Final Report for TWRI Grant
Rapid Risk Assessment of Watersheds and Dams using GIS and Modeling

by
Jacquelyn Duke, Joseph White, and Peter Allen
Baylor University, Depts. of Biology and Geology
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Summary of Findings

- Stream and ground water changes are coupled during periods of high or constant flow. This relationship becomes weaker during the late season drought or when soil moisture declines.
- Ground water changes and transpiration rates show a similar pattern though lagging each other by 4 to 5 hours. This demonstrates the influence of saturated soil water resources for riparian vegetation usage.
- From the initial data, evapotranspiration rates from vegetation appear to exceed precipitation inputs in the riparian corridor.

Introduction

The mechanisms of riparian development due to the presence of the PL-566 reservoir imposed flow and the dam have been initially described in this study based on observations of stream, soil, and vegetation water movement. Interactions between stream, soil, and plant water were assessed to better understand the influence of altered hydrologic regimes on terrestrial ecological communities. Initially, investigation of the development and growth of riparian vegetation associated with PL-566 reservoirs was chosen to assess the impacts that changes in the storage of the reservoirs have on peripheral groundwater and vegetation water uptake. Other considerations were assessed including vegetation succession and enhancement of biological diversity influenced by the presence and structure of the reservoir. While this analysis was originally intended for upstream communities, accessibility issues required establishing an intensive field study site downstream of a PL-566, namely SCS structure No. 25 in the Cow Bayou drainage. The shift in site also required and changes in research focus. The downstream hydrologic environment is unique in that a constant flow regime is created by the presence of the reservoir. Vegetation, namely various tree species including *Ulmus crassfolia, Carya illinoiensis, Fraxinus texensis, Populus deltoides*, and to a lesser extent *Juniperus ashei* now flourish in this environment, potentially due to near perennial stream-derived groundwater resources. In addition, the flow regime has also fostered the development of a beaver dam that until recently was inhabited and active. The beaver impoundment is located approximately 400 meters downstream of the reservoir dam and further restriction of water flow has also potentially broadened the lateral movement of stream water into the surrounding soil.

Questions regarding removal of PL-566 dams as well as dam refurbishment are based on assumptions about the normal function of unrestricted stream flow. Ecological arguments for dam removal are based on effects on fish migration, movement, and landscape connectivity. In addition, concerns about dam integrity are valid where the safety of downstream communities is considered (Doyle *et al*, 2000). In most cases, the cost of removing dams presumably is less than the cost of refurbishment and rejuvenation of the reservoir. Also, aquatic community connectivity within the landscape is reduced due to dams. However, the function of connectivity is mostly based on northern fish species with specific breeding requirements. Observations from this study indicate that PL-566 dams potentially have important functions in agriculturally dominated landscapes by changing stream flow regimes and promulgating ecological development. These are latent features of mature dams that create habitat both upstream and downstream of the dam, increasing landscape diversity and potential connectivity within terrestrial communities. Increases in riparian corridor development are potentially beneficial ecologically and hydrologically. Large trees near streams decrease bank erosion by enhancing soil stability due to large root structures and decreasing soil saturation by transpiration.

Methods

In January 2001, an intensive measurement study site was established at the Greene Family Camp site near Bruceville, TX. This camp is situated on the PL-566 Reservoir in the No. 4 of the Cow Bayou watershed. The study area lies totally within the Blackland Prairie Province of Texas. The dam and stream are underlain by outcropping Cretaceous Age, Eagle Ford Shale. The stream bottom at the site is shale. The alluvium in which the piezometer is located consists of silty clay. The upland site consists of clay soil underlain at shallow depth by the Eagle Ford Shale. The upstream floodwater structure was completed in 1956. It has a contributing drainage area of 5.25 square miles. The average runoff/rainfall percent for the basin is 12 percent (Mills 1969). Approximately 87 percent of the inflow to the flood retarding structure is routed through the structure on an annual basis. This particular structure was chosen based on the average size and proximity of the floodwater structure but also due to the amount of previous work and monitoring completed at this site (Mills, 1969; Dunbar *et. al*., 1999).

Figure 1 - Images showing Dr. Joseph White, Baylor University, installing Granier TDP probes to measure transpiration (left) and graduate student Jacquelyn Duke, (right) collecting data from soil and ground water monitoring station.

To monitor hydrologic flows in the stream corridor, various instruments were installed approximately 300 meters downstream of the SCS impoundment. Two soil moisture probes were installed at the site. These consist of ThetaProbe (MLx2) instruments. The ThetaProbe measures volumetric water content by the well established method of responding to changes in the apparent dielectric constant. These changes are converted into a DC voltage, virtually proportional to soil moisture. The probes were located at a 15 cm. depth in the immediate floodplain of the stream next to the groundwater piezometer and in one upland position. Both probes were attached to a datalogger and records taken at 1 hour intervals over the study period. Recording submersible pressure transducers (Global WL-14) were also installed at the site to measure stream and groundwater levels at 0.2% accuracy. Both water level and stream levels were taken every hour over the study period. Due to the remoteness of the site and heavy understory, canopy, the piezometer was installed by hand. The total depth of the piezometer below grade was 154 cm. This depth was chosen so that the base of the piezometer was always below the level of water in the stream. A Global TDR pressure transducer was placed 2 meters offshore and 3 inches above the stream bottom to measure stream water depth. The transducer wire was threaded through a plastic pipe to prevent exposure and connected to a datalogger adjacent to the stream bank. The datalogger was housed inside a sealed plastic tote suspended 1.5 meters above ground. The transducer measured hourly stream water elevations. Global Water software was used for periodic downloads of data.

Another Global TDR pressure transducer was placed inside a piezometer located approximately 10 meters from the stream and at a depth of 61 inches below ground. During installation, soil compositions at different depths were observed. The top 10 inches of soil removed from the hole were dark clay containing lots of organic humus. From 10 inches to 26 inches the soil contained a mixture of 95% alluvial clay and 5% pebble size colluvial limestone. At a depth of 21 to 26 inches, blue veins were observed along with red patches. This indicated the water table depth, blue being reduced iron from the water and the red indicating oxidized iron. From 37 to 48 inches, roots were no longer found to exist in the soil. At a depth of 53 inches a small amount of water appeared to be seeping into the auger hole. Once the hole was dug to a depth of 61 inches, a 10' PVC pipe was installed. Cutting slits at one-inch intervals, located at three locations around the circumference of the pipe and staggered ½ inch apart, screened the PVC. These slits were made along two feet of the pipe. A 2 inch cap was then placed over the end of the PVC and the pipe was inserted upright into the well. Sand was poured to cover the screened area and the final 37 inches surrounding the underground section of pipe were filled with small and large bentonite pellets. A plastic seal was placed around the bottom of the pipe to prevent water runoff along the pipe from seeping into the well and altering groundwater table readings. The transducer was then lowered into the PVC and the datalogger stored inside the sealed tote. Notching the top of the PVC made an air hole and another 2-inch cap was placed over the end. The air hole facilitated underground water flow into and out of the piezometer with changing water table depth. Hourly groundwater depth measurements were taken and Global Water software was used for periodic data downloads.

Two Dynamax THLog soil moisture probes were installed 10 and 12 meters adjacent to the stream. Both probes were buried 8 inches below ground surface. The probe wires were threaded through plastic pipe and connected to dataloggers inside the tote. All pieces of pipe were strapped to the tote using duct straps and sealed with garbage bags to prevent rain from entering the suspended ends and infiltrating near the probes. The soil moisture probes measured soil moisture content (in cm) hourly and BoxCar Pro software was used for periodic data downloads.

An electronic rain gage was placed approximately 20 meters uphill of the stream and positioned in an area with little tree canopy. It was secured atop a metal fence rod at a height of about 1.5 meters. The gage recorded the date and time for each 1/100 inch of precipitation recorded. BoxCar Pro software was used for periodic data downloads. In addition, an ET Gage from C&M Meteorological Supply was installed to measure overall evapotranspiration (ET) in the riparian zone. It contained a canvas cover to simulate vegetative and soil ET. The gage was installed about 15 meters from the stream at a height of about 2 meters above stream surface. ET loss was recorded continuously and manual readings were taken approximately every two weeks. Values for ET were equated by averaging loss over the two week periods.

To monitor transpiration in the upper canopy, thermal dissipation probes were installed in six different trees – two *J. ashei*, one *U. crassifolia*, and three *F. texensis* trees at various distances and elevations to the stream. The probes were inserted at about 1.5 meter height and sealed to prevent exposure. They measured xylem sap flow based on the Granier method of heat dissipation (Kostner *et al.*, 1996). Each probe wire was wrapped in rubber water hoses for protection and connected to a Campbell Scientific datalogger. An adjustable voltage regulator was also installed to prevent power fluctuations. The whole system was contained in a watertight instrument panel and powered by two 12 volt batteries and a 50 watt solar panel. Transpiration rates of the trees were taken every 5 minutes and averaged and recorded hourly. The system required a minimum of

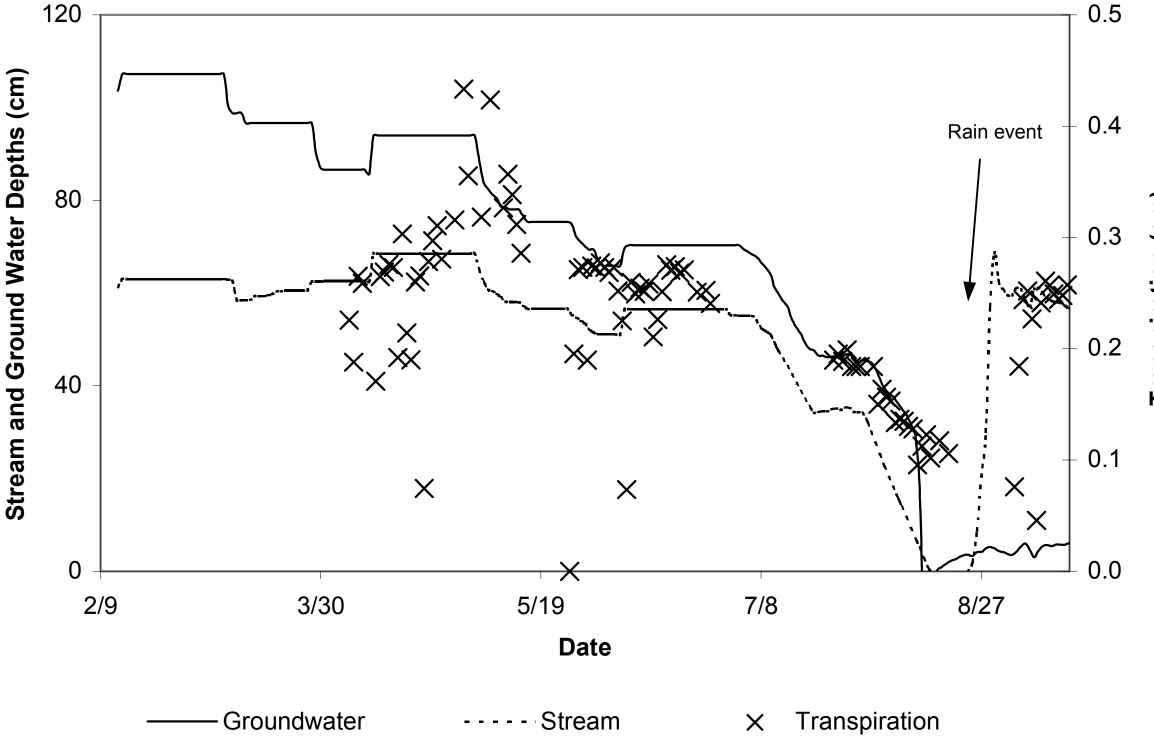
10 volts to operate, thus due to power limitations, continuous monitoring was achieved in blocks of days to weeks with gaps in between.

Transpiration in the understory was measured monthly using a TPS-1 infrared gas analyzer from PP Systems. A 15 X 15 meter plot was laid out in the study site and 16 points were placed in a grid within. Each month, measurements were taken from understory vegetation nearest each of the 16 points. For each point, two separate leaves of a plant were measured, each 6 times. An average of overall understory transpiration was then computed. Leaf area index (LAI) was measured using the LAI-2000 plant canopy analyzer. Both understory and upper canopy lai were recorded within the 15 X 15 meter grid. Measurements were taken monthly in conjunction with understory transpiration rates. This allowed for the scaling up of transpiration rates from individual plants to riparian zone.

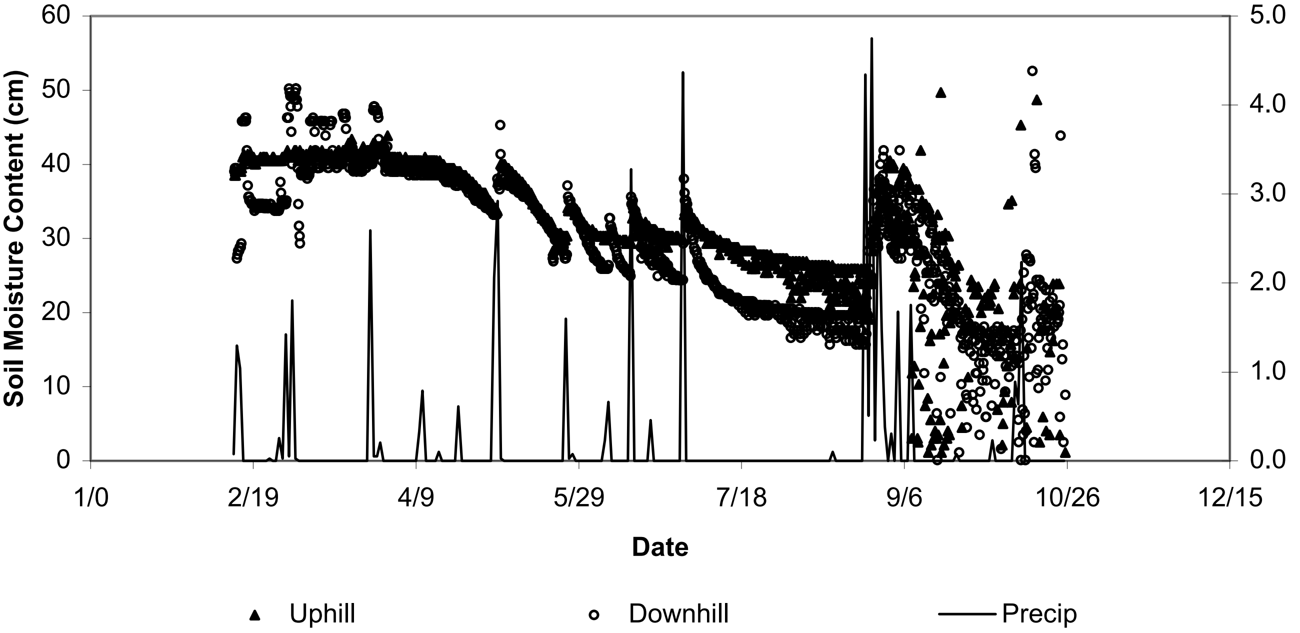
Results and Discussion

Groundwater level, stream level and average transpiration rates for the period of February 2001 to October 2001 (Julian days 43 through 299) are shown in Graph 1. The Groundwater and stream levels are shown the maximum daily values shown in centimeters. Depth does not reflect actual water depth because the transducers are located at different elevations. Groundwater is slowly being depleted over an 8 month period as it drops from 106.7 to 0 cm. It rebounds slightly with the late August/early September rains, but remains suppressed well below spring and early summer levels. The stream water level shows a similar depletion, from about 68.6 in February to 0 cm in mid August. The late summer rainstorms recharge the stream to pre-summer

Graph 1
Comparison of Daily Groundwater Level, Stream Level and Transpiration



Graph 2
Comparison of Soil Moisture and Precipitation

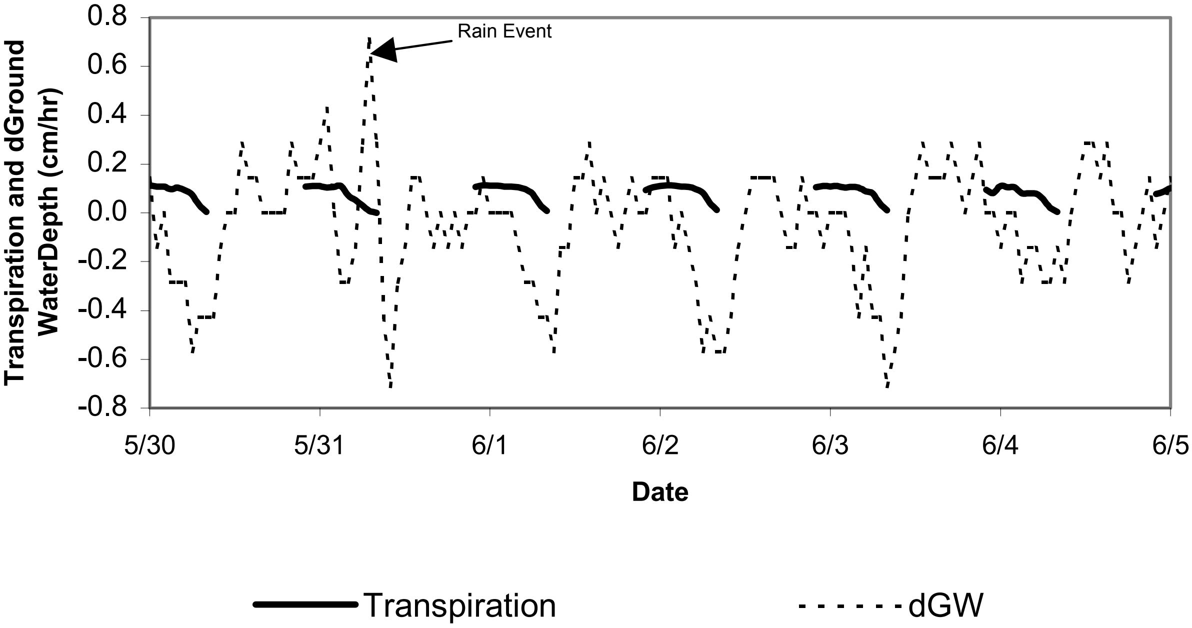


levels. Comparison between groundwater and stream levels would indicate that in the early months of the year, groundwater closely follows stream levels; however, long periods of no rain result in severe loss of water. Even after a series of rainfall events, groundwater does not recharge to pre-drought levels although stream levels do. Increased in overstory transpiration does occur following the rain event although ground water is low. This is further evidence of a possible linkage between the water in streams and water utilized by trees. The transpiration rate of the trees was obtained by using the daily average 12:00 p.m. transpiration rate for each of the five trees measured. This was converted into a daily value by assuming that the noon value was approximately 5% of the total daily based on measurements of diurnal transpiration amounts (See Graph 3). Because of power supply difficulties, we are missing data for the full period. A corresponding drop in transpiration is shown during and immediately following each precipitation event, but reaches pre-storm event levels within a day. A slight decrease in the weeks prior to the August/September storm events is seen, probably due to the subsiding groundwater, but transpiration rates later in September and October appear to reach pre-summer levels.

Soil moisture and precipitation are compared in Graph 2. The graph shows that there is a general decline in soil moisture from February to August as expected with approximately 20 cm depleted from the unsaturated soil column. A large rain event in mid September increases soil moisture levels almost to spring levels. However, this is followed by a pattern of large daily fluctuations. Large diurnal fluctuations of soil moisture in September and October are likely due to depleted soil moisture and soil cracking which separates the soil surface from the probe contacts. The diurnal pattern is also associated with transpiration. Often, the lowest moisture values are seen in the early morning hours during which time plants are likely reestablishing their pre-dawn moisture content. It is also possible that it is somehow related to the lowered groundwater table caused by a time lag between transpiration, vegetation stem storage, plant water uptake, and ground water response.

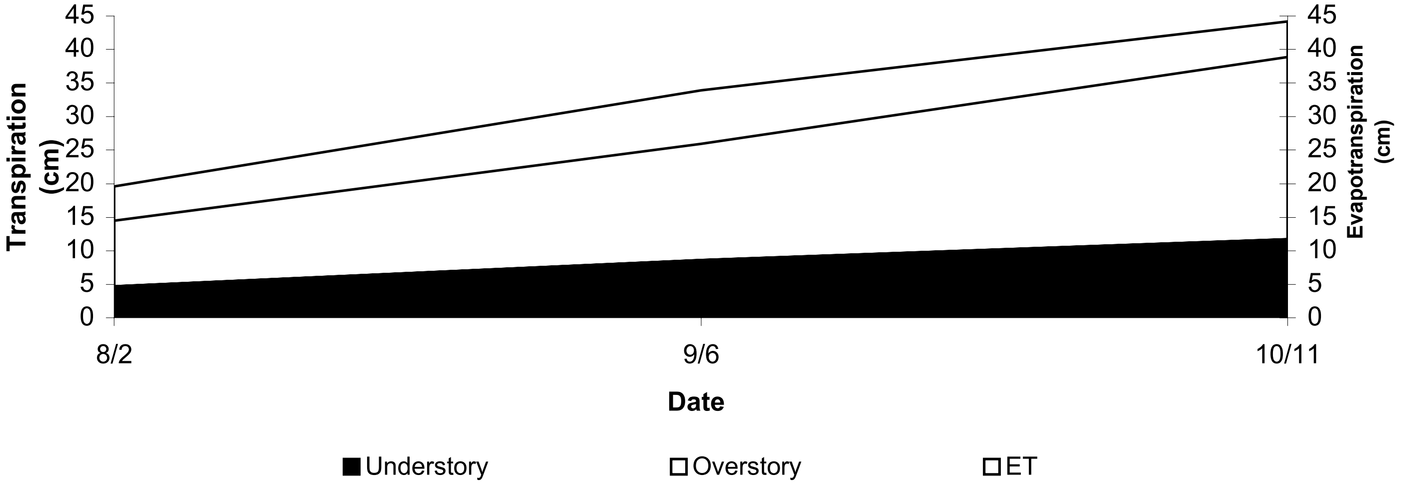
Graph 2 also displays the differences between soil moisture at the uphill and downhill locations. As is expected the uphill site dries out during the late summer drought more rapidly than the downhill site. However, the two sites remain fairly close in moisture content until mid-July. The upper site is relatively steep with shallow residual soils (12-15 inches to weathered rock). Therefore, the available water capacity of the upper soil is far less than the alluvial soil. The beaver dam activity has increased lateral flow of water into the alluvial soil and stream level and groundwater level in the alluvial soil are highly related. This lateral recharge from the stream influences the riparian corridor development by increasing the lateral width of the corridor. Because understory vegetation are more likely to be influenced by unsaturated soil moisture than overstory trees due to rooting depth limits, investigation of structure (i.e. LAI development) and function (i.e. transpiration rates) is warranted to characterize the limits of the stream system on the surrounding vegetation community.

Graph 3
Comparison of Groundwater and Overstory Tree Transpiration



Part of the purpose of this study is to assess what impact PL-566 reservoirs have on flow regimes, how sustained water availability affects riparian corridors seasonally, and how interconnected are water resources between stream, ground, and vegetation. Comparison of hourly measurement of transpiration and groundwater for a one week (May 30 to June 5) with groundwater shown as the derivative values (dGW) to illustrate the change in storage over time (Graph 3). The results show that both experience diurnal fluctuations. Transpiration rates are highest in the mid to late afternoon and lowest at night, as would be expected. Groundwater tends to increase in the early morning and decrease at night. The peak transpiration tends to precede the lowest groundwater value, interpreted as the maximum depletion rate, on average by about 4 to 5 hours. This lag time indicates that an intermediate storage of water is occurring in the trees such that the loss of water through the stomata from the soil water is not immediate. Trees are known to store water in stems to avoid water stress with seasonal fluctuations in storage amount (Waring and Running, 1978). There is likely a similar diurnal pattern where water is temporarily stored in the stems which delays water loss from soil to leaves.

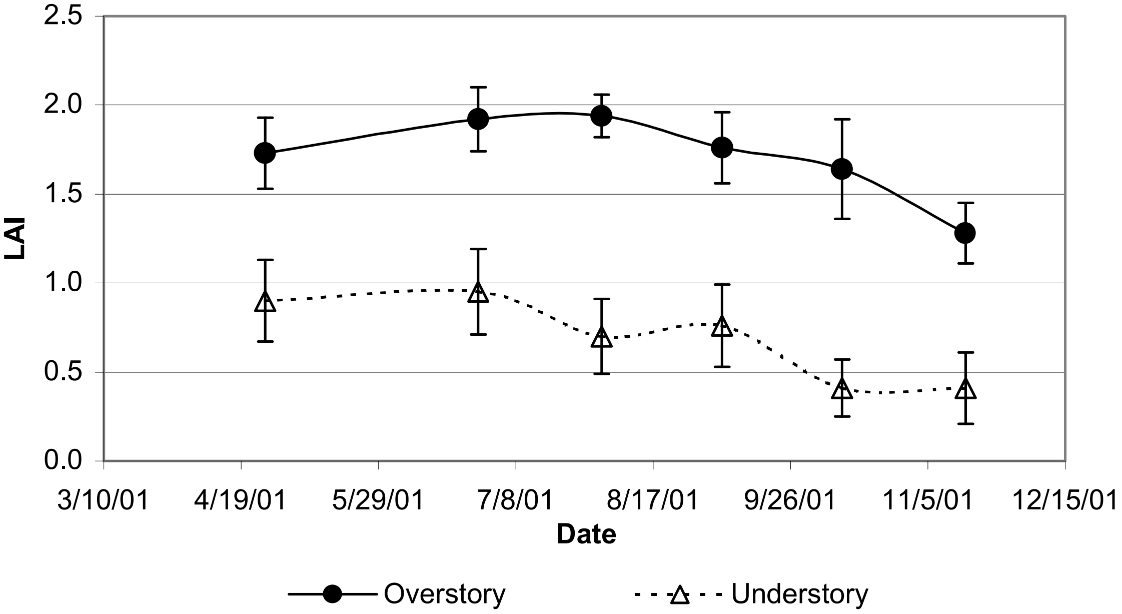
Graph 4
Comparison of Transpiration and Evapotranspiration



The cumulative amounts of canopy transpiration, understory transpiration, and evapotranspiration beginning with Julian Day 179 through 285 in centimeters, are shown in Graph 4. This first demonstrates that the various methods of estimating transpiration and evaporation seem to work within reason given that the sum of the canopy and understory transpiration values are less than the measured evapotranspiration (ET) values. On average, transpiration accounted for approximately 75% of evaporated water during this time. Transpiration from the upper canopy trees dominates most of the water loss. The proportion of transpiration by the overstory increases over time presumably associated with leaf area losses in the understory canopy (Graph 5). Cumulative precipitation measured during this same time period were 24.5 cm, therefore much less than the observed ET amounts indicating an overall water deficit for this time of the year. In comparison, measured cumulative precipitation on site since the beginning of February was 49 cm. We are missing electronic precipitation data for days 64 through 85; however, a manual rain gage indicated a rainfall total of 7.0 cm for this period. This gives a total estimated precipitation total from February to November of 68 cm. Comparison of this value to an ET value of 45 cm for July through October indicates that either the bulk of ET occurs in the late portion of the season and/or the methods of measuring and extrapolating ET values are overestimated. Another alternative is that ET exceeds precipitation on this site because of the proximity to the stream that increases water availability at a local scale. Riparian corridors should have greater access to water than the surrounding landscape terrestrial communities.

Leaf area index measurements were taken to characterize the canopy dynamics over time in the riparian corridor, for both overstory and understory components. Graph 5 shows leaf area index (LAI) from April 26th through November 16th. Overstory LAI peaks between July and August with a value of around 1.9. Understory LAI is more variable ranging from 0.5 to 1.0 over the season. Understory vegetation is comprised mostly of grasses, herbaceous annuals and perennials, as well as shrubs and a few sapling trees. Variability in understory LAI is expected based on the composition of the understory coupled with sporadic precipitation received on site during the summer season. Total site LAI peaked during June with a value of 2.9. The understory comprises approximately one-third of the leaf area of the site. This is compared to the transpiration values (Graph 4) in which understory accounts for approximately 32% of all transpired water. This implies that there are no environmental limits to transpiration imposed by the overstory on the understory. However, in the absence of diurnal measurements of understory transpiration, it is difficult to assess from where understory vegetation is deriving water. For the overstory, it is now assumed that the saturated soil zone provides a significant amount of water based on the diurnal fluctuations shown in Graph 3. This is also intricately linked

Graph 5
Leaf Area Index



to the stream system as shown in Graph 2 as well. However, is assumed that the water source for the understory vegetation is likely derived from the unsaturated zone based the sensitivity of the LAI in precipitation and the inference from the soil moisture content variation.

Summary and Future Work

A definite pattern of connection between the stream, ground, and vegetation water system was observed in this initial study. Traditional characterization hydrologic balances in riparian corridors are based on water moving from the upland landscape through the ground water or overland where vegetation intercepts water either physically, or captures water through plant uptake from the soil. In the system at the Greene Family Camp with the hydrological modification of the PL-566 reservoir and 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 vegetation growth and potential nutrient and pollutant uptake and retention by vegetation. Whether this distinct interconnection is unique to this site due to the presence of the reservoir and the beaver dam is uncertain. Future work at the site will include extracting increment cores from trees affected by water inundation. Several large dead cottonwoods are standing in the main beaver pool that when compared with increments of living specimens on the bank may provide a timeline of the effects of dam construction. Then, coupled with increment data from other trees, growth rates from the cores collected along transect away from the stream can be assessed to infer water availability affects attributed to the beaver's activity. It is also anticipated that we will remove the beaver dam season and monitor changes in vegetation, ground, and stream water to further characterize the effect of the dam on this particular riparian corridor.

Continued monitoring of the site through the winter and early spring season will provide changes to hydrologic flows in the absence of much of the annual understory vegetation and deciduous leaf loss. In addition, topographic models of stream water influence in the absence of the beaver dam flow restriction can be constructed and compared with riparian corridor size to test whether damming has a long-term affect on riparian corridor development. Other work may include installation of additional soil moisture probes to assess moisture amounts at different levels in the soil. This will characterize the state and use of water in the unsaturated zone.

In addition, detailed sedimentation surveys have been done on the flood water structure. Sediment will impact the water storage capacity of the structure and therefore have a dominant influence on the structure's effect on the water balance of the local riparian corridor. Past studies indicated an annual sedimentation rate of 2.76 acre feet per square mile per year from the drainage basin. At these rates, the storage and routing behavior of the floodwater structure will change dramatically over time. Future studies will incorporate the effects of reservoir storage loss to the inflow/outflow and routing of water to the downstream riparian system through the use of continuous simulation models such as SWAT. Such integrated modeling must be done to assess the changes in impacts of unmonitored structures and to properly assess the ecological interrelationships of the structure to the riparian corridor.

Outcomes from this Study

Dissertation in progress, Jacquelyn R. Duke, Department of Biology, Baylor University

National Science Foundation Graduate Research Fellowship application (11/5/01), Jacquelyn R. Duke, Department of Biology, Baylor University

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