IMPACTS OF FLOOD IMPOUNDMENTS ON WATER BALANCES OF DOWNSTREAM RIPARIAN CORRIDORS

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ABSTRACT: Over 10,450 flood control dams have been built in 47 states. Many are nearing their design life of 50 years and have significant rehabilitation needs, the cost of which approaches over $540 million. While assessment of engineering safety is a major consideration, little is known about the effects of these structures on downstream riparian corridors. Detailed monitoring of local water budgets conducted downstream of one structure has verified links between the flow regime of the dam and riparian vegetation. Stream flow, soil water, and transpiration rates were measured in a downstream riparian community for a one-year period. This monitoring showed that riparian vegetation is linked directly to both the stream and the groundwater system. The riparian zone is enhanced by low flow release from the upstream structure in which plants utilize available stream water via a groundwater pathway. This positive feedback system has direct benefits for the downstream ecosystem through increased and constant water availability.
KEYWORDS: hydrology; impoundment; riparian corridor; transpiration

INTRODUCTION

Under Public Law 566 (PL-566), the construction of flood control structures was begun in the 1950's with the purpose of reducing storm flow and decreasing downstream sediment. Since then, more than 10,450 have been built in the United States. Funding for refurbishment of the dams has been approved, however, questions remain regarding the economic and ecological costs and benefits of repair versus removal of these structures.

In many cases, the economic costs of removal are less than the cost of repair. However, the ecological effects of small upland dam refurbishment or removal are less understood. Ecological arguments for removal are based on the effects of unrestricted stream flow on fish migration and sediment transport at the landscape scale. In addition, there are valid concerns about dam integrity where the safety of downstream communities is considered (Doyle, *et al* 2000). However, the function of connectivity is based on northern fish species with specific breeding requirements that is not applicable in all biogeographical regions.

An area that has received less consideration is the benefit of enhanced riparian vegetation associated with floodwater structures. Observations from this study indicate that PL-566 associated dams potentially play important roles in agriculturally dominated landscapes of Texas by changing stream flow regimes and promulgating ecological development. This creates habitat both upstream and downstream of the dam, increasing landscape diversity and potential connectivity within terrestrial communities. In addition, large trees near streams decrease stream water temperature through shading, bank erosion by enhancing soil stability due to large root structures, and soil saturation through transpiration. The corridors also perform vital ecological functions such as wildlife habitat, conduits for networks and filters for groundwater contamination (Gregory, *et al* 1991).

The hydrologic environment downstream of an impounded structure is unique in that flood events are stabilized and there is a near-constant low-flow regime. Riparian corridor development is potentially enhanced in response to persistent water availability from the slow release of stored water. The mechanism

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of riparian development is possibly due to the presence of Pl-566 impoundments. Measurements of stream, soil, and vegetation water were assessed to better understand the influence of these altered hydrologic regimes and the interaction of terrestrial plant communities, ground and stream water.

STUDY SITE

The study was conducted along the Cow Bayou Stream in McLennan County, TX, a second order stream in the Lower Brazos Watershed with a drainage area to the reservoir of approximately 3 km^2. The study site was established 300 meters downstream of PL-566 Dam No. 4. Long-term mean annual rainfall is 82 cm (Mills, 1969) with most precipitation occurring in late spring and early fall. Vegetation is grass-prairie with isolated patches of trees and land use is predominantly agriculture and rangeland. Riparian vegetation consists of several species of perennial and annual shrubs with woody vegetation dominated by cedar elm (*Ulmus crassifolia*), Texas ash (*Fraxinus texensis*) and Ashe's juniper (*Juniperus ashei*). The soil texture is dominated by clay derived from shale and limestone. Late spring and summer convective storms are responsible for the most intense flooding and thus impoundment of water in the structures. Since impoundment of the stream in 1956, no storm event has exceeded storage capacity of the dam. Stored water is slowly released and creates year-round stream flow. In addition, the flow regime has fostered the development of a beaver dam 400 meters downstream of the reservoir that has further slowed water movement from the site and enhanced low-flow conditions for much of the year.

METHODS

Global TDR pressure transducers were used to monitor stream and groundwater levels. A stream transducer was installed 6 cm above stream bottom to measure water depth. A groundwater transducer was installed inside a piezometer approximately 10 meters from the stream bank at a depth of 155 cm. The soil is mapped as the Ovan series silty clay (fine, montmorillonitic, thermic, Udic, Chromusterts). During installation, soil compositions were observed. The top 24 cm of soil were dark clay with high organic humus. Deeper soils consisted of 95% alluvial clay and 5% colluvial limestone. A 10' PVC pipe with ½ inch screening along the bottom 2 ft was installed in the well. The transducer was inserted and the pipe was capped, with a side notch for airflow. Sand was poured to cover the screened area and covered with bentonite pellets. A plastic seal was added around the base of the pipe to prevent water seepage. Hourly depth measurements were taken and Global Water software was used for periodic data downloads.

On-site meteorological measurements include an electronic precipitation gage placed in an opening 20 meters from the stream. In addition, evapotranspiration (ET) was estimated from an ET Gage (C&M Meteorological Supply) installed in July 2001 in the riparian zone. Water loss was recorded continuously and manual readings were taken every two weeks. Thermal dissipation probes (TDP) were installed in four different trees with diameters less than 20 cm – two *J. ashei* and two *F. texensis*,, to monitor canopy transpiration. One ash and one juniper were located along the stream bank and the other trees were located in the uphill region of the study area, 1.5 meters above stream level. The probes were inserted 30 mm into the stems at diameter breast height (DBH) and measured xylem sap flow based on the Granier method of heat dissipation (Kostner, *et al* 1996). Probe wires were connected to a Campbell Scientific datalogger and powered by 12-volt batteries and a 50 Watt solar panel. Transpiration rates were sampled every 5 minutes and averaged and recorded hourly. Understory transpiration was measured using a TPS-1 infrared gas analyzer and samples were taken monthly for 16 shrubs located in a 15 X 15 m grid during the growing season.

RESULTS AND DISCUSSION

The results of our analysis indicate there are large differences in transpiration flux between species that also varies with distance to stream channel. Figure 1 shows transpiration estimates from the Granier-type TDP where transpiration for juniper greatly exceeds that of ash despite all trees having comparable stem diameters and heights. Streamside trees are also using water at a higher rate than those located in the uphill region.

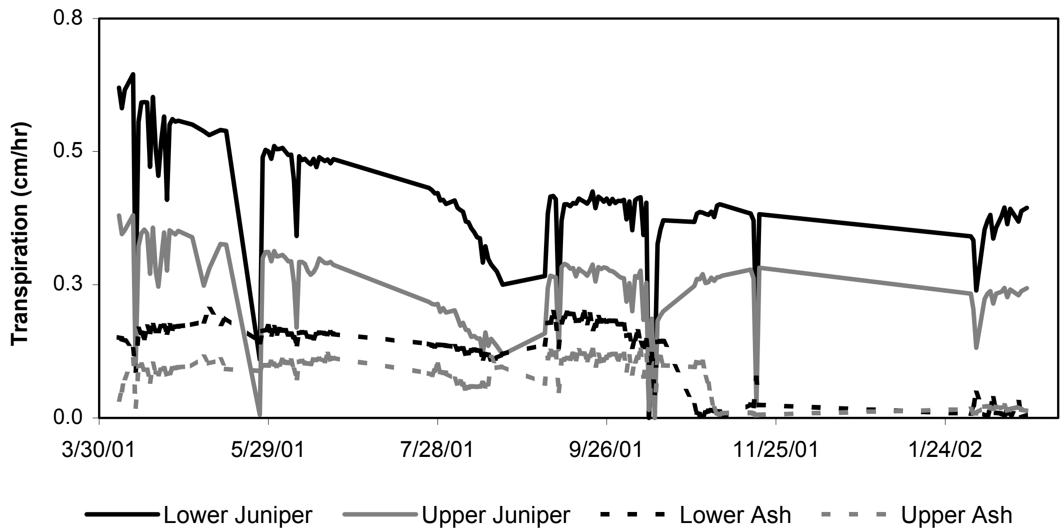

Figure 1: Canopy Transpiration Fluxes for Individual Trees for February 2001 – February 2002

The trees showed sharp reductions in transpiration in response to individual rainfall events which saturated leaf surfaces. In summer months, reduced stream flow and groundwater apparently increased water stress in all trees, with noticeable declines in transpiration between August and September 2000. This reduction was also associated with high daily maximum temperatures that exceeded 40ºC during this time period. From October to November transpiration in the ash declined as trees lost leaves and remained near zero during winter months. In contrast, the juniper continued to transpire during winter months with rates only slightly less than summer values. This illustrates the advantage of ready access to water from the stream as well as impacts that evergreen trees may have on riparian water budgets. Other studies in Texas have shown (Dugas, *et al* 1998) that juniper species can have a significant effect on reducing water availability in watersheds.

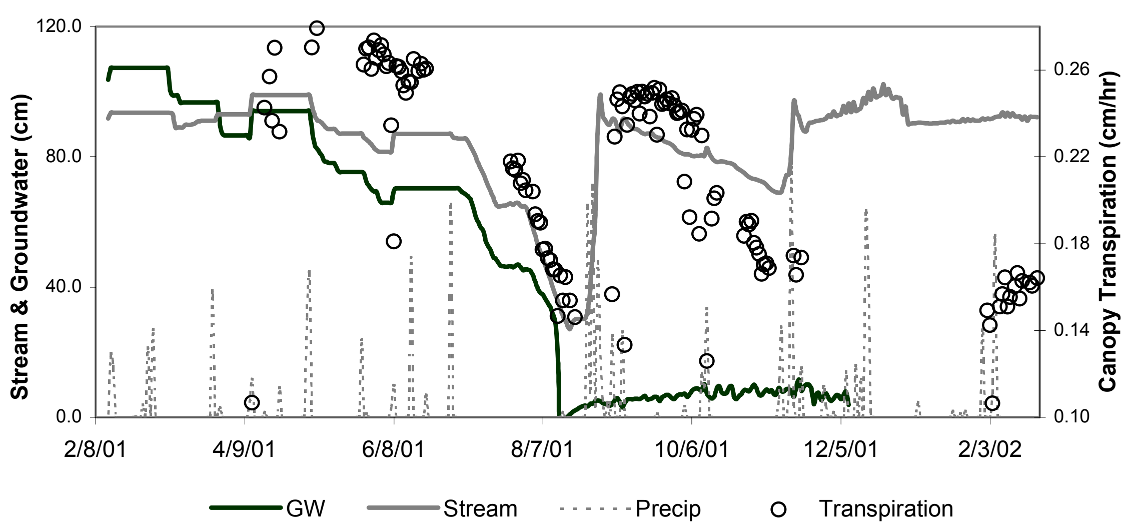

Figure 2: Stream Level, Groundwater Level, Precipitation, and Average Canopy Transpiration Fluxes for February 2001 – February 2002

Figure 2 shows stream flow, groundwater level, precipitation and overstory transpiration. Rainfall is not shown to scale on Figure 2 but is used for illustrating storm event occurrences and relative amounts. Total measured precipitation was 76 cm from February 2001 to February 2002, slightly less than the mean annual 82 cm for the area. Stream water level is slowly depleted in the spring and summer months as it drops from

90 cm in February to 25 cm in mid-August. Groundwater shows a similar depletion from 105 cm to 0 cm by late August. Some recharge occurs in early September following large precipitation events but it remains suppressed in the fall months, well below spring and early summer levels. The groundwater transducer failed in mid-December and no data was obtained for the remainder of the period shown. Fall precipitation increased stream water to pre-summer levels. Comparison between groundwater and stream levels indicate that in the early months of the year groundwater, though depleting at a higher rate, closely follows stream levels.

Overall transpiration rates declined in response to stream and groundwater level reductions during summer drought months. Following several early September storms, stream levels increased that also stimulated transpiration rates in the trees, however groundwater water remained depleted, an indication the trees may be receiving stream water directly as a flow-through system rather than from groundwater storage. In this special case, effluent stream conditions appear to be laterally diverting water to the riparian zone via the groundwater that is rapidly utilized by vegetation for transpiration.

Comparison of derivative values (dGW) for hourly groundwater and average transpiration rates show that both have distinct diurnal fluctuations (Fig. 3). Maximum groundwater depletion lags plant uptake by 4 to 5 hours and indicates that loss of water through stomata from soil water uptake is not an immediate process. Rather, trees are known to store water in stems to avoid water stress (Waring and Running, 1978).

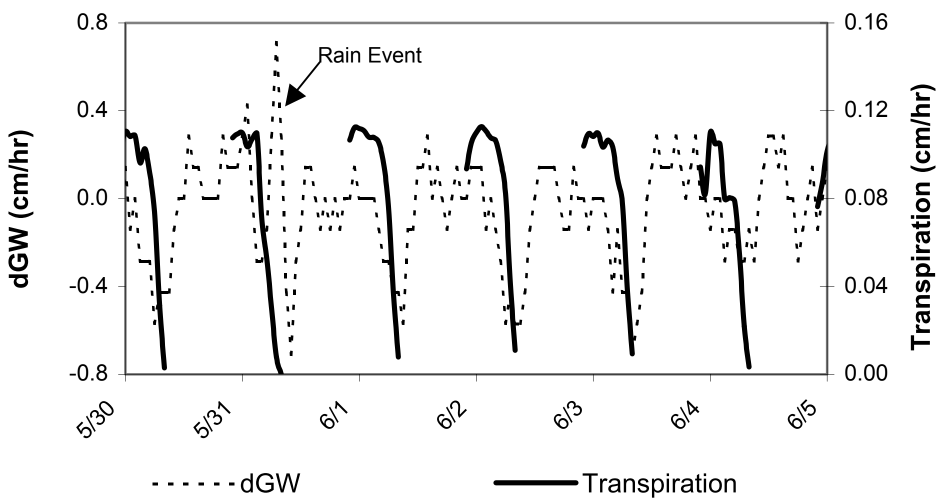

Figure 3: Comparison of Average Canopy Transpiration and Groundwater Flux in 2001

The relationship between transpiration and groundwater in the spring shows the trees are pulling water from the saturated zone that is then recharged. Whether recharge occurs primarily from the stream or from watershed groundwater storage cannot be elucidated for this time period. However, Figure 4 shows there exists a strong relationship between stream water and transpiration for fall months. In September and October a relationship was found between stream water and transpiration ($r^2 = 0.96$) indicating that as the groundwater buffer is removed, the stream shows a response to plant uptake as water is diverted laterally to the tree roots. Other studies have shown that whereas more mature trees utilize much deeper groundwater sources, trees of this size do depend on stream water for transpiration (Dawson and Ehleringer, 1991). In this system the extreme ground water depletion coupled with the low-flow stream, increases that relationship with water diversion that becomes immediately available for plant use. This stream/plant water linkage also indicates a mechanism whereby the riparian corridor has the potential to act as a filter to the stream itself, an area that has received little study (Forman, 1995).

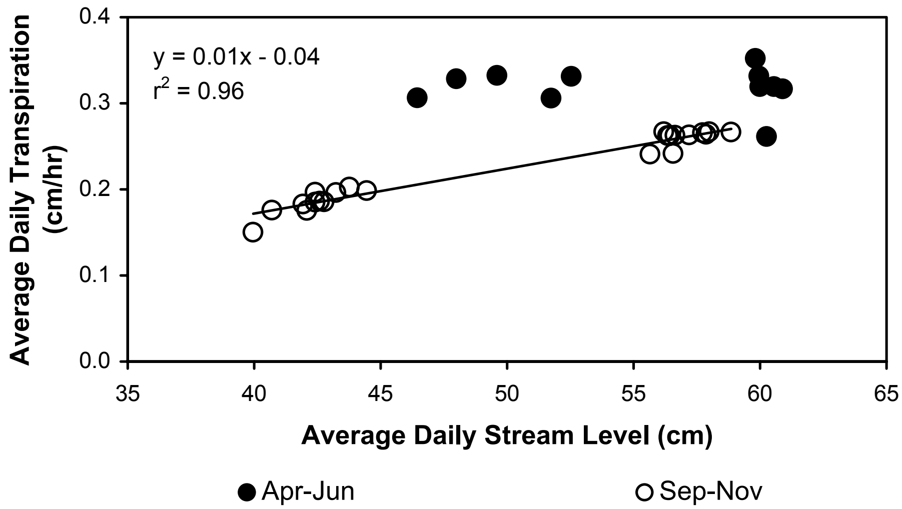

Figure 4: Comparison of Average Canopy Transpiration and Stream Level for 2001

Date	ET (cm)	Understory Transpiration (cm)	Overstory Transpiration (cm)	Precipitation (cm)	Groundwater Storage (cm)	Stream Level (cm)
7/28 - 8/3/01	19.6	4.7	9.8	4.4	-25.3	-26.4
8/3 - 9/7/01	33.9	8.6	17.3	21.3	-64.4	54.7
9/8 - 10/12/01	44.2	11.7	27.1	24.9	-103.5	84.1

Table 1: Water Budget for the Riparian Corridor between 7/28/01 – 10/12/01.

Cumulative amounts of various components of the water budget between July 28th and October 12th are shown in Table 1. Negative values for ground water indicate decreases in soil water storage. Likewise, the negative stream level value indicates a decline in the stream level between the dates indicated. This information illustrates that the values of ET measured directly are comparable with those from the TDP and gas exchange estimates. The cumulative value of ET on October 12 is 44.2 compared with the sum of understory and overstory transpiration of 38.8 cm. The difference is likely bare soil evaporation. On average, transpiration accounted for approximately 88% of evaporated water during this time. Comparison of canopy to understory transpiration shows understory vegetation accounts for approximately 32% of all transpired water and canopy vegetation represents 68%. Cumulative precipitation during this same time period was 24.5 cm, much less than observed ET amounts, indicating an overall water deficit for the period. In addition, the groundwater shows an overall depletion of over 1 m of water storage, however, the stream shows and overall increase in flow. The riparian corridor thus appears to depend on lateral diversion of stream water for uptake and exhibits a strong relationship with stream water availability as shown earlier (Fig. 3 and 4). This indicates that water budgets of riparian corridors below PL-566 structures in this region are likely to show shifting utilization of ground water and stream water depending on seasonal fluctuations in precipitation and soil water availability**.** This also implies that riparian vegetation may interact with groundwater that is derived from upslope or from streams directly. In general, the upslope vegetation is more reliant on soil water whereas downslope vegetation utilizes ground and stream water more directly.

CONCLUSION

A strong interconnectivity between the aquatic interface of stream and groundwater and terrestrial interface of vegetation water uptake was observed in this study. Traditional understandings of riparian corridors have been that water movement is from the upland landscape as runoff or through ground water and that vegetation intercepts this incoming water. In this system, with the hydrological modification of the

PL-566 reservoir and enhancement by the beaver impoundment, water is apparently moving from the stream outward to the ground water where a significant amount is being utilized for transpiration. The implications for this include changes in water yield in slow moving waters with dense riparian growth and potential stream nutrient and pollutant uptake and retention by vegetation. Also, proposed simple streamside models rely totally on downward movement of soil water and this study illustrates the potential significance of lateral flow. Whether this distinct interconnection is unique to this site due to the presence of the reservoir and the beaver dam is uncertain.

Future studies include extracting increment cores from trees affected by water inundation. Several large dead cottonwoods are standing in the channel that when compared with increments of living bank specimens may provide a timeline for beaver dam construction. Coupled with increment data from other trees, growth rate from the cores collected along transects away from the stream can be assessed to infer water availability effects attributed to beaver activity. In addition, analysis of oxygen and hydrogen stable isotopes in groundwater, unsaturated zones and stream water will further characterize hydrologic flow through the system. Finally, analysis of remotely sensed data on riparian corridors downstream of PL-566 dams will verify if such dams do indeed enhance riparian development at the landscape scale. This should also include analysis of evergreen species within affected riparian zones as their high rates of water loss outweigh the ecological benefits of the riparian zones and juniper densities may need to be managed in these areas.

ACKNOWLEDGMENTS

This work was funded by a grant from the Texas Water Resources Institute. We thank Carl McBrearty and Pam McKernan for assistance in data collection and Dennis McMahon for technical assistance. We also thank the staff of Greene Family Camp for access to the study area.

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