WATER TABLE AND OVERBANK FLOW FREQUENCY CHANGES DUE TO SUBURANIZATION-INDUCED CHANNEL INCISION

By
EVAN CHRISTIANSON

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Under the supervision of Professor James Welsh

ABSTRACT

Channel incision is a widely observed response to increased flow in urbanized watersheds, but the effects of channel lowering on riparian water tables are not well documented. It is hypothesized that channel incision lowers floodplain water tables and decreases the frequency of overbank flows. These changes may result in a dramatic change in riparian vegetation cover. A study was conducted on riparian water table response to channel incision along an incised tributary to the James River in the Virginia Coastal Plain. The stream drains an area of 1.3 km^2, of which ~15% is impervious cover. Incision has occurred largely through upstream migration of a ~1 m high knickpoint which moves primarily during high flow events at a rate of 1-2 m/yr. To assess water table elevations, 33 wells in six floodplain transects were installed in the riparian zone. Two transects are in unincised floodplain, ~30 and ~50 m upstream of the knickpoint, and the remainder are in the incised floodplain, ~5, ~30, ~70, and ~100 m downstream. Significant differences were observed in the water table above and below the knickpoint. Above the knickpoint, the water table is relatively flat and is ~0.2-0.4 m below the floodplain surface. In the transect immediately downstream of the knickpoint, the water table possesses a steep gradient, rising from ~1 m below the floodplain at the stream to ~0.3 m below the surface within 20 m. In the most downstream transects, the water table shape is similar to unincised transects, but is ~1 m below the floodplain surface. Upstream of the knickpoint, overbank flooding occurs frequently while below the knickpoint, the majority of storm flow is contained within the channel. During storm events, water table response to precipitation is nearly immediate. However, the magnitude of water table fluctuation is greater downstream of the knickpoint; in the unincised portion of stream, the water table rapidly rises to the surface and forms ponds. Plant diversity surveys reveal differences in the total density of herbaceous growth and species distribution between the floodplain above and below the knickpoint. This suggests a link between water table levels, flooding frequency, and plant growth.

ACKNOWLEDGEMENTS

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INTRODUCTION

It has been shown that in almost all instances, urbanization increases stream discharge (Leopold, 1968; Kibler et al., 1981; Sauer et al., 1983; Konrad, 2003). Urban, or developed, watersheds often experience an increase in runoff due to an increase in impervious surface area. With more impervious surface, infiltration of water to the subsurface is greatly reduced leading to an increase in overland flow. This increase in runoff and reduction in infiltration leads to higher stream discharge.

Urbanization of a watershed not only increases discharge but also reduces the time lag (Fig. 1). Time lag as defined by Leopold (1968, pg 3) is "the time between the center of mass of the storm precipitation and the center of mass of the resulting hydrograph." This reduction in the time lag means that, for a given precipitation event, a stream in a developed watershed will respond more quickly and reach its peak discharge much sooner than an equivalent stream in an undeveloped watershed.

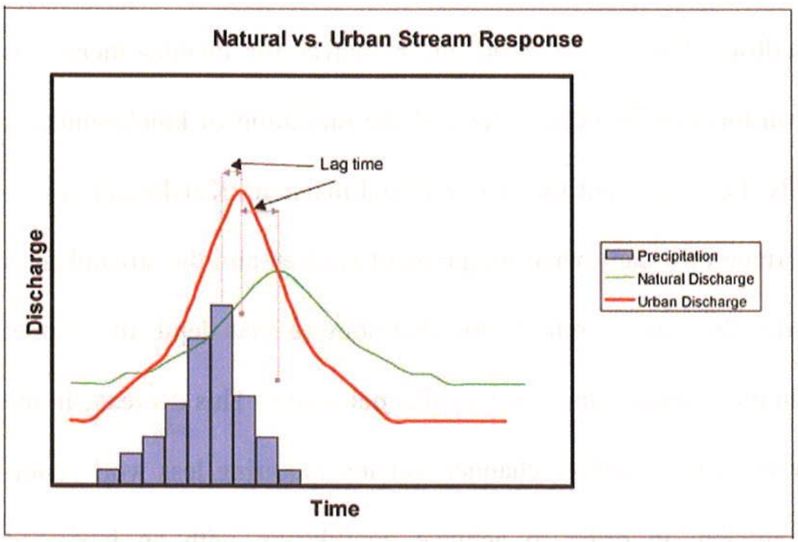

Fig. 1 *Natural verses urban stream response showing a reduction in the time lag with urbanization adopted from Leopold (1968).*

Also, because there is less infiltration, less groundwater is available for baseflow to the stream. With reduced baseflow, urban streams are not able to sustain high flow for extended periods of time. Most of the water being contributed to the stream is through overland flow. The contribution of baseflow after a storm event tends to be short lived. The periodicity of high flows is increased but the flows are sustained for much shorter periods of time compared to an undeveloped watershed (Wolman and Miller, 1960).

With more runoff over smooth, sediment-free surfaces such as paved roads and parking lots, there is typically a decrease in sediment supply to the stream. Water is transported by storm water pipe to the stream, arriving free of sediment. This decrease in sediment supply in conjunction with the increased flow typically leads to channel incision, defined by Booth (1990) as rapid channel deepening disproportional to the increase in water discharge. Booth (1990) showed that with urbanization, there is commonly an increase in channel depth downstream of development. However, this channel incision is normally not caused by uniform downcutting. Instead the migration of knickpoints, or steps, upstream is typically the major contributor to channel incision. Knickpoint migration is more likely to continue upstream when the gradient is steep and the streambed is composed of fine-grained sediment. Booth (1990) also showed that depth of channel incision is much greater in proportion to increases in channel width. This decrease in the channel width to depth ratio is the result of channel incision requiring less work, compared to channel bank erosion, in order to achieve equilibrium with an increased discharge. However, Booth (1990) does not show whether or not, over a longer period of time, a stream would eventually erode its banks and partially fill in its already degraded channel to achieve a more standard width to depth ratio.

Channel incision can cause the stream—floodplain interaction to become hydrologically disconnected, defined by Schilling et al. (2004). The term disconnect may be misleading as it implies that baseflow is cut off. The natural connection between the floodplain is significantly altered however it is not completely disconnected. The riparian water table is lowered changing the interaction between the floodplain and the stream. The purpose of this study is to better understand this alteration and the process by which the water table goes through to achieve a new equilibrium.

Williamsburg, Virginia, (city and county) (Fig. 2) along with the surrounding areas of James City County and York County began to experience a rapid and sustained period of growth beginning in 1930-1950 when a push was made to preserve the historic

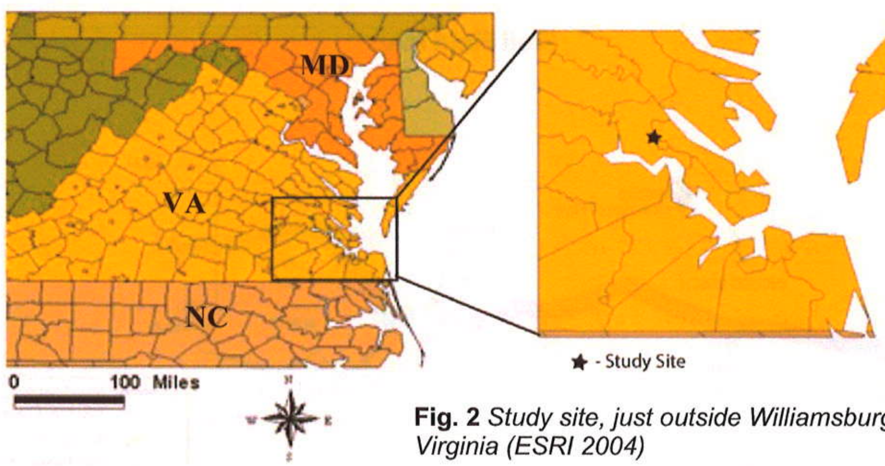

Fig. 2 *Study site, just outside Williamsburg, Virginia (ESRI 2004)*

colonial area of Williamsburg and the Jamestown settlement (Feldaum et al., 2002). This push soon made tourism a vital component of the local economy, jumpstarting sequential growth in both retail and industry for the area. From the period of 1980-2000 the three county area saw an increase in population of 111 percent with projections of growth not slowing through 2010 (Feldaum et al., 2002).

This dramatic increase in development has had an equally dramatic effect on small first-order and second-order streams in the area. Channel incision and water quality degradation are a common observation (Feldaum et al., 2002; Groffman et al., 2003; Hupp, 2000). Because these small streams all drain directly into Chesapeake Bay, a highly degraded yet protected waterway, there has been much concern as to how changes in local watersheds are affecting the bay.

STUDY AREA

The study area for this project consists of a well field containing 33 wells in six parallel transects installed in the riparian zone of Upper Chisel Run, a small, first-order, actively incising stream of the Virginia coastal plain (Figs. 3 & 4). For this study,

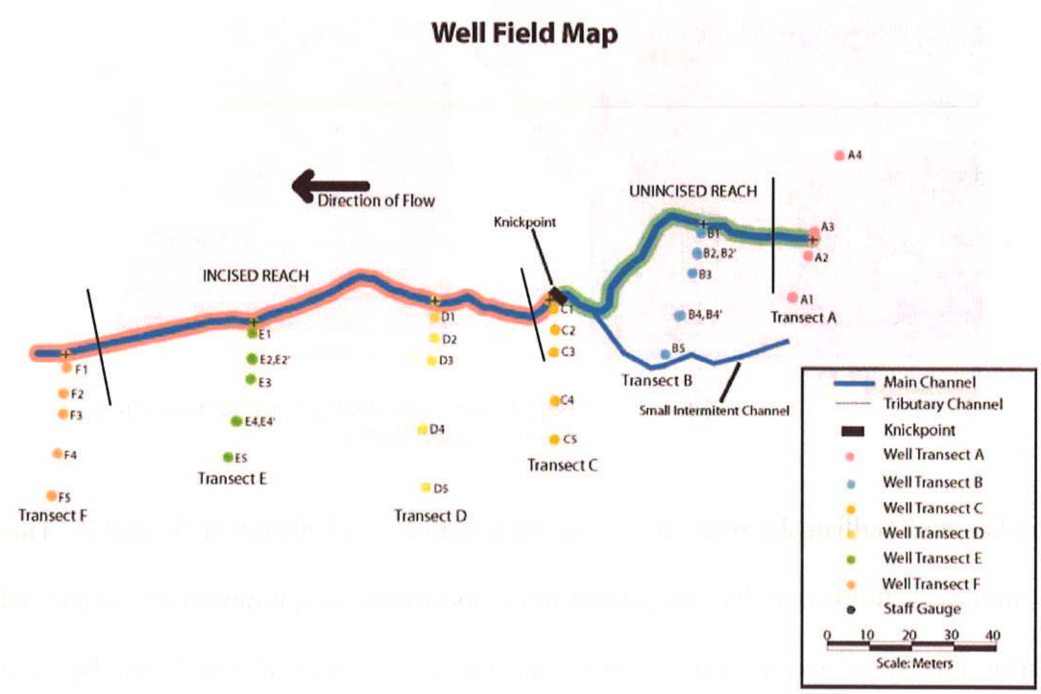

Fig. 3 *Well field map of study site. Two well transects, A and B, are in the unincised portion of the floodplain. Four well transects C, D, E, and F are in the incised portion of the floodplain. Channel incision is occurring through upstream migration of a 1m high knickpoint. Lines crossing stream indicate channel cross sections.*

"riparian zone" and "floodplain" can be used interchangeably as defined by Hupp (2000, p. 2992); "that part of the landscape supported by and including recent fluvial landforms and inundated or saturated by the bankfull discharge." The riparian zone of Upper Chisel Run is a typical bottomland hardwood forest, consisting of a diverse number of plant species sensitive to water conditions. A small difference in topographic elevation, on the order of centimeters, often leads to drastic changes in the hydroperiod, or length of inundation, for bottomland hardwood forests. These changes can dramatically alter the distribution of plant species (Hupp, 2000).

Typical stratigraphy consists of the fossiliferous, semiconfining, silt to clay Pliocene Yorktown Formation at ~2 m depth below the surface with ~1–1.5 m of blue-gray modern floodplain sand, silt and clay deposits with iron staining and intermixed undecomposed organic material above this contact. The upper ~5–10 cm consists of brown to black soil with mixed organics. Most wells were drilled to a depth of ~2 m both because it was a sufficient depth to allow for large fluctuations in the water table level of the semiconfined floodplain and because the Yorktown Formation is extremely difficult to auger through.

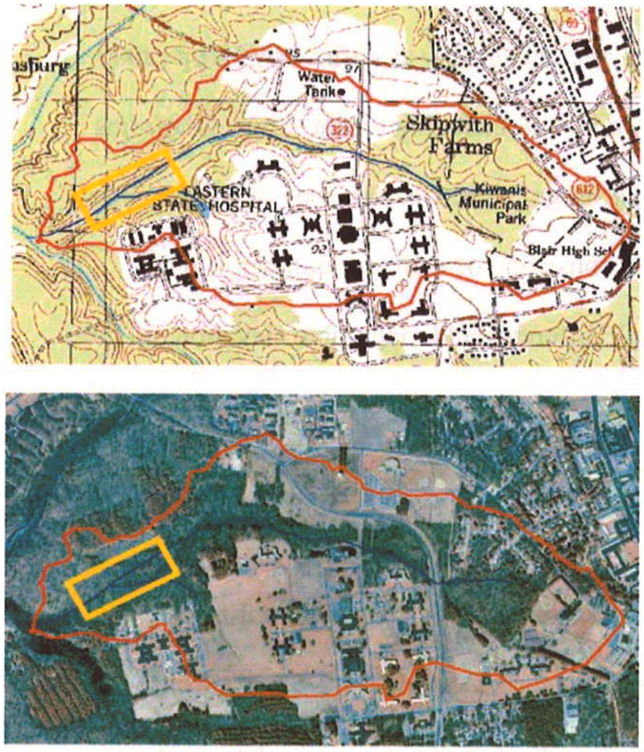

Fig. 4 *Topographic map and aerial photograph of the Upper Chisel Run watershed. Box shows study area.*

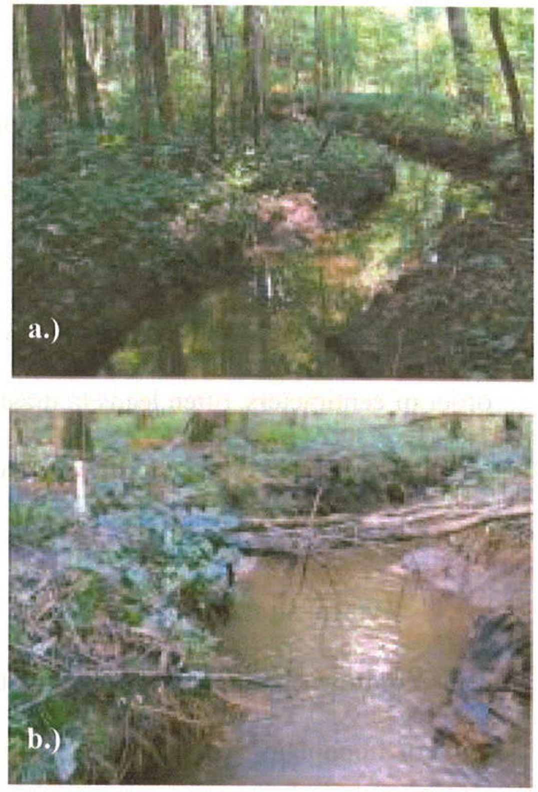

Fig. 5 *a.) Photograph of unincised natural portion of the stream. b.) Photograph of incised portion of the stream*

Upper Chisel Run drains an area of ~1.5 km^2 of which ~1.3 km^2 is upstream of the study site (Fig. 4). The south-central region of the watershed underwent development in 1950-1960 with the relocation of the Eastern State Hospital to its current site. After the construction of Eastern State Hospital, the watershed saw little development for several decades. However, in the last ten years development has occurred in the north-east and north-central parts of the watershed. Overall, approximately 15 percent of the watershed surface area is impervious. Along with the increase in impervious surface, much of the upper part of the watershed's vegetation has been significantly altered. Large, open, manicured grass areas and playing fields have replaced the natural forest. This alteration increases overland flow, but to a lesser extent than the impervious surface. Because of the high susceptibility to overland flow, Upper Chisel Run exhibits a rapid response to nearly all precipitation events.

Stream incision is actively occurring primarily through the upstream migration of a 1 m high knickpoint. During the study, the knickpoint was observed to move primarily during high flow storm events at an estimated rate of 1–2 m a year. For this study, the reach of the stream that is downstream of the knickpoint is referred to the incised portion of the stream while upstream is considered to be unincised and in its natural state (Fig. 5). Numerous methods have been used to try to quantify changes in riparian water table levels, channel morphology, and flooding with respect to urbanization. In most cases it has been shown that the best method to quantify change is to directly compare streams experiencing urbanization with natural streams (Booth, 1990). It is this control, having both unincised and incised reaches of the same stream within a close range and in the same riparian environment that allows for direct comparisons. In other studies (Burt et al., 2002; Groffman et al., 2003; Schilling et al., 2004) no work was done on reaches of a stream in its natural state. In effect, they were only able to look at the results of incision and not the process and rate at which the water table drops.

METHODS

Two of the six well transects (A and B) were installed in the unincised, natural reach of the riparian zone at ~30 m and ~50 m upstream of the knickpoint. The remaining four transects (C, D, E, F) were installed in the incised portion at ~5 m, ~30 m, ~70 m and ~100 m downstream of the knickpoint (Fig. 3). The wells consisted of a 1¼ inch PVC pipe riser with ~0.4 m of well screen at the base. The lowest ~5 cm of the riser was capped and ~30 cm of pipe was set above the ground surface. The top of each riser was sealed with a threaded screw cap for easy removal during measurements (Fig. 6). All wells were hand-augered into the floodplain to depths ranging from 1.4–2.7 m. At four locations (B2', B4', E2', E4') wells were nested and drilled to a deeper ~3.5 m in order to measure vertical hydraulic gradients. Each well was backfilled with coarse sand and sealed at the top with ~0.2 m of bentonite. Wells were developed and water levels were measured by hand with a Solinst Water Level Meter 101 on average three times per week from June 2004 to August 2004. Calibrated GE Druck Pressure transducers and Campbell Scientific CR510 data loggers were installed at 6 wells (B1, B2, B4, E1, E2, E4) (Fig. 3). For these wells, water levels were measured every 1-minute with the mean over a fifteen-minute interval being recorded in the data logger. Also, an un-averaged value at each fifteen-minute interval was recorded. Both of these values were recorded in order to accurately observe rapidly fluctuating head levels, especially near the stream, during storm events.

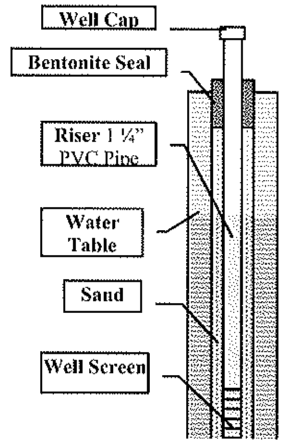

Fig. 6 *Diagram showing well construction and components*

Staff gauges were installed in the stream at each well transect (Fig. 3). Visual readings of the staff gauges were taken in conjunction with manual well readings. Also, readings were taken during large storm events in order to record stream response. All staff gauge readings were then correlated to a previously installed stilling well used to measure stream elevation located at transect D. The stilling well recorded stream elevation every ten minutes throughout the study. Correlations of staff gauge readings with stilling well measurements allowed for the calculation of stream elevation in ten minute intervals at each well transect for a period of two years (July of 2001 to August 2003). This allowed for estimations of the frequency of overbank flows at each well transect without direct observation of each event.

Precipitation was measured using two automated tipping-bucket rain gauges. Both gauges were within ~2 km of the study site with one being in the same watershed. Precipitation events were then correlated to stream response recorded both manually from the staff gauges and with the automated stilling well.

The floodplain topography, along with the location and elevation of staff gauges, wells, and channel was surveyed to a 0.5 cm scale accuracy using a Topcon GTS-211D total station and an arbitrary base point. Channel cross-section geometry was measured for fourteen sections in both the incised and unincised portion of the stream using a leveling scope, meter tape and measuring pole.

An analytical model was developed to better understand changes in hydraulic head of the water table in response to stream incision. Results were then used in an effort to estimate time since incision for various reaches of the stream and to predict future change in the water table levels. The Boussinesq equation, modified for two- dimensional groundwater flow, was used.

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{Sy}{Kb}\frac{\partial h}{\partial t}$$

Boussinesq Equation

$$\left(\frac{\partial^2 h}{\partial x^2}\frac{Kb}{Sy}\right)\partial t = \partial h$$

Boussinesq Equation modified for two-dimensional analysis

Where K is the hydraulic conductivity, b is the aquifer thickness, Sy is the specific yield, t is the time since incision, x is the distance from the stream and h is the hydraulic head or water table elevation. All assumptions and equations were written into the Stream Incision Model (SIM) using the Visual Basic Language. Source code for SIM can be found in Appendix 2.

When running the model all variables are adjustable for calibration. Hydraulic conductivity (K) of the floodplain was measured using slug tests and the methods derived by Bouwer and Rice (1976), Bouwer (1989) and Hvorslev (1951). Hydraulic conductivity was found to range from 0.05–0.18 m/day. A range for the specific yield (*Sy*) was estimated based on the sedimentological characteristics of the floodplain. Values ranged from 0.10–0.18. The aquifer thickness was varied to properly calibrate the model and a time step (∂t) of 10 minutes was used to find the change in head (*h*) at 0.01 m intervals (*x*). The model was run multiple times, varying aquifer properties within the range defined above, over periods ranging from 20 to 50 years. Final values used in estimating time since incision were determined by calibrating to hydraulic gradients know for ~3m downstream of the knickpoint. Final values used were: K=0.07 m/day *Sy*=0.18 *b*=3 m.

RESULTS

Changes in the Water Table

Results of well readings show a distinct increase in the depth below the surface of the water table and a hydraulic gradient steepening (of the water table) in conjunction with stream incision (Fig. 7). Results of all well readings for the study period can be found in Appendix 1. For well transects A and B, in the unincised portion of the floodplain, the water table remained relatively close to the surface at a depth of ~0.3 – 0.4 m throughout the study period. The gradient of the water table in these transects was shown

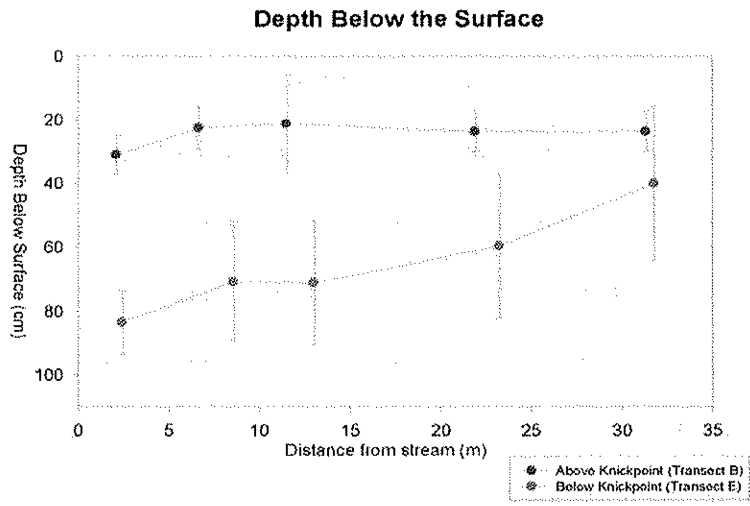

Fig. 7 *Depth below the surface for the water table in the incised and unincised portion of the steam. Data here are of 7-21-04*

to be flat with little variation in slope throughout the floodplain (Appendix 1, Fig. 7). The hydraulic gradient for these two transects ranged from 0.001 to 0.004 throughout the study period with a mean gradient of 0.002. The hydraulic gradient of these transects is interpreted to be in an equilibrated, natural state, typical of the water table for the riparian zone of small costal streams.

For well transects in the incised portion of the floodplain (C, D, E, F) the water table was found to consistently remain much further below the surface and to have a much steeper gradient compared to the unincised well transects (A, B). For the first two transects downstream of the knickpoint (C and D) the water table is lowered near the stream ranging in depth from ~1.0–0.7 m but further from the stream it remains close to the surface at a depth ~0.4–0.5 m, representative of its natural state (Appendix 1, Fig. 7).

Away from the stream (>20 m) the hydraulic gradient in these two transects (C and D) is relatively flat but increases significantly near the stream. Hydraulic gradients ranged from 0.012–0.016 with a mean of 0.015 far from the stream (~20–50 m) for transect C and 0.008–0.017 with a mean of 0.014 for transect D. Near the stream (~0-20

m) the hydraulic gradients were much steeper ranging from 0.106–0.137 with a mean of 0.121 for transect C and 0.016–0.090 with a mean of 0.047 for transect D (Appendix 1).

Further downstream in well transects E and F, where the stream has been incised for a longer period of time, the water table is consistently much further below the surface throughout the transect. Unlike transects C and D these two transects show a consistent hydraulic gradient sloping toward the stream rather than a sharp drop off near the stream. For transect E far from the steam the gradients ranged from 0.007–0.015 with a mean of 0.012. Near the stream they ranged from 0.016–0.052 with a mean of 0.029. For transect F, far from the stream, the gradients ranged from 0.005–0.009 with a mean of 0.006. Near the stream the gradients ranged from 0.016-0.069 with a mean of 0.043 (Appendix 1).

Following stream incision, the water table is working toward a new equilibrium state with a low gradient. However, this re-equilibration does not happen rapidly after incision. A progression of the hydraulic gradient working to achieve a new equilibrium can be seen moving downstream from transect C to transect F. A dramatic steepening of the water table gradient in the floodplain near the stream is seen in the early stages (transects C and D). Further downstream the gradient is reduced but is consistent throughout the transect.

Channel Geometry

Maximum channel depth for the unincised reach of the stream ranged from 1.64–1.90 m. Channel depth after incision was increased to a maximum depth of 2.92 m directly below the knickpoint. Channel depth gradually decreases moving downstream of

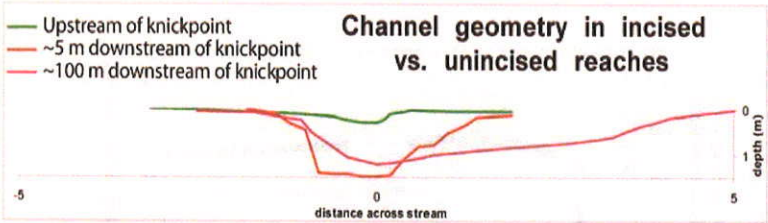

Fig. 8 *Changes in channel geometry with channel incision. Profiles are shown including floodplain near the stream. Location of cress sections can be found in Fig. 3.*

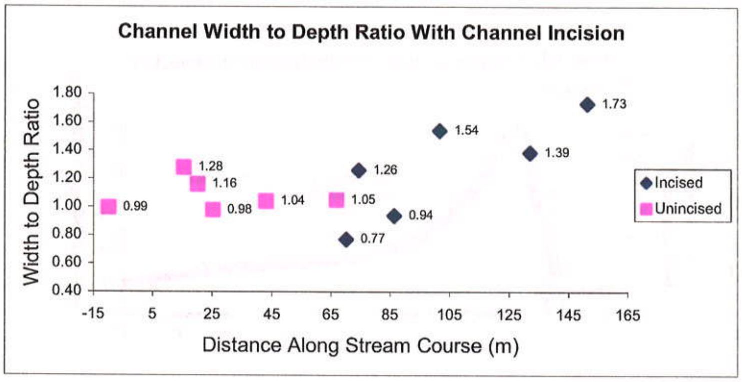

Fig. 9 *Width to depth ratio for both the unincised and incised portion of the stream*

the knickpoint with a minimum measured depth of 2.52 m at well transect F (Fig. 8). Depth was observed to decrease further downstream of well transect F but was not measured.

Initially after incision, channel width is not significantly increased and the stream banks are nearly vertical. The lack of channel width enlargement initially after channel incision is in agreement with Booth's (1990) conclusion that the depth of channel incision is much greater in proportion to changes in channel width as a result of incision. Further downstream channel width increased as the stream bank slope was reduced.

Channel width to depth ratio was initially reduced from ~1.0 to a new value of ~0.7 after incision as channel depth increased and channel width remained the same (Fig. 9). Further downstream the width to depth ratio increased to a value of 1.7 at well transect F (~80m downstream of the knickpoint) as the channel banks eroded.

Storm Response

Overbank flow, or flooding, is dramatically affected by channel incision. The unincised portion of the stream overflowed its banks during medium precipitation events (0.5–0.9 in) 64 percent of the time far upstream of the knickpoint at transect A, and 14 percent at transect B over a period of two years as calculated from stilling well data and staff gauge colorations. In the incised portion of the stream overbank flow only occurred for seven percent of the medium storms. For large storm events (>0.99 in) the unincised portion of the stream went overbank 85 and 62 percent at well transects A and B respectively. For the incised reach overbank flow only occurred for 23 percent of the large storms.

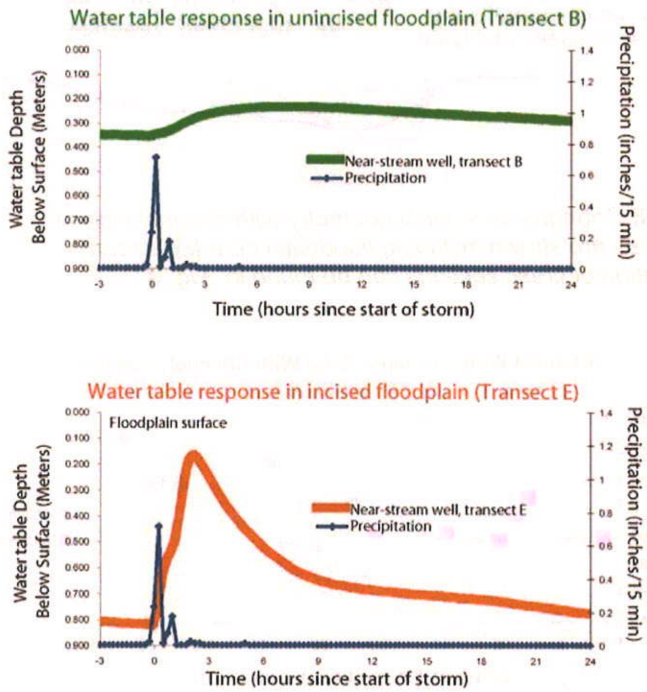

Fig. 10 *Water table response to for the incised and unincised portions of the floodplain to a large storm*

Often during storm events the unincised portion of the floodplain would become fully saturated leading to puddling and ponding of water at the surface. The incised portion the floodplain was never observed to be fully saturated during the study period (June-August 2004). The water table remained below the surface even during the largest storms. This lack of full saturation in the incised portion of the floodplain may simply be because there is more room available for the water table to rise since it is initially at a lowered state. In the unincised portion of the floodplain, with the water table so near the surface, there is not as much room for the water table to rise and it can breach the surface and pond with only small fluctuations. The lack of full saturation and inundation in the incised portion has led to significant effects in the riparian vegetation to be discussed later in this paper.

In both the incised portion and unincised portion of the floodplain, a rapid response in the water table is observed for all precipitation events. However, the recovery of the water table back to normal, non-storm levels, is much more rapid for the incised part of the floodplain. Response is more rapid nearest the stream as the water in the stream rises to a level sufficient to allow for a reverse-gradient wedge, where the stream is discharging to the water table (Fig. 11). For the incised portion of the stream, the water table is further below the surface and the stream does not go overbank as often, a severe reverse gradient wedge is formed. As stream level drops the gradient is reversed back to normal. However, because the reverse gradient during the storm was so high,

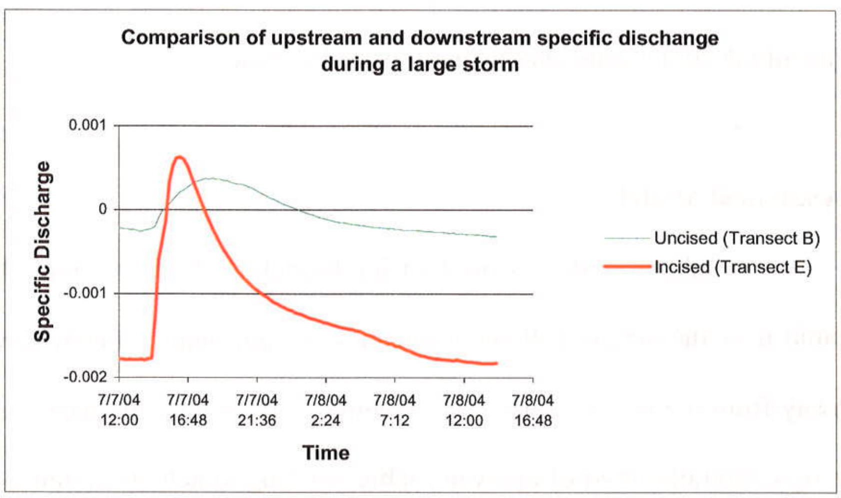

Fig. 11 *Specific discharge comparisons of the incised (transect E) versus the unincised (transect B) parts of the stream. A positive specific discharge indicates flow from the stream to the water table. A negative specific discharge indicates flow from the floodplain to the stream. Slope indicates the amount of discharge. Greater slope indicates a greater discharge.*

baseflow is significantly increased in the incised portion of the stream for a short period after the storm event. This is the result of a very large hydraulic gradient being formed as the stream rapidly returns to a normal level while the water table is not able to respond as quickly. These results are consistent to those seen by Burt et al. (2002) for incised portions of the River Severn in England. For the unincised, natural, reach of the stream the reverse gradient is not as severe and baseflow is slower.

During storm events for the incised reach, a large amount of water is stored in the stream banks. As stream elevation is lowered, the stored water is rapidly discharged back into the stream. For the unicised reach of the stream during medium to large storm events, overbank flow occurs and water is able to infiltrate throughout the floodplain. Because all the stored water is spread throughout the floodplain, and not just near the stream as in the incised portion, baseflow returning to the stream is much smaller in magnitude and occurs over a longer period of time.

Analytical Model

Results from the Stream Incision Model (SIM) show a rapid lowering of the water table near the stream following channel incision with a much slower response further away from the stream. These results agree with water table measurements taken and the progression observed of the water table working to achieve a new equilibrated hydraulic gradient. The time of initial incision for each transect was estimated by comparing hydraulic gradients predicted by SIM with those measured for each well transect (Fig. 12). At transect C the stream was estimated to have been incised 0–1 years and at transect D 6–8 years. The stream at transects E and F was estimated to have been incised between 15 and 30 years (~20–35 years after initial development). Because the rate of change for the hydraulic gradient slows significantly after 8–10 years the accuracy of predicting the time since incision significantly decreases after that time. The difference between the predicted hydraulic gradient after 15 years and that predicted after 25 years is less than the error expected in the measured hydraulic gradient.

In the calibration of SIM, it was found that aquifer thickness (*b*) is the most sensitive variable in modeling the rate of gradient reduction. Greater aquifer thickness significantly increased the rater in which the water table was lowered. Variations of hydraulic conductivity and specific yield, within values measured, had little effect on predicting the rate of water table lowering.

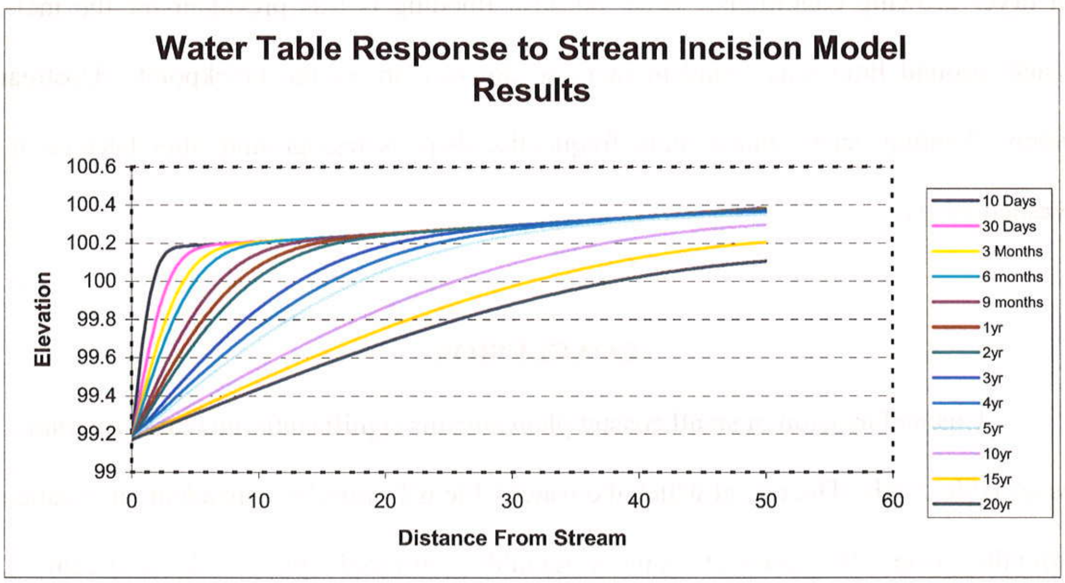

Fig. 12 *Stream Incision Model (SIM) results. K=0.07 m/say Sy=0.18 b=3 m.*

Changes in Vegetation

Changes in flooding frequency and lowering of the water table following channel incision have been found to alter the riparian vegetation. Work done by Wacksman (2004) at the same site has shown that downstream of the knickpoint, were the water table has been lowered, wetland indicator species were much less prevalent than up-stream of the knickpoint. Golden Ragwort (*Senecio*) showed a dramatic decrease in abundance downstream of knickpoint in the incised portion of the floodplain. Nepal Grass (*Microstegium*), an invasive species, and Indian Strawberry (*Duchesnia*), both upland indicator species, were found to increase in abundance downstream of the knick-point. These two species have thrived where the water table has been lowered resulting in dryer growing conditions. Also, because flooding is less prevalent for the incised reach, ground litter was found to increase downstream of the knickpoint. Upstream, where flooding occurs much more frequently, there is less ground litter because it is washed away.

CONCLUSIONS

Channel incision of small coastal plain streams significantly increases riparian water table depth. The rate at which the water table is lowered is dependent on distance from the stream. Near the stream, the water table is lowered rapidly with significant changes seen as early as ten days since incision. This is a result of the steep hydraulic gradient produced immediately after channel incision. Further from the stream, water table lowering is not as immediate, nor as severe.

Stream response to storms is also significantly altered following stream incision. As a result of incision, the channel has a much larger cross sectional area and an increased width to depth ratio. Because the channel has more volume it is able to hold more water and therefore overbank flow occurs much less frequently. Channel incision decreasing the frequency of overbank flow has been well documented in other studies (Booth, 1990; Schilling et al. 2004; Sauer et al., 1983). However, the change in baseflow following storms for an incised channel was not previously well documented for small streams. Following channel incision, and subsequent water table lowering, more water is able to be stored in the stream banks during high flow events. As the stream elevation recovers to normal following the precipitation event this stored water is able to discharge quickly back into the stream. For an unincised stream, water is stored throughout the floodplain as the stream is able to overtop its banks. This stored water returns to the stream as baseflow at a much slower rate than seen for the incised channel. In effect channel incision magnifies the quickened flow response often seen for urban streams.

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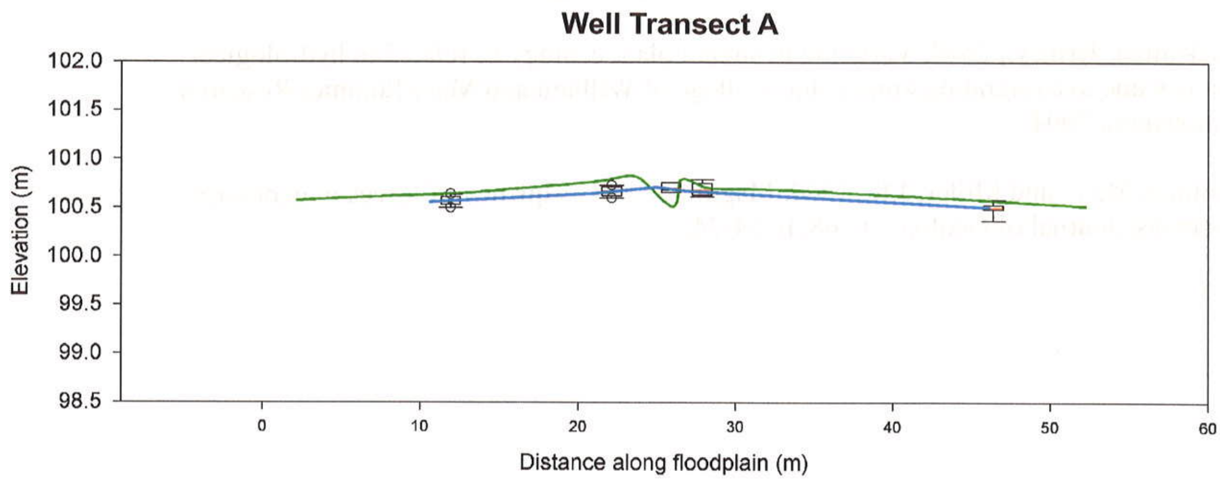
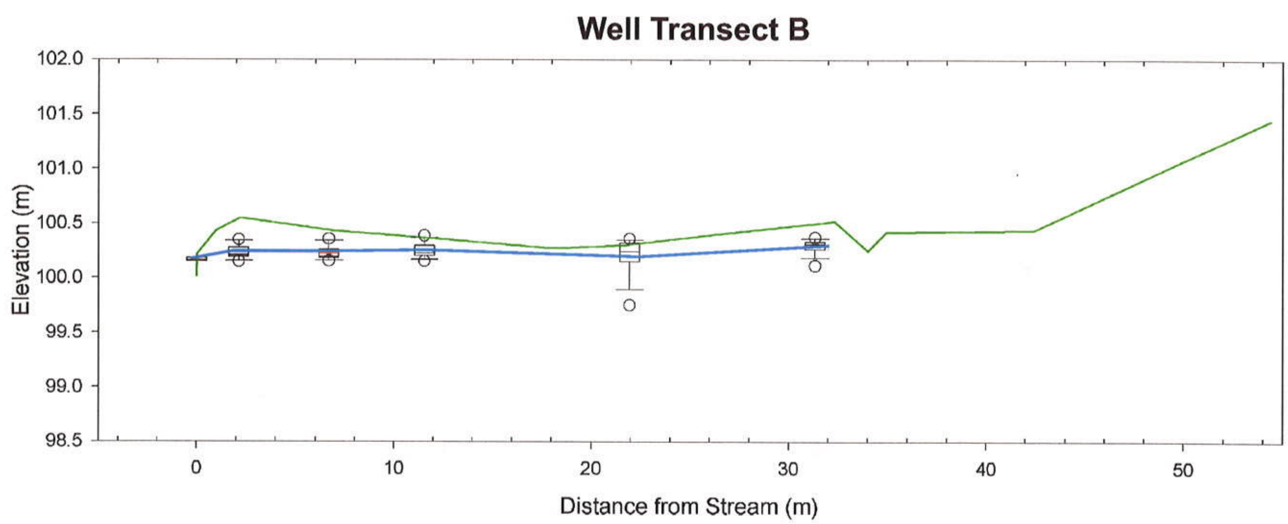
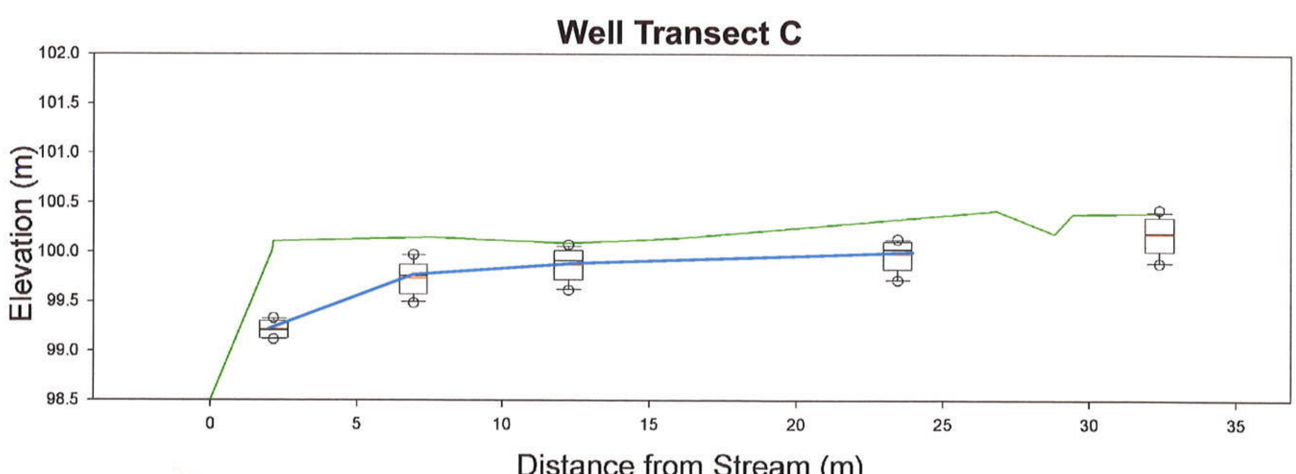
APPENDIX 1

Water Table Readings June 2004 to August 2004. Green line is floodplain surface. Blue line is mean water table elevation.







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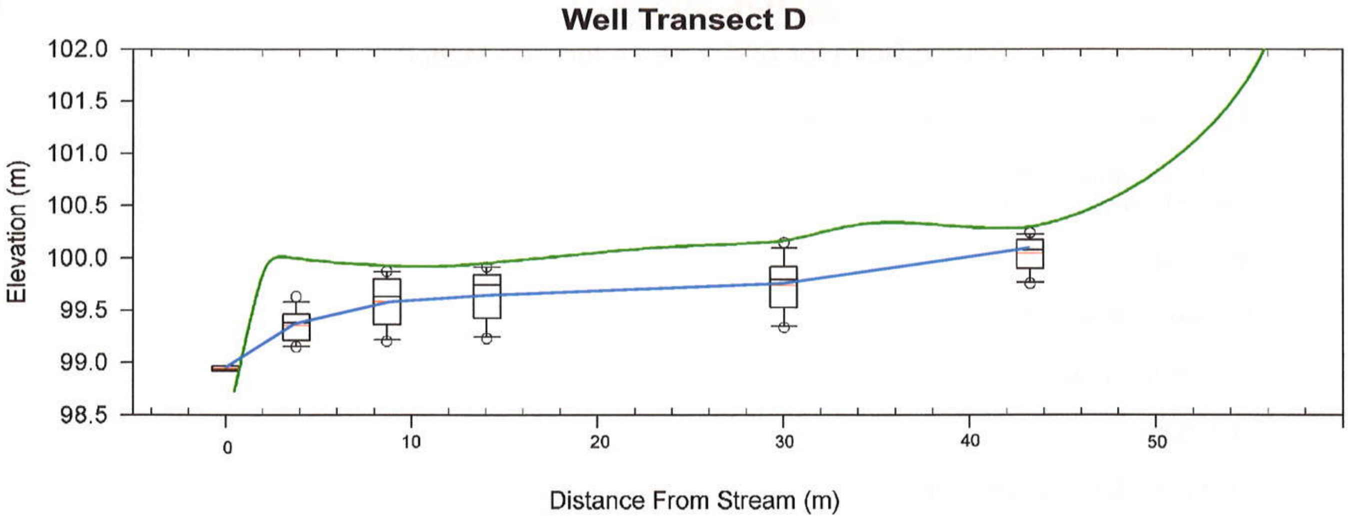

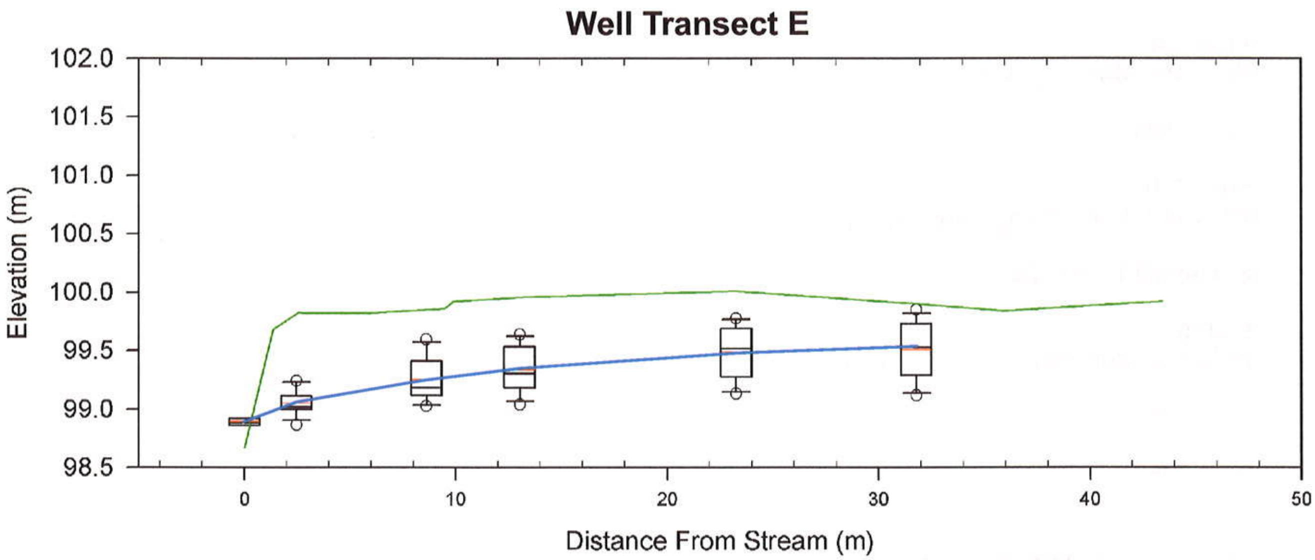

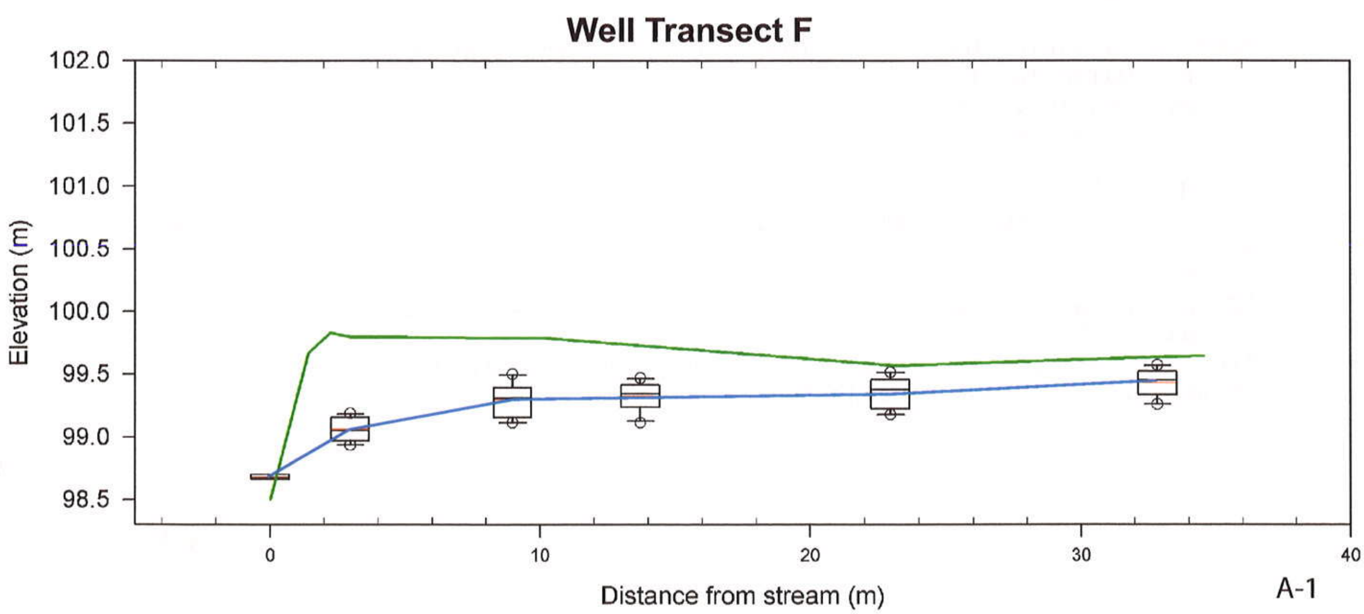

APPENDIX 2

Source Code for SIM (Stream Incision Model)

```
Sub SelectAllText(tb As TextBox)

tb.SelStart = 0
tb.SelLength = Len(tb.Text)

End Sub

Private Sub K_GotFocus()

SelectAllText K

End Sub

Private Sub Sy_GotFocus()

SelectAllText Sy

End Sub
Private Sub b_GotFocus()

SelectAllText b

End Sub
Private Sub Days_GotFocus()

SelectAllText Days

End Sub
Private Sub depth_GotFocus()

SelectAllText depth

End Sub


Private Sub Run_Click()
Form1.MousePointer = 11

'Define variables based on values entered in the text boxes
    b = Val(b.Text)
    Sy = Val(Sy.Text)
    K = Val(K.Text)
    Days = Val(Days.Text)
    d = Val(depth.Text)
'Allow for a time step of 10 min.  144 is number of 10 min periods in a
day
    Tsteps = Days * 144
'Find that head value every 0.1m, so dx is defined as 0.1
    dx = 0.1
'Part of equation not involving the derivitive defined as C
'number value should be adjusted to the time step
```

```
'Here it is 0.0069444 because 10 min divided by number of min in 10
days is 0.0069444
    C = ((K * b) / Sy) * 0.0069444444
'Set so that for every ten days the vaules will be saved to text file
'Set here at 1440 beacuse there are 1440 ten min periods in 10 days and
time step was set at ten min
    Noutput = 1440
    filenum = 1
'Set number of steps for distance
'since dx is 0.1m to run to 50m from stream Nsteps is set to 500
    Const Nsteps = 500
'Find intial conditions
'Based on curve fit from acutal data
    Dim H(Nsteps)
        For i = 0 To Nsteps
            x = i * dx
            H(i) = (0.00001 * (x ^ 2)) + (0.0038 * x) + 100.17
        Next i
'Incise the stream 1 meter at distance of 0
    H(0) = H(0) - d
'Find the second derivitive at each time step and plug in new values
'Saves text file to location defined for every ten days or as defined
earlier
'If change how often it is saved reconfigure the (filenum * 10)
'Displays finished when done with run
    Dim Time
    For Time = 1 To Tsteps
             Dim Hnew(Nsteps)
             For i = 1 To (Nsteps - 1)
                D2 = (H(i - 1) - 2 * H(i) + H(i + 1)) / dx
                dh = D2 * C
                Hnew(i) = H(i) + dh
             Next i

             Dim H2(Nsteps)
             For i = 1 To Nsteps - 1
                H(i) = Hnew(i)
             Next i


             If Time / Noutput = filenum Then
                f$ = "C:\sim\Day_" + Str$(filenum * 10) + ".txt"
                Open f$ For Output As #1
                For i = 0 To Nsteps
                    x = i * dx
                    Print #1, x; ","; H(i)

                Next
                Close #1
                filenum = filenum + 1
   'Set far end so that it is not held constant but instead is lowered
along with the others
                H(Nsteps) = H(Nsteps - 1)

            End If
    Next Time
```

```
f$ = "C:\sim\info.txt"
Open f$ For Output As #2
Print #2, b, Sy, K, Days, d
Close #2

Done.Text = Finished.Text
Form1.MousePointer = 0

End Sub
```