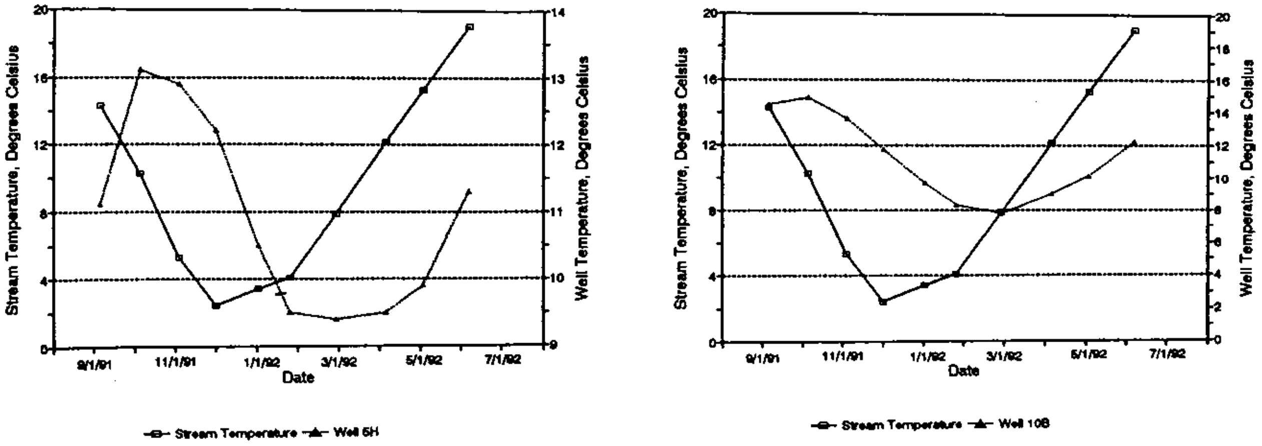

Figure 5. Time series of stream temperature and temperature of well 5A, located 21 m upstream of beaver dam, 1 m from the pond, and well 10B, located 32 m downstream of the dam for September, 1991 through June, 1992.

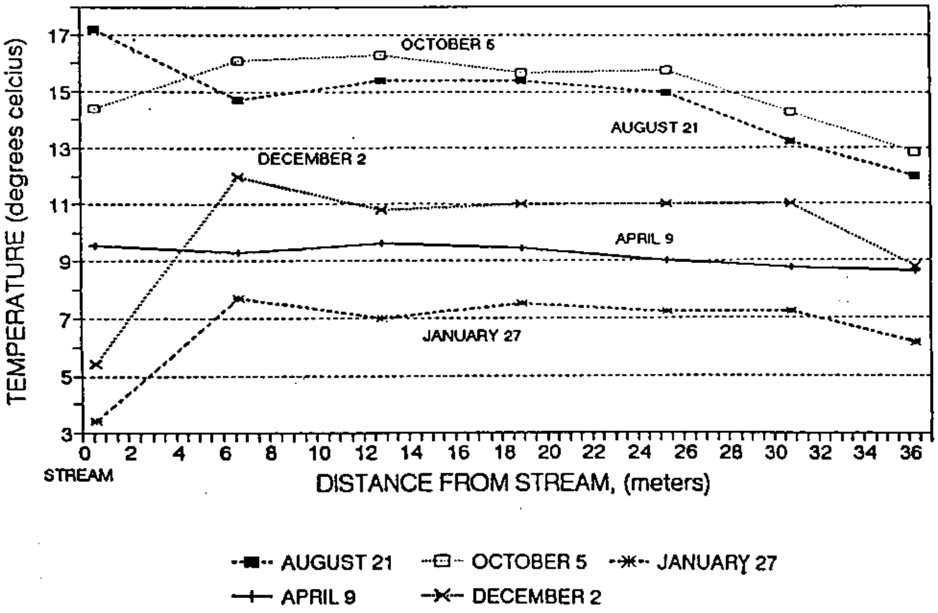

Figure 6. Groundwater temperatures of well transect 6 for August, October, and September, 1991, and January and April 1992.

comparison to that associated with downstream areas. All wells at the study site responded to changes in stream flow and associated stream stage, and thus appear to be hydraulically connected to the stream. The pond appears to be particularly effective at recharging the near-stream aquifer due to a substantial hydraulic gradient from the pond to the water table. Just below the pond, the hydraulic gradient was oriented toward the stream, allowing groundwater to seep into the stream. Farther downstream, below these seeps, the hydraulic gradient is oriented away from the stream, allowing the stream to recharge subsurface water.

Because groundwater temperatures tended to follow the temporal patterns of stream temperature, stream temperatures influenced groundwater temperatures, particularly groundwater close to the stream, especially where groundwater recharge occurred. Furthermore, wells located near the beaver pond were nearly in phase with stream temperature. This further substantiates the notion that stream temperature influences groundwater temperature, and that groundwater recharge is

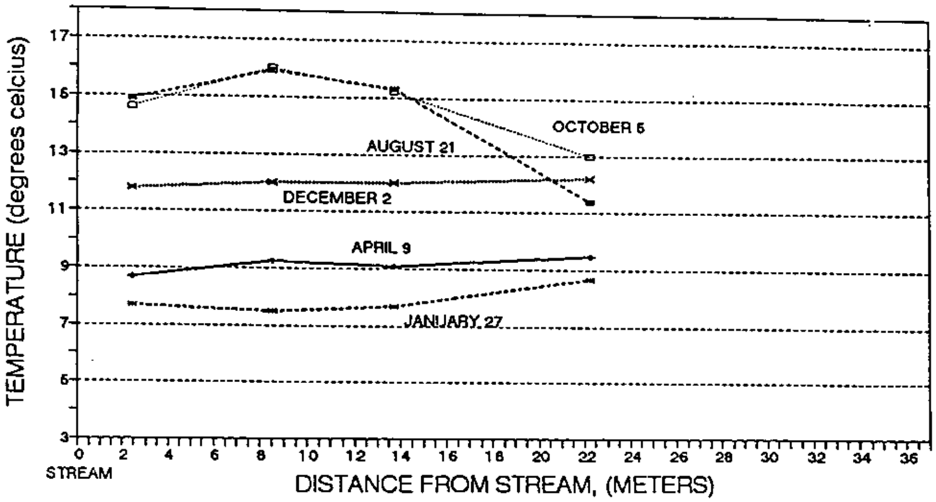

Figure 7. Groundwater temperatures of well transect 9 for August, October, and September 1991, and January and April, 1992.

occurring near the pond. This research supports the conclusions of several authors (Apple, 1983; Parker et al., 1985; DeBano and Heede, 1987; Skinner et al., 1988; Gebhardt et al., 1989) that water tables are raised next to beaver ponds. Research on riparian groundwater is essential in understanding the relationships between groundwater storage, stream temperature and streamflow. Understanding the spatial and temporal patterns of groundwater in these systems and the factors affecting these patterns is crucial to maintaining and enhancing the quality of riparian ecosystems.

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