The effects of stream channelization on floodplain groundwater levels, Anacostia River, Maryland

Jessica Rose Kronenwetter

Advisors: Dr. Karen Prestegaard
Dr. Nicholas Schmerr
April 25, 2016
Geology 394

TABLE OF CONTENTS

ABSTRACT

Stream channelization, the enlargement, straightening, and bank stabilization of streams to prevent bank erosion and overbank flooding, is a common practice in urban watersheds. Stream channelization, however, significantly affects the movement of water between the channel and the floodplain. Channel deepening can increase floodplain groundwater gradients towards the stream, that can lower floodplain water tables. Floodplain groundwater can be recharged by streambank seepage, overbank infiltration, and net infiltration (I-ET). Containment of flood flows within channel boundaries decreases the frequency of overbank flooding and recharge of the floodplain groundwater. Thus, channelization may decrease groundwater recharge in floodplains and increase groundwater drainage.

In this study, I compare groundwater recharge processes and their influence on floodplain groundwater elevation in a channelized coastal plain floodplain with a similar-sized non-channelized coastal Plain floodplain. I tested two hypotheses: a) that groundwater is deeper in floodplains along channelized than along non-channelized streams b) that channelized rivers have fewer groundwater recharge processes and less total groundwater recharge. To test these hypotheses, I compared a) the frequency of overbank flooding, b) the ratio of bank recharge versus draining duration from hydrographs, and c) groundwater elevation data across the floodplains. The groundwater elevation was determined using Ground Penetrating Radar (GPR). During winter season GW maximum, the groundwater was within 0.5 meters of the surface in Zekiah Swamp Run, but 2 meters below the Anacostia floodplain. The un-channelized Zekiah swamp run shows a much flatter water table with little elevation change compared to the channelized NE Branch of the Anacostia River. Grain size analysis shows Zekiah Swamp run has more porous and permeable sediments, allowing for greater infiltration rates. Though there are many differences between the two rivers today, there is evidence of the systems being similar before channelization.

INTRODUCTION AND PREVIOUS WORK

Channelization is a general term that refers to a variety of processes causing stream channels to be straightened, deepened, and stabilized. Channelization tends to decrease stream sinuosity, but to increase flood depths and gradients, leading to higher flood velocities (Shankman & Pugh, 1992). Channelization can confine the stream within its banks during major floods. This can prevent damage to homes, roads, sewer lines, and other infrastructure.

Stream channels have varying morphologies formed in response to sediment load and discharge (Leopold et al, 1964; Church, 2006). Many streams in humid temperate environments have stream channels that fill to the bankfull level during frequent, small magnitude storm events, often between 1.2 and 2 years in recurrence interval with an average around 1.5 years (Dunne and Leopold, 1978). Many flood control channels are designed to contain the 100-year flood that is the design flood for most urban areas. In the Maryland Coastal plain, many natural channels are anastomosing in planform; these channels expand into multiple distributary channels during high flows. They are similar to braided streams, but the floodplains are usually heavily vegetated, that stabilizes the distributary channels. These channels play a role in the distribution of discharge when high flows are present. The bases of these channels are at different elevations allowing them to become activated when the stream water level reaches different heights. Overbank flooding from single-thread and anastomosing channels will both result in the recharge of the groundwater table over broad areas of the floodplain width. Groundwater recharge can be summarized with a floodplain water balance equation [1]

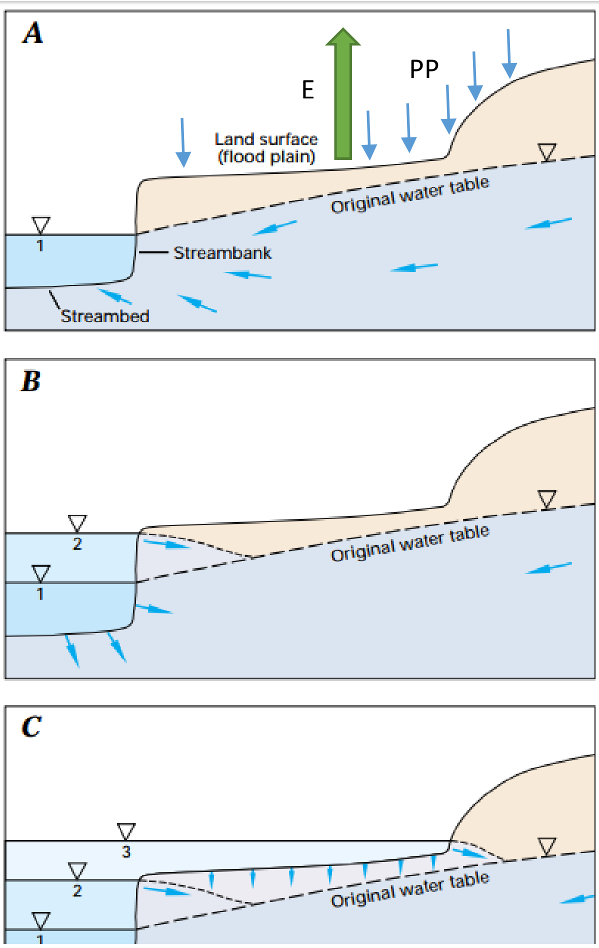


Figure 1 shows the stages of groundwater recharge. Each stage represents a different portion of the water balance equation. U.S. Geological Survey Circular 1139

$$[1]\ \text{Groundwater Recharge} = S_{bank} + OBF + PPT - ET$$

Where S_{bank} is the bank storage, OBF is the overbank flooding, PPT is the precipitation, and ET is the evapotranspiration. Precipitation allows for water infiltration through the floodplain, whereas evapotranspiration takes from the groundwater table through the roots of plants (fig. 1A). Bank storage occurs locally at through the bank when the elevation of the water in the stream is greater than the elevation of the groundwater table in the surrounding floodplain (fig. 1B). Overbank flooding allows for the addition of water through the floodplain seepage (fig. 1C).

Coastal streams tend to flatten as they approach the coast and sea level. This is a result of sea level rise. There has not been much research on Coastal Plain floodplains, but previous researchers have noted that the streams tend to have multiple channels and anastomosing channel patterns (Hupp, 2009). Recent research on distributary channel systems indicates that they tend have multiple, shallow channels. During high discharges, flow expands in each channel and spills over into multiple distributary channels. Thus, the increase in channel discharge is primarily carried by an increase in channel width, not increases in depth and velocity as would be expected for single-thread channels (McDowell, 2016). Distributary channel systems also exhibit channel filling and switching. During flood flows, the largest channels have the highest shear stresses and carry the most bedload. Laboratory studies and field observations indicate that this bedload can stall in the channels, leaving a permeable channel fill and spreading flow laterally into adjacent distributary channels (fig. 2) (Edmonds, etc.). These channel processes distribute coarse-grained permeable sediment on the floodplains, these sediments increases infiltration rates. Channels that end in permeable sediment can also be sites of focused groundwater recharge (fig. 3).

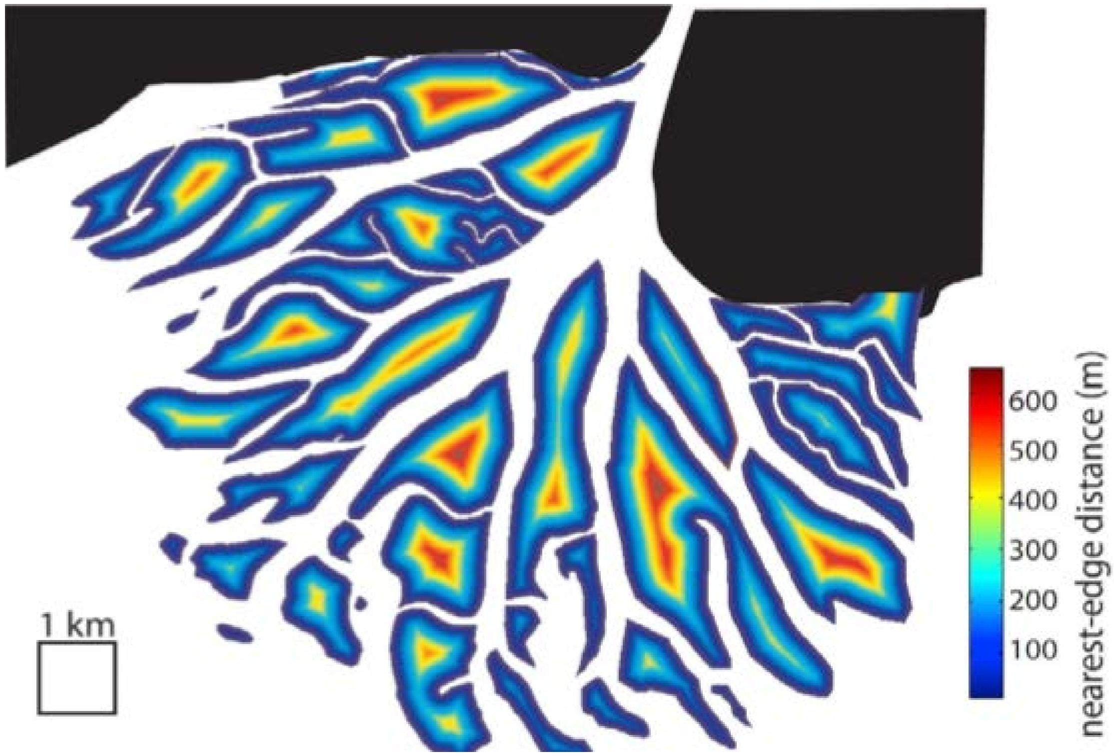


Figure 2 Distributary channel system showing proximity of each area to a channel (Edmonds, et al.)

Figure 3 Distributary channel system, Zekiah Swamp Run showing gravel bar islands between channels

Channel morphology and hydraulics in channelized and non-channelized Coastal Plain streams has recently been studied by McDowell (2016). She found that channelization of NE Branch and its tributaries has significantly increased flow velocity and decreased channel width compared to a non-channelized Coastal Plain stream with distributary channels

Surface-groundwater interactions have also been studied in Coastal Plain streams. Lundberg (2011) examined an unchannelized reach of Little Paint Branch creek, a tributary of the NE Branch of the Anacostia River. The site that she studied exhibits active gravel bar formation and distributary channels. She determined that the coarse-grained stream sediments adjacent to the channel had groundwater levels that were as high as the stream elevation. The fine-grained sediment of the floodplain had higher groundwater levels during winter months, when evapotranspiration was at a minimum and lower groundwater levels than the stream in summer months. Thus, floodplain groundwater was recharged by stream water during summer months if the stream channels were not channelized. These seasonal reversals in flow direction are driven by riparian zone evapotranspiration along a shallow stream and is not likely to occur along channelized portions of stream that have significantly lowered riverbed elevations.

OBJECTIVES OF RESEARCH AND BROADER IMPLICATIONS

I am interested in examining the relationship between channel morphology and groundwater recharge and discharge processes in Coastal Plain Floodplains. This examination begins with the comparison of channel and floodplain morphology of the urban Anacostia River to the non-urban Zekiah Swamp Run to identify the likely pre-urban condition of the Anacostia River and its floodplain. The examination then continues with the determination of groundwater recharge mechanisms in the floodplain by two different methods;

M1: Determining the frequency of overbank flooding and the volume of water recharged into the floodplain by overbank flood events from floodplain elevation data and gauge height data

M2: Determining the time available for bank seepage and groundwater drainage at different gauge heights from hydrograph recession curves.

Previous works by McDowell (2016) and Lundberg (2011) suggest that channelization procedures, that include deepening of the channels, straightening and smoothing the bed channels, result in increases in both channel area and velocity and thus the magnitude of discharge that can be carried in the channel. The deepening of channels would initially cause an increase in groundwater gradients to the stream and drainage of the floodplain. The confinement of stream flow would tend to decrease the frequency of overbank flooding or eliminate it, thus eliminating or reducing overbank flooding as a source of water to the floodplain groundwater. This should result in a reduction of the groundwater recharge in the floodplain. To evaluate these consequences of channelization, I have developed the following hypotheses:

H1: The depth to the groundwater table will be deeper in floodplains along channelized streams than along non-channelized streams.

H2: The depth to the groundwater table can be predicted based on groundwater recharge rates and processes from river gauge height data. Examining the relationship between channel morphology and groundwater recharge and discharge processes in Coastal Plain Floodplains will provide further insight into the consequences of channelization.

METHODS

Selection of Study Sites: I selected Zekiah Swamp Run (fig. 5) for comparison with NE Branch watershed (fig. 7) because it has many watershed similarities to NE branch Anacostia but very different channel morphology. In addition, both streams are gauged by the USGS. The size of Zekiah Swamp Run is larger than the size of The NE Branch of the Anacostia River, but they both have similar geologies. Figure 4 is a geological map of the sites showing similar floodplain sediment characteristics. Similarities between the two include the following: First, the NE Branch of the Anacostia River and Zekiah swamp run have very similar floodplain gradients as well as basin areas. Second, the two sites report having similar annual discharges. Third, the geological soil types are comparable. All of these similarities suggest that prior to the channelization of the NE Branch of the Anacostia River, the two sites could have looked and behaved very much the same.

Although the two field sites have similar basin areas and similar wide valleys, the channel morphology is considerably different. The lower 4.9 km of the NE Branch of the Anacostia River has been channelized by the Army Corps of Engineers and Prince George’s county up to the confluence of its two major tributaries Paint Branch Creek and Indian Creek. The three major tributaries, Paint Branch Creek, Little Paint Branch Creek (fig.6), and Indian Creek all contain major channelized or bank protected reaches, particularly in their lower sections.

Zekiah Swamp Run is an unchannelized stream with many distributary channels (fig. 5). The floodplain contains standing pools of water, shallow channels, and buttressed trees with shallow roots.

Another factor that influenced the selection of sites was their suitability for Ground Penetrating Radar (GPR) analysis. GPR is sensitive to the composition of the floodplain sediment. Finer sediments hold more water and therefore cannot be penetrated by GPR.

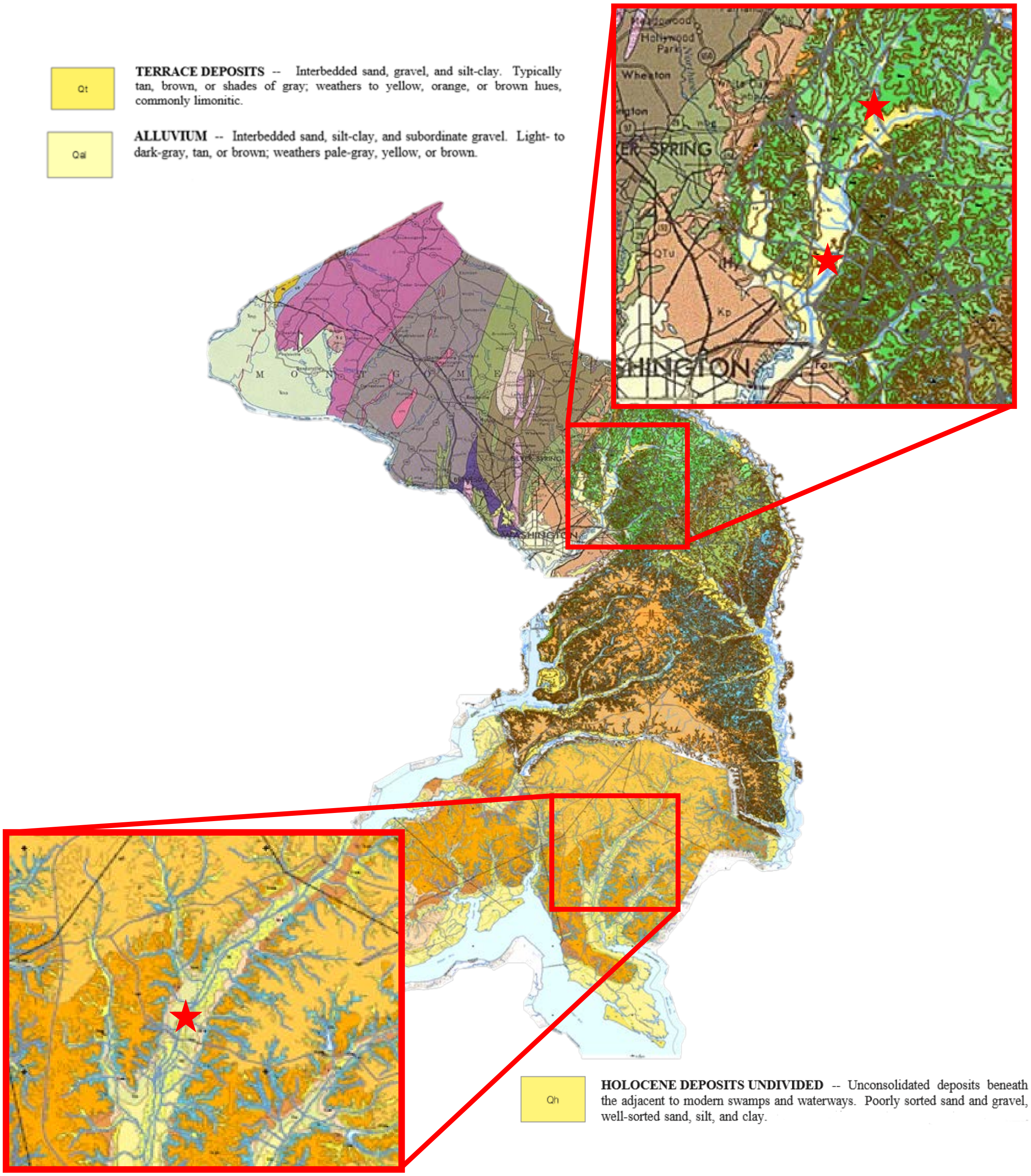


Figure 4 is a map compiled of three geological maps to display my stream sites from Department of Natural Resources and Maryland Geological Survey. (Glaser, 2003) (McCartan, 2003) (Maryland Geological Survey, 1968)

Figure 5 shows the unchannelized site, Zekiah Swamp Run and some of its distributary channels.

Figure 6 image of the channelized stream, the NE Branch of the Anacostia River.

Figure 7 is an image of the unchannelized tributary of the NE Branch of the Anacostia River, Little Paint Branch Creek.

Field Data Collection Procedures

The following set of data was measured at each site: a) Floodplain widths and gradients b) channel and floodplain topographic surveys, b) time series of stream gauge height, c) groundwater elevation, and d) floodplain sediment grain size. These data were to determine: a) the frequency of overbank flooding, b) the groundwater elevation, c) the time available for bank seepage and groundwater drainage, and d) the groundwater hydraulic gradient towards the stream and across the floodplain.

Channel and Floodplain Cross Sections by Topographic Surveying

Topographic surveys of the channel and floodplain were conducted to determine surface topography variations and a basis for determining the relative elevation of the groundwater below the ground surface. At each field site, I selected a transect of interest that is adjacent to the stream gauge and is a site with a clear pathway for GPR analyses between the channels and the floodplain. Horizontal distance is measured with a tape measure starting at the far bank of the stream. Elevation is measured by using a surveying level and stadia rod. Elevation, relative to a local datum, is calculated as the height of instrument minus the foresite (see appendix). Topographic elevation is measured at 2-3 meter intervals along the topographic transect. The topographic measurements are used to evaluate ground surface elevations and used in the flooding frequency analysis. Topographic measurements are also used in the analysis of the depth to groundwater water (for both well measurements and Ground Penetrating Radar (GPR) measurements).

Gauge Height Monitoring

The USGS has several stream gauging station in the Anacostia Watershed. I utilized these pre-installed gauges and the continuously monitored data provided by the USGS, saving time as well as money by not installing my own gauges at every site. Gauge height is used to define flooded depth each site. The stream hydrograph data can be utilized by evaluating the symmetry and asymmetry of curves. This information will indicate expected times of discharge and recharge of the groundwater table relative to one another. One of the major variables that I used in my analysis is Bank height – gauge height. I used a time series of this variable to define the frequency of overbank flooding and the elevation of the groundwater table immediately adjacent to the stream.

Determination of Water Table Elevation Ground Penetrating Radar

Ground Penetrating radar is an advanced piece of shallow earth seismological equipment that has the ability to detect the saturated zones below the earth's surface. GPR works by emitting approximately 25MHz to 1GHz radio waves into the ground, then recording the time it takes for the reflected waves to return (Burger, Sheehan, & Jones, 2006). This method of groundwater detection is time saving compared to well monitoring and accurate to a few tens of centimeters. However, GPR is not effective at finding the groundwater table where sediments are predominantly clay. Clays generally have high saturations causing the radio waves not be able to penetrate the subsurface to the groundwater table. For this reason, I have chosen sites with lower clay contents and higher sand content. These sediments can have layered compositions that the GPR can detect and map. The changing in sediment changes the velocity that the wave will travel through the subsurface and even cause some of the waves to be reflected back to the surface. The wave velocities change due to the changing permeability and therefore, dielectric constant of each soil layer.

In order to find any possibility of spatial variation I created several transects per site. The GPR is equipped with both GPS logging capabilities and a scroll wheel. I pushed the GPR along the transect by using both the scroll wheel and the GPS to record position along the transect as it takes radar measurements of the subsurface. I then imported this data into the program RADAN 7 for data processing. The program first converts the data from a length of time taken for the radio wave to penetrate the subsurface, reflect, and return, into a measure of distance below the surface. The program can then apply a filter that eliminates both the high and low frequency noise. For the low pass filter double that of the antenna frequency is applied and for the high pass filter one-fourth that of the antenna frequency is applied. The GPR uses a 400 MHz antenna so the set low pass frequency is 800 MHz and the set high pass frequency is 100 MHz. Next, RADAN 7 performs migration. This removes any hyperbolic tails caused by solid structures in the subsurface such as pipes or tree roots. In the case of my research, I find primarily tree roots. The program is able to correct this by using an equation that correlates the velocity, v, the magnetic permeability, μ, the dielectric permeability, ε, and the speed of light, c [eq. 2].

$$[2] \quad v = \frac{c}{(\mu_\varepsilon \times \varepsilon_r)} \qquad where\ c = 3 \times 10^8\ m/s$$

First, I must select the approximate size of the hyperbolic trail so the program can detect the dielectric permeability. Using the dielectric constant determined, the speed of light, and a magnetic permeability of one, the program is able to determine the velocity of the signal at this precise feature. Once I apply this velocity to the migration settings, the program will remove any hyperbolic trail of this velocity.

I then use the 2D- interactive mapping function. This allows me to pinpoint the depths of specific layers that can be viewed in the newly processed GPR and turn these data into an excel sheet. These data will be in the format of distance from stream along a transect versus the depth below the ground surface. To construct an accurate representation of the topography of the subsurface I used the topographic surveys of the surface, subtracting the depth below the surface from the topographic elevation along the transect. I finally created a 3D representation once I performed these steps on all of the transects from a single site.

Sediment Grain Size Analysis

I have collected floodplain and channel sediments from my sites and sieved them to obtain grain size distributions (fig. 8). The 10^{th} and 50^{th} percentile data are used to estimate hydraulic conductivity. The 10^{th} percentile is used to determine hydraulic conductivity because the finer grained sediments fill larger pore spaces (Alamani & Sen, 1993). Floodplain Grain Size Characteristics. The grain size data are used to estimate hydraulic conductivity (Alamani & Sen, 1993). This method uses the x intercept, the 10^{th}, 50^{th} percentile grain sizes to estimate hydraulic conductivity. The estimate for the grain size distribution shown below predicts a hydraulic conductivity of 0.105 m/day.

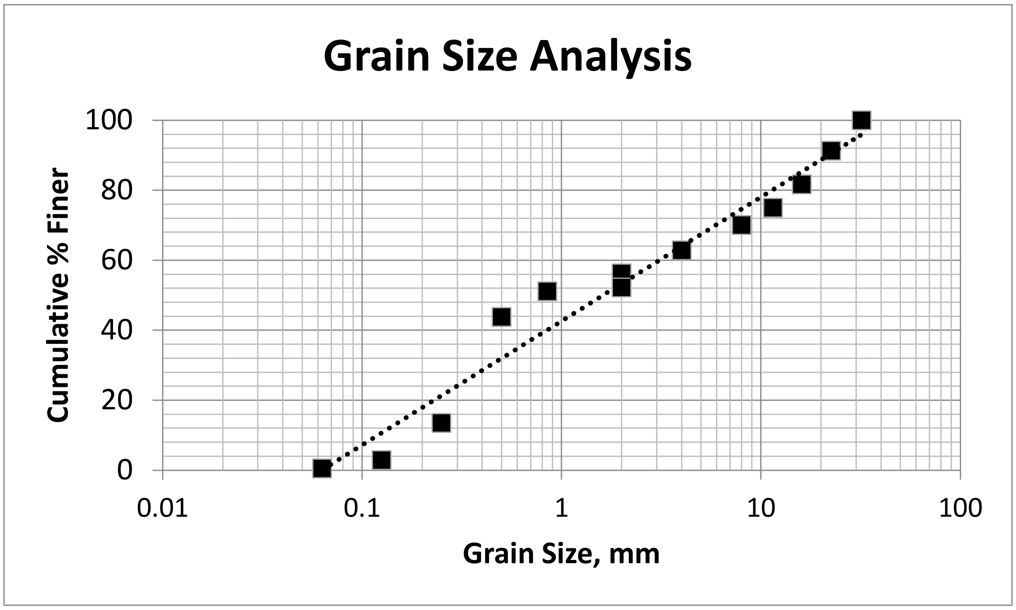


Figure 8 is a graphical representation of the grain size analysis. The smaller grain sizes are representative of the pore space.

RESULTS

Floodplain Characteristics

The site selected along the NE Branch of the Anacostia River is downstream of the junction with Paint Branch Creek. The down valley gradient average was calculated to be 0.0121 ± 0.00512 for the NE Branch (fig. 9) compared to 0.0135 ± 0.00403 for Zekiah Swamp Run (fig. 10). The cross-valley gradients are also very similar, 0.0409 for the NE Branch of the Anacostia River and 0.0418 for Zekiah Swamp Run. These values were calculated from data viewed on Google Earth from the elevation profile generator as shown in figures 8 and 9. Also calculated from the elevation profile generator was the overall floodplain widths. The NE Branch of the Anacostia River has a floodplain width 684 - 740 meters and Zekiah Swamp Run has a floodplain width of 1960 meters. The Anacostia River floodplain has been modified by urban construction.

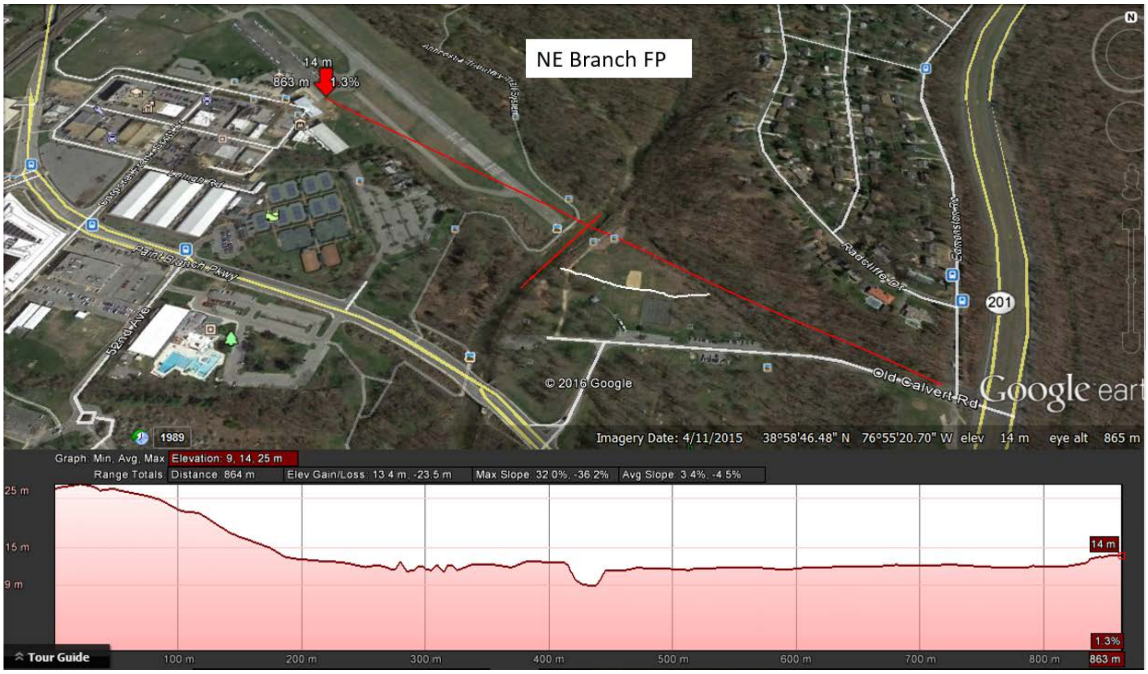


Figure 9 This image viewed from google Earth and collected from SIO, NOAA, U.S. Navy, NGA, or GEBCO *showing the floodplain and stream of the NE Branch of the Anacostia River in the elevation profile generator.*

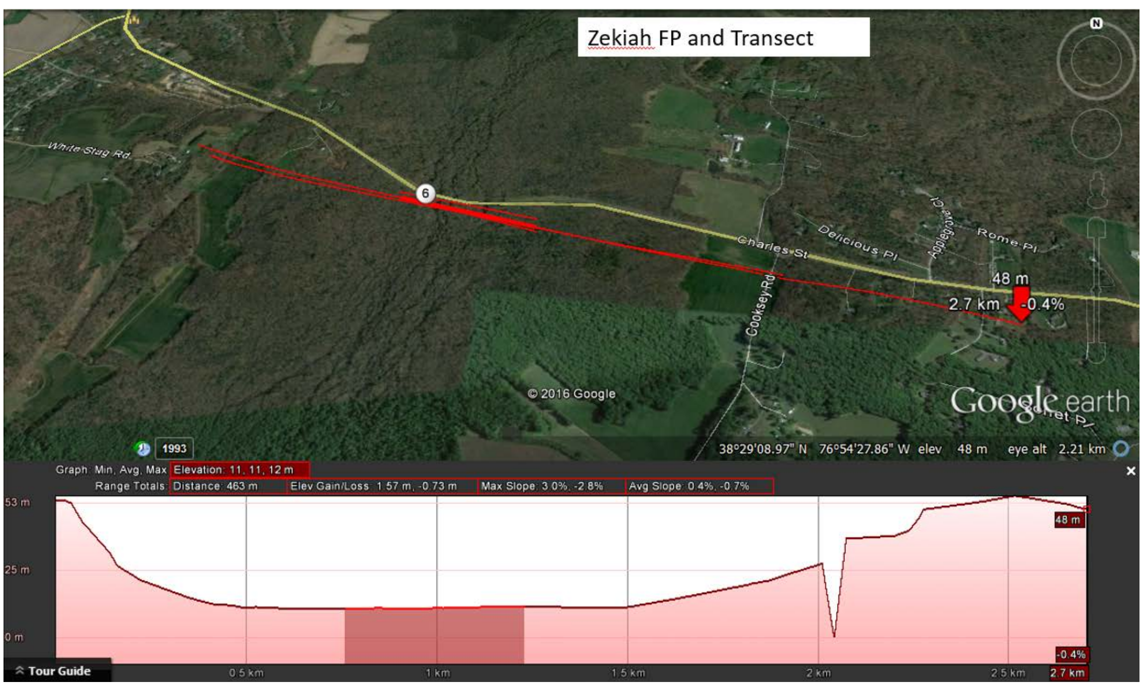


Figure 10 This image viewed from google Earth and collected from SIO, NOAA, U.S. Navy, NGA, or GEBCO showing the floodplain and stream of Zekiah Swamp Run in the elevation profile generator.

Elevation of floodplain groundwater

After collecting elevations from The North-East branch of the Anacostia River, the data were analyzed and plotted (appendix). Both sites have very flat topography, major topographic variations were the channels. Maximum channel depth below the floodplain was 2.44 meters in NE branch of the Anacostia and 0.3 meters in Zekiah Swamp Run. The floodplain of Zekiah Swamp Run was very flat, topographic highs were gravel bars, 0.5 meters above the average floodplain, and channels, that were anywhere from 5 to 70 cm below the average floodplain. I have plotted the elevation profile of the NE Branch of the Anacostia River floodplain that clearly shows the topography dipping downward toward the stream level, changing 2.4 meters in height. The upstream tributaries of The North-East Branch of the Anacostia River, Little Paint Branch Creek, has a much different topographic survey, as this is unchannelized. This channel has a calculated bank height of 1.5 meters. Finally, the topography of Zekiah Swamp run shows a relatively flat with any change in elevation representing channels.

Ground-penetrating radar surveys

The lower photos of figure 11 and figure 12 show the tracks of GPR surveys for Zekiah Swamp Run and the NE Branch Anacostia. Raw data collected using Ground Penetrating Radar are shown in figure 13. There are clear distinctions between layers of the subsurface. The top layer seen above the red line, about 0.0 m to 0.4 m in depth, is a loosely packed topsoil. Below the loosely packed topsoil and above the blue line, about 0.4 m to 1.0 m, is a more tightly packed sand. About 1.0 to 2.5 m below the surface, is a finer grained sand layer or a silty sand layer. This layer holds slightly more water than the previous layers. Finally, below the green line at a depth of 2.5 m below the surface, is the water table. This is the distance below the surface where the radio waves no longer penetrate the subsurface and are all reflected back to the surface.

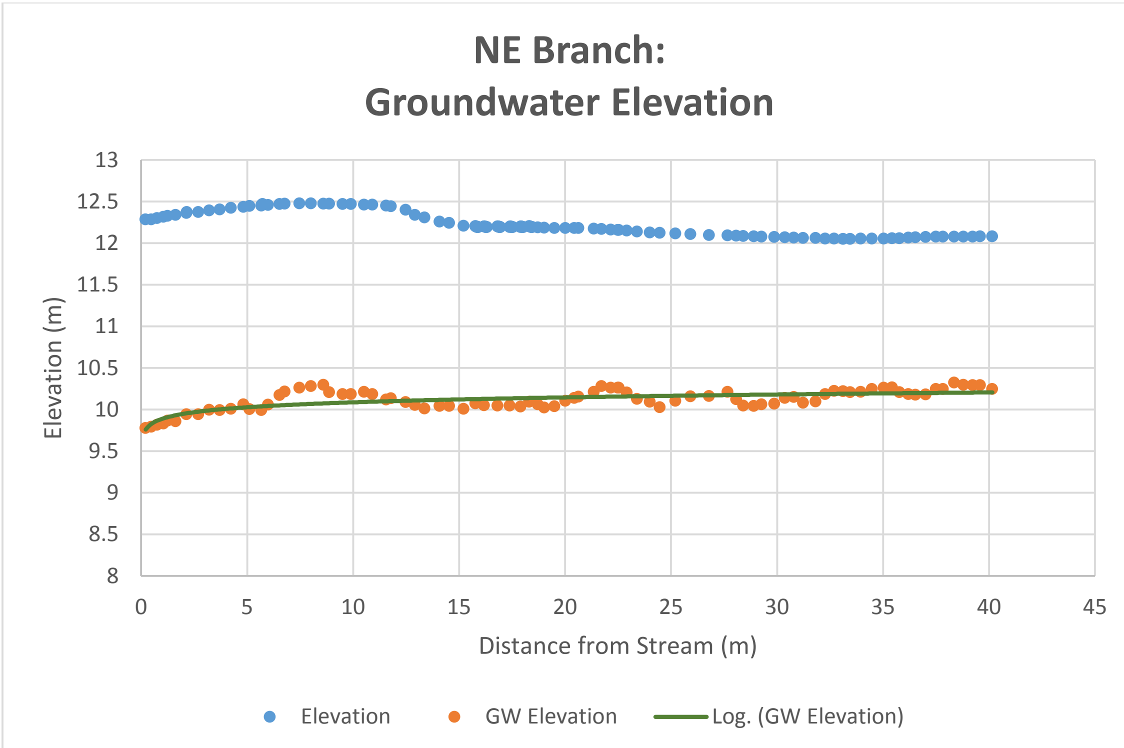


Figure 11 Upper diagram, ground and groundwater elevation determined from a GPR transect running perpendicular to the river bank shown in the lower diagram

.

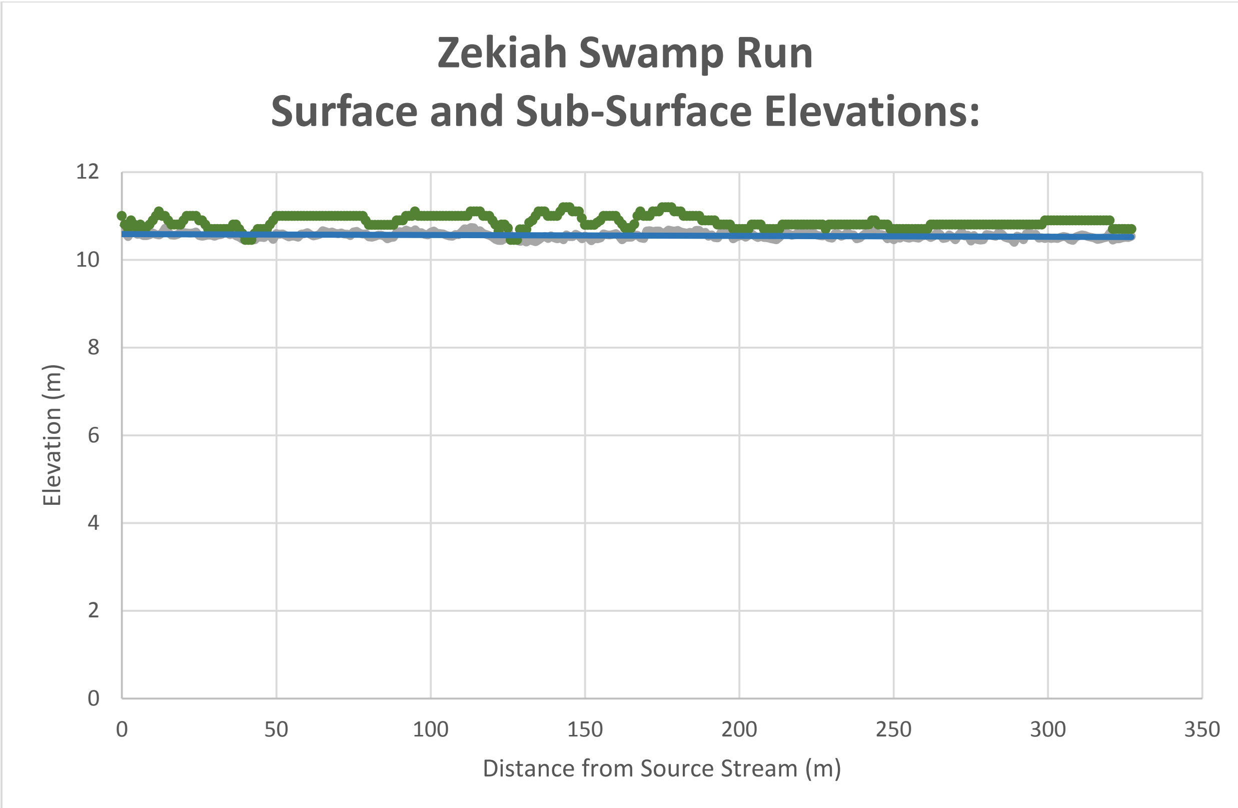


Figure 12 Upper diagram: Surface topography and groundwater elevations for the East half of the Zekiah Swamp Run active floodplain; Lower: trace of cross section on a Google Earth image.

.

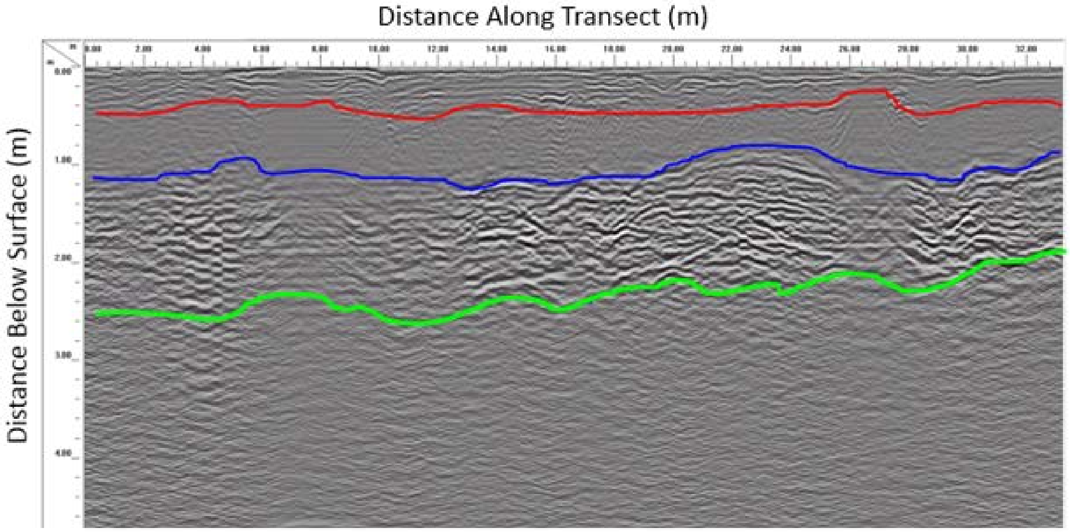
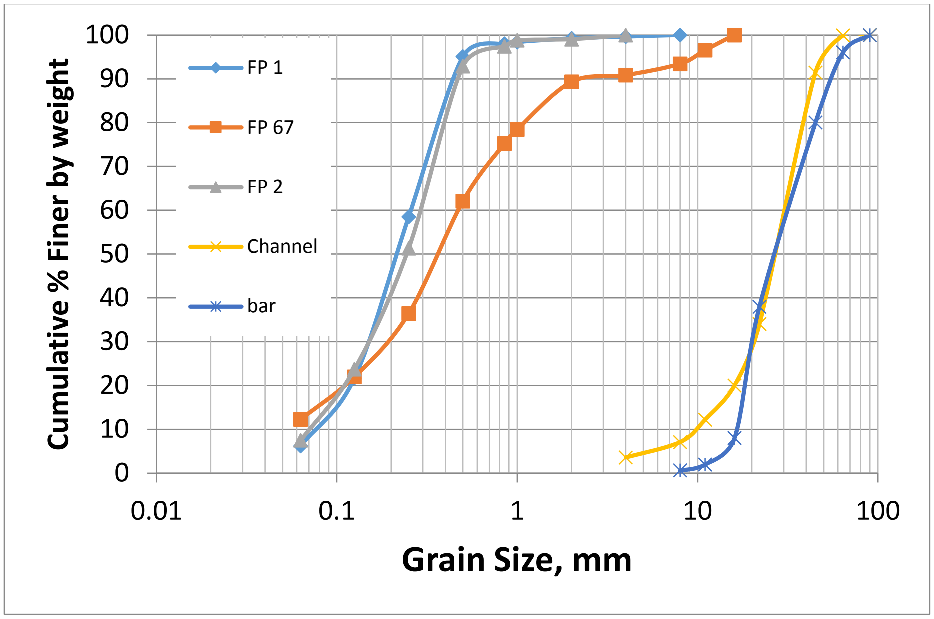


Figure 13 is the processed, pre- analyzed GPR data from my first site, the NE Branch of the Anacostia River. This image displays clear differentiation in soil composition and the defining line of the groundwater table.

I used RADAN 7 to turn the water table boundary into a series of points in an excel file that correlate to their geographical coordinates. I then was able to correlate the topographic data along the transect to the water table depth below the surface by using those geographical coordinates. This allowed me to determine the topography of the water table by subtracting depth to the water table from the surface elevation. I finally plotted the water table elevation as a function of distance along the transect.

Floodplain Grain Size Characteristics

Surface sediment samples were acquired from channels, bar deposits, and floodplains at the field sites. These samples were sieved and the data were plotted to determine grain size fractions. At all of the sites, the floodplain sediments were much finer-grained than the channel sediments (fig. 14). The difference between the sites, however, is the of the floodplain width covered by the different sediment types. In the Anacostia River floodplain, coarse-grained channel sediment are 3% of the floodplain -channel system. In Zekiah Swamp Run, the combined channel and bar coarse-grained sediments are 38% of the floodplain (table 1).



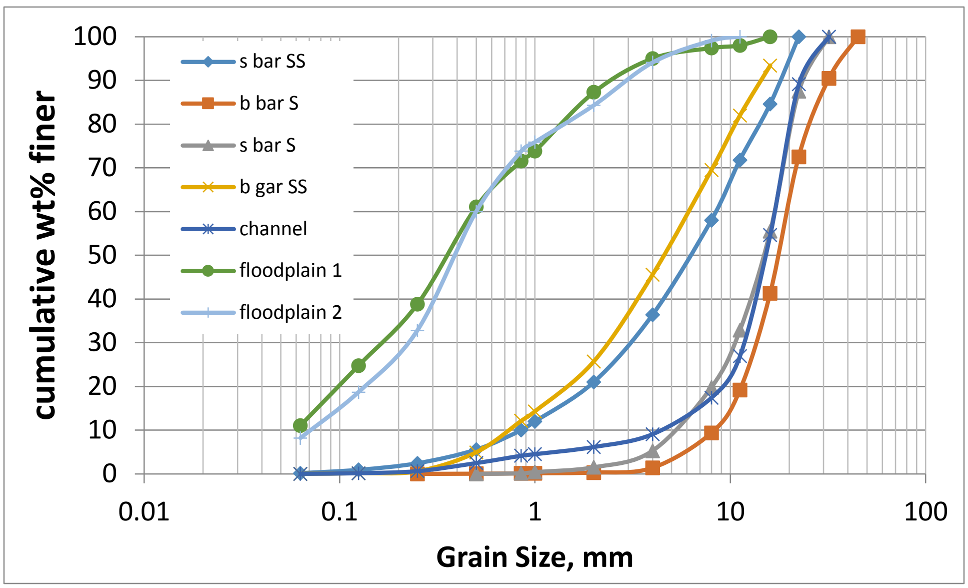


Figure 14 Upper diagram: Anacostia River, Lower Diagram: Zekiah Swamp Run. Channel surface and bar deposits are coarse-grained and well sorted at both sites. Floodplain deposits are much finer grained at both sites.

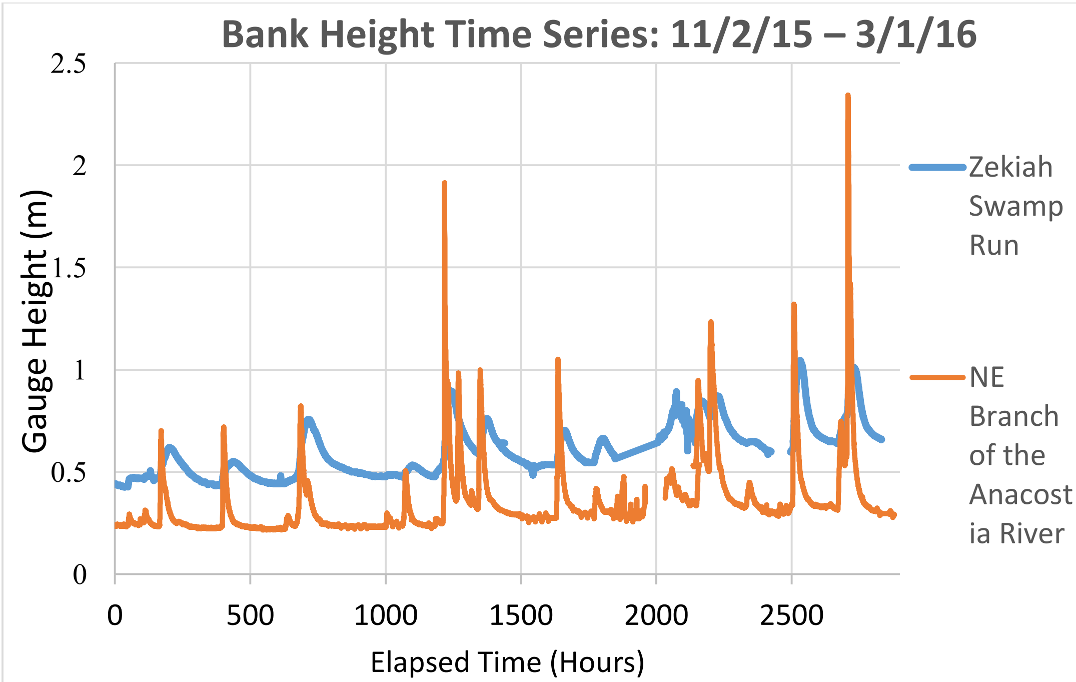
Table 1 Summary of Floodplain and Channel data

	NE Anacostia	Zekiah
Floodplain width , Wfp, m	740	1438
Channel Width(s), Wc, m	22	548
Wc/Wfp	0.03	0.38
Maximum depth, m	3.1	1.0
Floodplain D50, mm	0.28	0.4
Floodplain D10, mm	0.067	0.063
Channel/bar D50 mm	28	17
Channel/bar D10 mm	13	6.3
Subsurface D50		5.6
Subsurface D10		0.8

Groundwater recharge processes

Recharge and draining periods on Storm Hydrograph

These data from the USGS website display the gauge height elevation of the two streams on one graph (fig. 15: upper diagram). The data shown were taken over the period of November 2nd 2015 to March 1st 2016, the winter recharge period. This graph presents a maximum gauge height of about 2.3 m for the NE Branch and about 1.1 m for Zekiah. The USGS gauge height data is measured to an accuracy of 0.005 ft. The graph depicts floods that are flashy, showing the water level rapidly rising and falling during storm events for the NE Branch. The NE Branch of the Anacostia River and Zekiah Swamp Run have very different sized gauge height peaks for each individual storm event. Shown in (fig. 15: lower diagram), the storm event peaks for the two sites have a roughly linear relationship. This is more clearly viewed in figure 16, the hydrograph symmetry curves. The hydrograph (fig. 16: upper diagram) for The North-East Branch of the Anacostia River is very asymmetric, where the left hand side or the rising time is much shorter than the right hand side or the recession time. The hydrograph (fig. 16: lower diagram) for Zekiah Swamp Run is much more symmetrical having nearly equal rising and recession times.



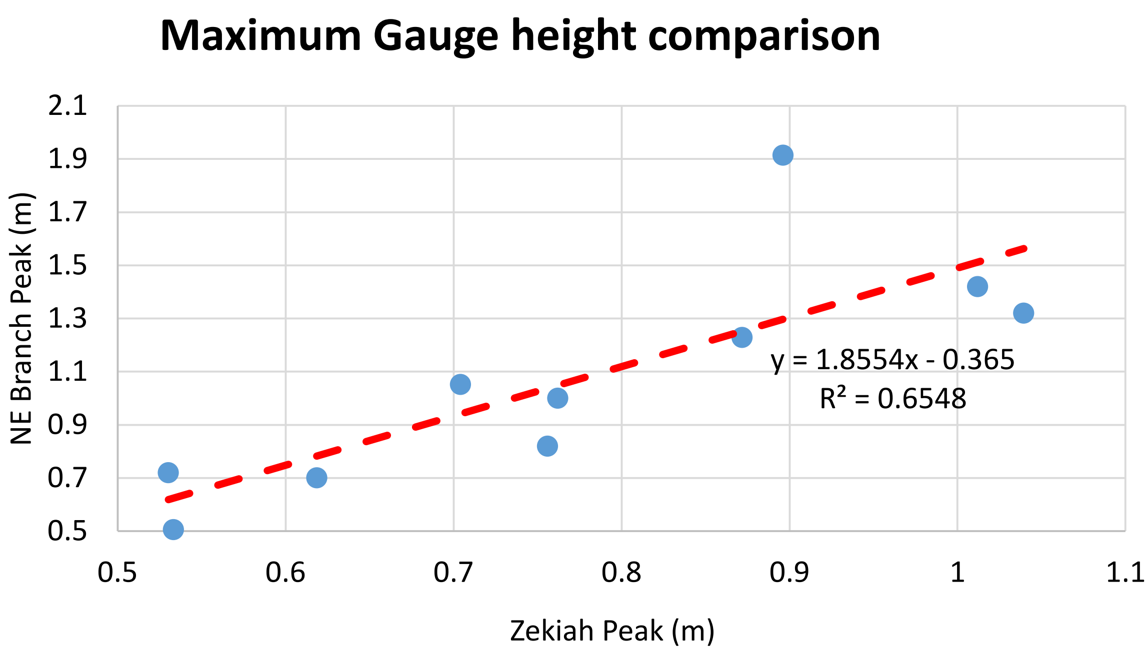
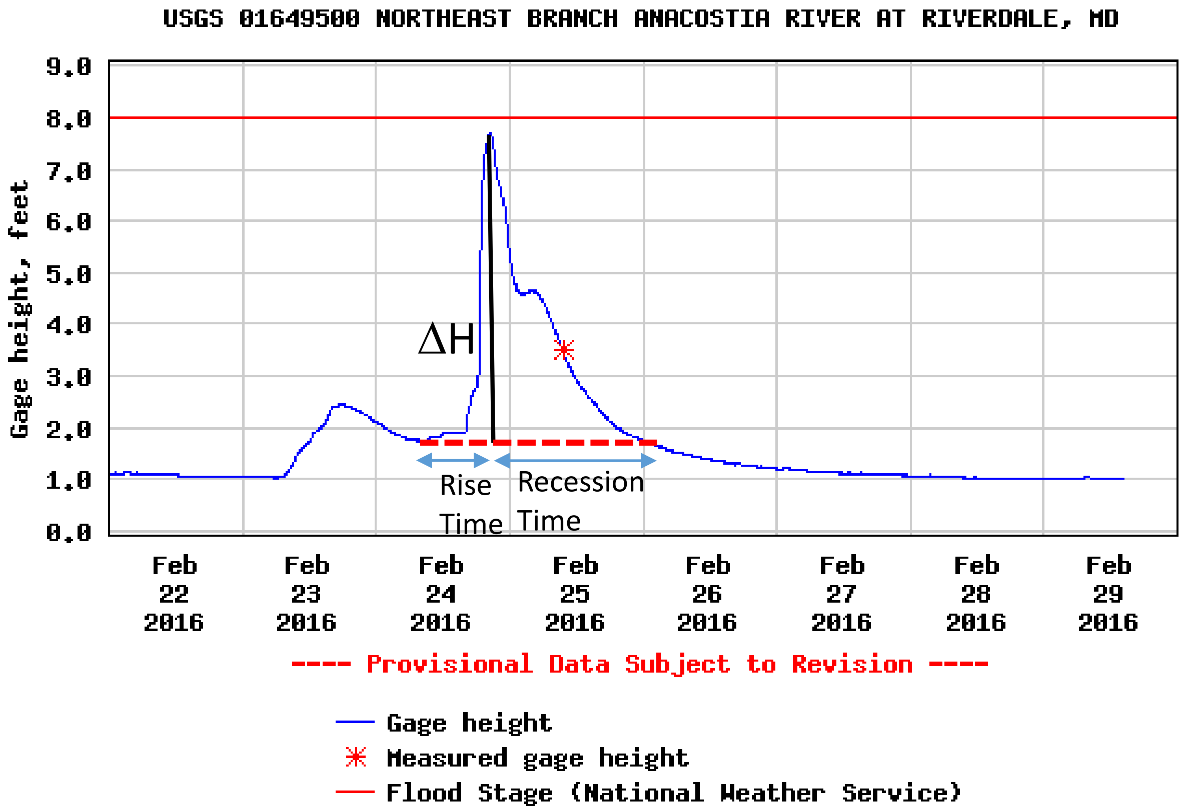


Figure 15 Upper diagram: USGS gauge height graph at the Northeast Branch of the Anacostia River at Riverdale, MD (bed) and the USGS gauge height graph for Zekiah Swamp Run (blue). Note differences in gauge height and hydrograph duration. Lower diagram: Comparison of maximum gauge heights at NEB and Zekiah Swamp Run.



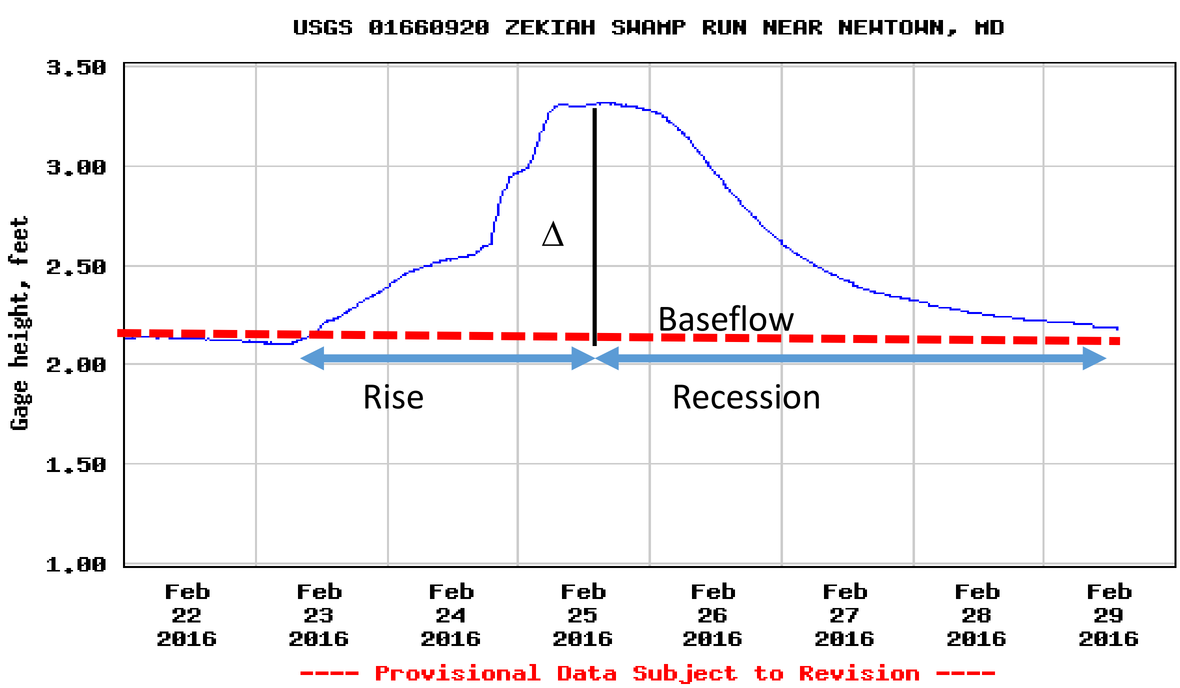


Fig. 16 Hydrograph asymmetry for: NE Anacostia (upper) and Zekiah Swamp Run (lower diagram)

Frequency of Overbank Flooding

Figure 17 shows the gauge height probability distribution curve for the North-East Branch of the Anacostia River. The dotted red line is the line of best fit that is representative of a linear trend between the probability of the stream exceeding a specified gauge height and the gauge height. This probability curve has a gauge height peak on the left hand side that exceeds the linear trend line. Figure 18, in contrast, shows the gauge height probability distribution curve for Zekiah Swamp Run. On this plot, the dotted red line is also representative of the curve's linear trend line. It is significant that this plot does not exceed the linear trend line, but rather flattens out as the fraction of time exceeded reduces, around 0.1.

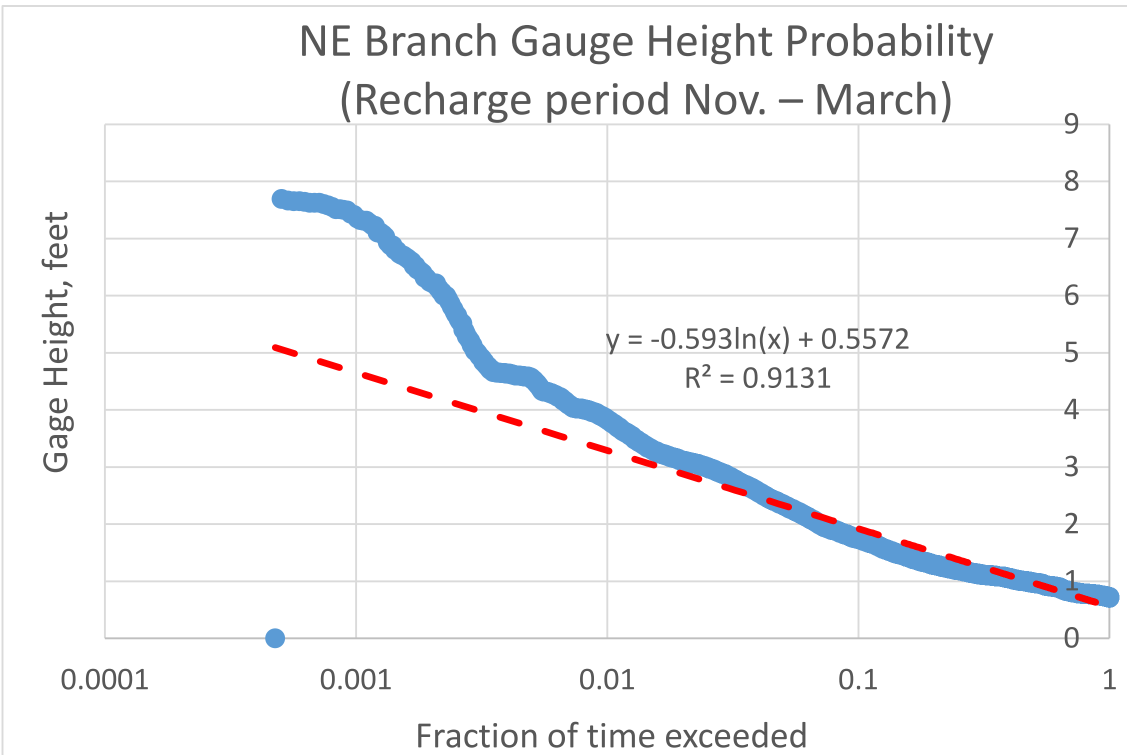


Fig. 17 River stage probability graph, NE Branch Anacostia River

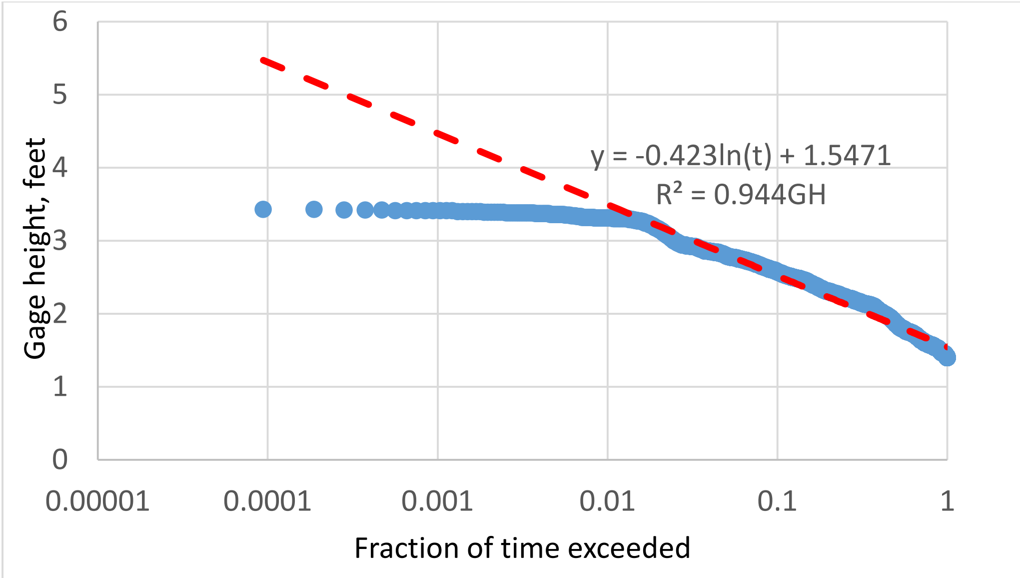


Figure 18 River stage probability graphs, Zekiah Swamp Run, the Flat trend indicates the filling of the main, gauged channel that forces flow into distributary channels and the floodplain.

DISCUSSION AND IMPLICATIONS

The North- East Branch of the Anacostia River and Zekiah Swamp Run were selected for study due to their similar watershed areas and general floodplain characteristics, including floodplain gradient. One stream is channelized and one is not, causing bank height differences of approximately 1.3 meters. The cross-valley stream gradients are similar slopes indicate the two rivers may have once had similar groundwater discharge gradients. The down valley stream gradients are shallow and very similar indicating the possibility of previously similar flow velocities in the streams if stream morphologies were similar. In contrast, the width of the floodplain with active channel processes is much larger in Zekiah Swamp Run. This is a result of the different channel morphology and over-bank flow mechanisms present at each stream. The NE Branch of the Anacostia River does not go out of its banks frequently due the large, deep channel. This single-thread, low sinuosity channel has high velocities during flood flows (McDowell, 2016). Zekiah Swamp Run, in contrast, has a much larger floodplain because of the many distributary channels that are formed and filled during large storm events and less encroachment by urban areas. High flows are distributed into many distributary channels, which greatly expands channel width at high flows. Gravel deposits observed in the field indicate that deposition in channels occurs during floods and causes formation of distributary channels. This mechanism of carrying large floods over wide regions of the floodplain was a likely mechanism that occurred at the NE Branch of the Anacostia River before channelization. Evidence for that is seen in the topographic survey taken of the NE Branch of the Anacostia River's, unchannelized tributary channel, Little Paint Branch Creek, which is upstream of the channelized reach. This tributary channel contains bar deposits and distributary channels.

I compared peak flow in the two streams by plotting one stream peak versus the other for each storm event. I determined that there is a nearly linear relationship, but significantly higher peaks in NE Anacostia. This is indicative of the streams receiving similar rainfalls from the storm events. The difference in gauge height however is produced the response to the storm events and the different ways the streams carry the discharge and their overall geomorphology. Due to their different morphologies, stream channels in two floodplains also have different processes for groundwater recharge. This can be observed by comparing the hydrograph response for the two streams. The duration of the rising and falling limbs of the hydrographs indicate rise time and recession time. The rise time is the groundwater recharge period through bank storage, while the recession time is the groundwater draining period. The NE Branch of the Anacostia River has an asymmetric curve, allowing for long periods of groundwater drainage and much shorter periods of groundwater recharge. However, Zekiah Swamp run has a much more symmetrical curve, showing that there is equal amounts of time for groundwater recharge and drainage. NE Branch Anacostia stream can recharge the floodplain through bank recharge, but the short rising limb times and fine-grained flood plain sediment limit this process.

The frequency of overbank flooding for storm events can contribute to groundwater recharge as depicted in the water balance equation. This means the frequency of overbank flooding is directly related to the amount of groundwater recharge in a floodplain. The gauge height probability curve for the NE Branch of the Anacostia River indicates that the stream has not gone out of bank during the winter groundwater recharge period, because gauge heights were lower than the floodplain elevation. The gauge height probability distribution graph for Zekiah Swamp Run flattens out due to the stream filling to the bank and overbank flooding. This curve indicates that Zekiah Swamp Run reached or exceeded bankfull stage about 2% of the time during the winter recharge period.

The NE Branch of the Anacostia River floodplain is flat with a topographic profile that dips toward the stream. The topographic profile that I surveyed in one of NE Branch of the Anacostia River's tributary channels, Little Paint Branch Creek indicates two separate channels and gravel bars. The smaller of the two channels is a distributary channel that carries water when the sill depth is reached and fills when the water level in the stream reaches bankfull. This distributary channel is also effective at delivering the stream water onto the floodplain and recharging the groundwater at a greater distance across the floodplain than would be reaches by the less frequent overbank flooding. The larger of the two channels is the primary stream channel. The topographic profile made of Zekiah Swamp Run extends for a large portion of the floodplain to show the many distributary channels that branch off from three main channels.

The comparison of hydrographs for the two streams indicates that the NE Branch of the Anacostia river is flashy and peaky compared to the Zekiah Swamp Run. This flashy hydrograph trend allows for little time for the ground water to recharge through overbank flooding. A probability curve was created that showed the NE Branch rarely experiences storm events large enough to cause overbank flooding. In addition to the rare over bank flooding, the NE Branch of the Anacostia river has a much finer grain size distribution indicating less permeable sediments and less groundwater recharge through both bank seepage and floodplain infiltration. Zekiah swamp, in contrast has a much smoother and more rounded curve, indicating a longer period of peak water levels. This hydrograph trend allows for a much longer period of ground water recharge showing that overbank flooding is a major and frequent source of recharge. Before overbank flooding, Zekiah Swamp Run fills it's distributary channels as well, allowing for a wider area of overbank flooding, bank seepage, and infiltration through the tips of distributary channels blocked by gravel deposits. In addition to frequent overbank flooding, Zekiah has coarser grain sized than The NE Branch of the Anacostia River. Between many of the channels are gravel bars brought in during large storm events and formed by the stalling of bedload in active channels, creating a channel fill. These gravel bars and deposits have a high permeability allowing for a much higher rate of infiltration through the floodplain than the fine floodplain sediments that cover the surface of the Anacostia floodplain. In the Anacostia floodplain, gravel sediments occupy only the channel bed area, which is 3% of the floodplain width.

The groundwater elevation data for the NE Branch of the Anacostia River show a downward sloping trend that mimics the surface topography. When I closely examined the topography of the groundwater table beneath the NE Branch of the Anacostia River floodplain, it appeared that the sudden spikes in elevation were buried channels. These buried channels are indicative of the pre-channelization geomorphology similar to a distributary system. The depth to groundwater in the Anacostia is between 2 and 2.4 m, much deeper than the 0-0.3m measured in Zekiah Swamp Run.

CONCLUSIONS

The use of GPR to locate the groundwater table allowed for the closer examination of the relationship between floodplain groundwater elevation adjacent to a stream and the stream gauge height. After applying various field methods, I concluded that the groundwater elevations are lower in floodplains along channelized streams. I was able to accurately locate the groundwater table during the winter recharge period using ground-penetrating radar at both sites, providing me with data to confirm this hypothesis. Along with the collected GPR data, the use of USGS supplied hydrographs, and grain size analysis I was able to test my second hypothesis. From these data, I concluded that during the past winter season, groundwater recharge in the NE Branch was only due to infiltration of rainwater that fell directly on the floodplain, with no overbank flooding and little bank seepage. In comparison, Zekiah Swamp run had multiple mechanisms for groundwater recharge, which included overbank flooding, flow into multiple distributary channels, seepage through gravel sediment that blocked distributary channels, a direct precipitation onto a wide, permeable floodplain. These data suggest that ground water recharge rates could be calculated for each of these recharge processes using precipitation and gauge height data for coastal plain streams. Understanding the groundwater recharge processes could improve predictions of groundwater elevations in the surrounding floodplain. Use of GPR afforded the opportunity to examine the depth to the groundwater table over broad areas of floodplain.

After comparing various stream characteristics of the North-East Branch of the Anacostia River to that of Zekiah Swamp Run, I have concluded that it is probable that the NE Branch was once a distributary stream network similar to Zekiah Swamp run. This is seen through the presence of similar geomorphologies such as floodplain gradients, basin areas, and the presence of tributary channels in upstream locations. The discovery of buried underground channels in the floodplain of the North-East Branch of the Anacostia River also supports this hypothesis.

Channelization of streams alter the stream hydraulics that affect the floodplain processes. High floodplain ground water levels provide support to riparian wetlands, increase water residence times, and aid in the retention of sediment and nutrients. In the case of the channelization of the NE Branch of the Anacostia River, the mechanism for flow distribution and groundwater recharge has been altered entirely. The NE Anacostia has significantly lower groundwater tables than the comparable, but unchannelized stream Zekiah Swamp Run.

ACKNOWLEDGEMENTS

Patrick Deery, UMD student, aided in the collection of topographic data as well as the collection of sediment samples.

Caroline Plank, UMD Graduate Student, aided in the collection of topographic data, sediment samples, and GPR data.

William Nyugen, High School senior, aided in the sieving of sediment samples.

REFERENCES

Alamani, M. S., & Sen, Z. (1993). Determination of Hydraulic Conductivity from Complete Grain-Size Distribution Curves. *Groundwater*, 551-555.

Beighley, R. E., & Moglen, G. E. (2002). Trend Assessment in Rainfall-Runoff Behavior in Urbanizing Watersheds. *Journal of Hydrologic Engineering*, 27-34.

Bravand, J. P., Amoros, C., Pautou, G., Bournaud, M., Creuze des Chatelliers, M., Gilbert, J., . . . Tachet, H. (1997). River Incision in Southeast France: Morphological Phenomena and Ecological Impacts. *Regulated Rivers: Research and Management*, 75-90.

Burger, H. R., Sheehan, A. F., & Jones, C. H. (2006). *Introduction to Applied Geophysics.* New York: W.W. Norton.

Cooke, R. U., & Reeves, R. W. (1976). In *Arroyos and Environmental Change in the American Southwest* (p. 213). London: Oxford University Press.

Darby, S. E., & Simon, A. (1999). The nature and significance of incised river channels. *Incised River Channels: Processes, Forms, Engineering and Management*, 3-18.

Devereux, O. H., Prestegaard, K. L., Needelman, B. A., & Gellis, A. C. (2010). Suspended-Sediment Sources in an Urban Watershed, Northeast Branch Anacostia River, Maryland. *Hydrological Processes*, 1391-1403.

Edmonds, D. A., & Slingerland, R. L. (2007, June 20). Mechanics of River Mouth Bar Formation: Implications for the Morphodynamics of Delta Distributary Networks. *Journal of Geophysical Research, 112*.

Edmonds, D. A., Paola, C., Hoyal, D. C., & Sheets, B. A. (2011, November 16). Quantitative Metrics that Describe River Deltas and their Channel Networks. *Journal of Geophysical Research, 116*.

Elliott, J. G., Gellis, A. C., & Aby, S. B. (1999). Evolution of Arroyos: Incised Channels of the Southwestern. *Incised River Channels*, 153-185.

Graf, W. L. (1983). The arroyo problem—paleohydrology and paleohydraulics in the short term. In K. J. Gregory, *Background to Paleohydrology* (pp. 279-302). New York: Wiley.

Harvey, M. D., & Watson, C. C. (1986). Fluvial Processes and Morphological Thresholds in Incised Channel Restoration. *JAWRA Journal of the American Water Resources Association*, 359-368.

Lundberg, D. J., & Prestegaard, K. L. (2011). *Seasonal Variation in Surface-groundwater Exchanges in an Urban Floodplain with Active Gravelbar Formation.* Maryland.

McDowell, M. (2005). *Comparison of Hydrologic and Hydraulic Characteristics of the Anacostia River to Non-Urban Coastal Streams.*

Poole, G. C., Stanford, J. D., & Running, S. W. (2006). Multiscale geomorphic drivers. *Journal of the North American Benthological Society*, 288-303.

Rus, D. L., Landon, M. K., & Harvey, F. E. (2001). Comparison of Instream Methods for Measuring Hydraulic Conductivity in Sandy Streambeds. *Groundwater*, 870-885.

Schilling, K. E., Zhang, Y. K., & Drobney, P. (2004). Water table fluctuations near an. *Hydrol.*, 236–248.

Shankman, D., & Pugh, T. B. (1992). Discharge Response to Channelization of a Coastal Plain Stream. *The Society of Wetlands Schientists*, 157-162.

Turner, R. M., Webb, R. M., & Bowers, J. E. (2003). In *The Changing Mile Revisited* (p. 334). Tuscon: University of Arizona Press.

Webb, R. H., & Leake, S. A. (2006). Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. *Journal of Hydrology*, 302-323.

Woessner, W. W. (2000). Streams and fluvial plain ground water interactions: rescaling hydrogeologic though. *Ground Water*, 423-429.

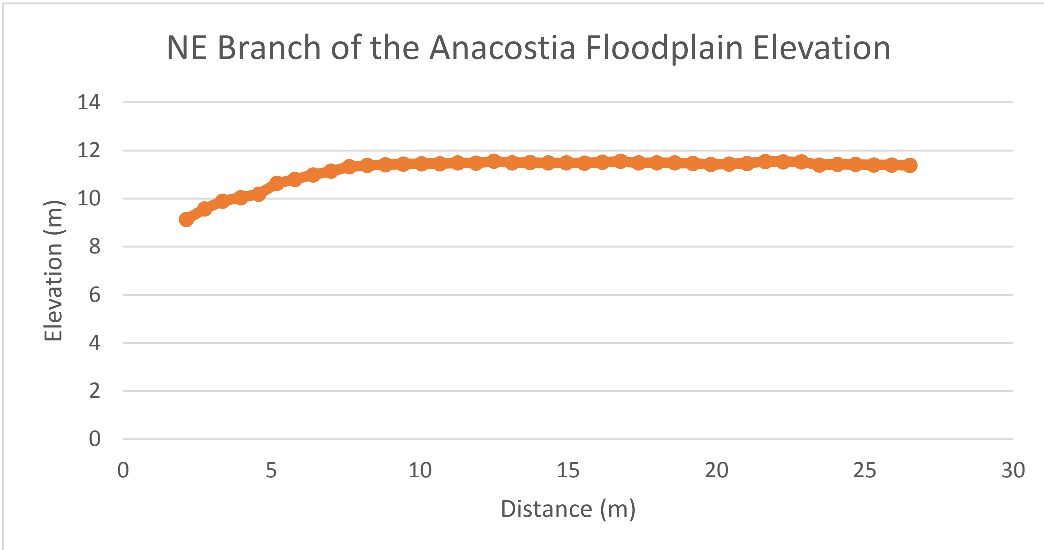
APPENDIX

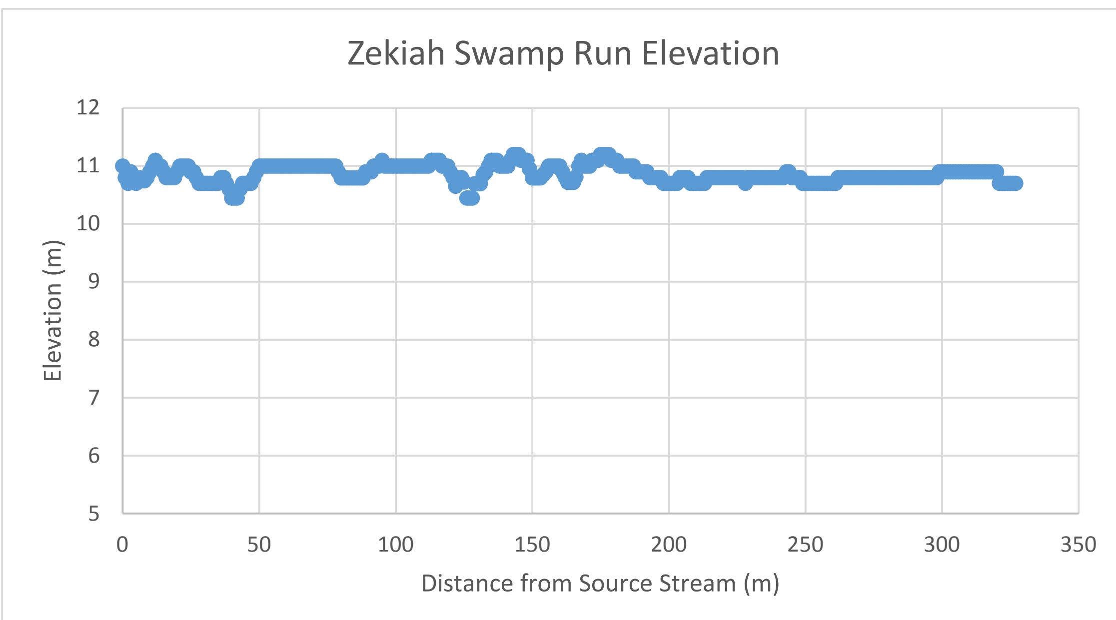
Topography and Surveying Data

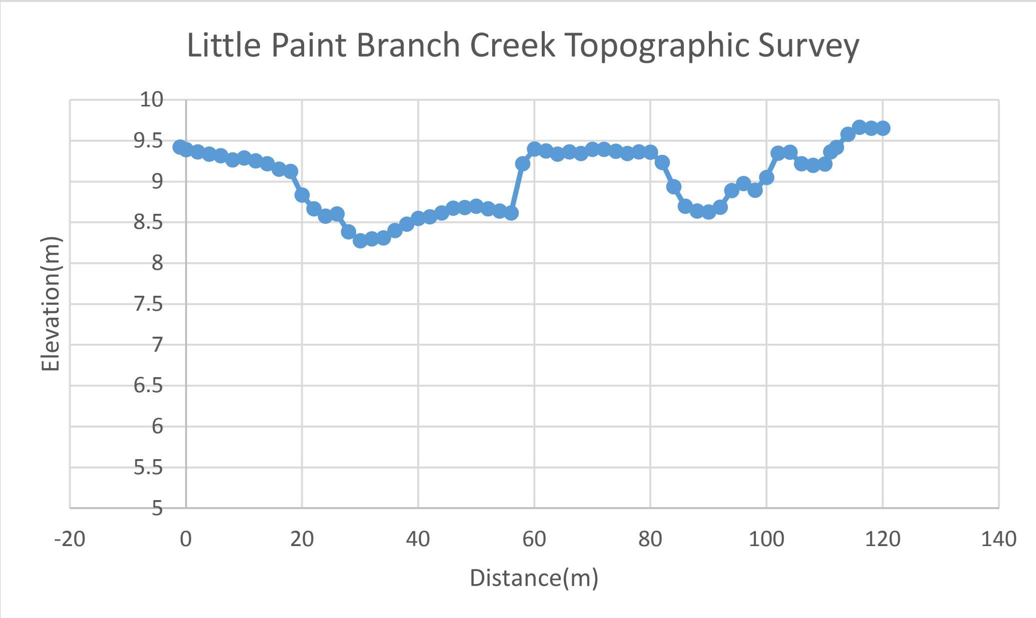
NE Branch Survey

Distance	F.S.	H.I.	Elevation
7	3.66	12.8	9.14
9	3.229		9.571
11	2.905		9.895
13	2.758		10.042
15	2.608		10.192
17	2.165		10.635
19	1.997		10.803
21	1.815		10.985
23	1.66		11.14
25	1.475		11.325
27	1.418		11.382
29	1.388		11.412
31	1.365		11.435
33	1.345		11.455
35	1.345		11.455
37	1.31		11.49
39	1.322		11.478
41	1.245		11.555
43	1.306		11.494
45	1.302		11.498
47	1.312		11.488
49	1.315		11.485
51	1.318		11.482
53	1.285		11.515
55	1.247		11.553
57	1.312		11.488
59	1.305		11.495
61	1.315		11.485
63	1.335		11.465
65	1.378		11.422
67	1.36		11.44
69	1.335		11.465
71	1.25		11.55
73	1.265		11.535
75	1.27		11.53

77	1.4		11.4
79	1.375		11.425
81	1.38		11.42
83	1.396		11.404
85	1.402		11.398
87	1.422		11.378







NE Branch Grain Size Data

Combined Data					
Size, mm	FP 1	FP 67	FP -2	Channel	chan bar
90				100	100
64				99.9	96
45				91.45	80
22				34	38
16		100		20	8
11		96.53		12.2	1.97
8	99.99	93.42		7.09	0.61
4	99.64	90.83	100	3.6	
2	99.23	89.3	99.05		
1	98.4	78.43	98.77		
0.85	97.99	75.23	97.4		
0.5	95.099	62.09	92.9		
0.25	58.49	36.4	51.3		
0.125	21.67	21.95	23.7		
0.063	6.21	12.27	7.48		
0.032					

Zekiah Swamp Run Grain Size Data

	small	big	small	big			
	bar ss	bar S	bar S	bar SS	channel	FP 1	FP 2
45		100					
32		90.46	100		100		
22.4	100	72.53	87.5		89.11		
16	84.6	41.3	55.5	93.39	54.65	100	
11.2	71.8	19.19	32.9	81.98	26.95	98	100
8	58.03	9.38	19.8	69.48	17.41	97.38	99.1
4	36.4	1.39	5.3	45.57	9.08	95	94.1
2	21	0.32	1.5	25.71	6.14	87.26	84.3
1	12	0.16	0.41	14.3	4.51	73.81	75.9
0.85	10	0.13	0.11	12.12	4.15	71.54	73.8
0.5	5.55	0.05	0.02	4.93	2.47	61.07	60
0.25	2.44	0.012		0.59	0.625	38.81	32.8
0.125	0.93			0.16	0.151	24.76	18.7
0.063	0.17			0.026	0.019	11.07	8.2

Determination of Deration and Seepage

Gauge Height, ft	**start**	**end**	**duration, hrs**	**GH, ft**	**Dur, days**	**V/Dur**	**V/Dur**	**GH, ft**
1.02	19:00	3:45	32.75	1.02	1.31	0.080153	1.3755	1.02
2.07	19:30	9:50	26.33	2.07	1.0532	0.110586	1.10586	2.07
3.19	20:15	3:15	7	3.19	0.28	0.0294	0.294	3.19
4	20:35	0:55	4.34	4	0.1736	0.018228	0.18228	4
5	21:03	23:25	2.5	5	0.1	0.0105	0.105	5
6	21:20		1.25	6	0.05	0.00525	0.0525	6
6.4			0.5	6.4	0.02	0.0021	0.021	6.4

Head, m	**dh/dl**	**dh/dl**	**dl = 1**
0.310896	1.05	1.310896	0.105
0.630936	1.05	1.630936	0.105
0.972312	1.05	1.972312	0.105
1.2192	1.05	2.2192	0.105
1.524	1.05	2.524	0.105
1.8288	1.05	2.8288	0.105
1.95072	1.05	2.95072	0.105