ISLAND FORMATION THROUGH BAR GROWTH AND FLOODPLAIN INCISION IN THE BEDROCK CONTROLLED SOUTH RIVER, VIRGINIA

by

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ABSTRACT

Islands in braided and meandering alluvial channels form by bar accretion and floodplain incision, however, island formation in bedrock-controlled channels is poorly understood. The South River is a single-thread, sinuous, gravel-bed, bedrock river. It is neither meandering nor braided but aerial photographs show the development of gravel bars and the formation of islands that have formed through floodplain incision. This study deciphers processes that lead to both types of island formation and their role in the channel morphology of the South River. The South River was analyzed using aerial photographs and work in the field provided additional data that were used to identify islands and their properties. A Geographic Information System (GIS) was used to evaluate historical aerial photographs dating back to 1937 for location, morphology, origin, and development of islands along a 39 km study reach. Field studies included the surveying of cross sections to determine elevations of islands relative to neighboring floodplains, as well as pebble counts and cores to define sediment characteristics. Aerial photographs indicate that nine islands had formed before and an additional 11 islands formed after 1937, placing the average island formation frequency at 0.008 islands per km per year since 1937. Field data indicate that elevation, grain size, stratigraphy, and vegetation of 17 islands closely resemble those of the floodplains, supporting the hypothesis that those islands formed.
through floodplain incision. The sediment of three islands was similar to that of the channel and did not show similarities to floodplains or any other islands indicating formation through gravel bar deposition. Studies of bank erosion rates along the South River demonstrate that 33% of bank erosion along the South River occurs in divided reaches of the channel associated with islands. Understanding the formation and evolution of these islands may allow for an accurate prediction of future island development and possible sediment sources.
Chapter 1

INTRODUCTION

1.1 River Forms and Features

Fluvial geomorphologists have defined stream planform morphology by describing channel width, sinuosity, meander form, bars, and islands. The behavior of rivers under various conditions has also been described. We can use this knowledge to facilitate safer land use by identifying and avoiding flood prone areas or building suitable structures such as bridges designed to withstand short and long term changes in river morphology.

Although sometimes difficult to distinguish clearly, rivers are generally categorized as straight, sinuous, meandering, braided, or anastomosed. The first three categories describe single thread channels that differ from one another in sinuosity and through the geometries of bends (Leopold and Wolman, 1957). Braided and anastomosed rivers are associated with channel bars and islands that divide the flow into two or more channels. Brice et al. (1978) noted that factors such as fluctuations in flow and sediment discharge influence the development of different channel patterns.

Although islands are features found in both braided and anastomosed channel systems, Knighton and Nanson (1993) and Nanson and Knighton (1996) note that the flow in braided rivers is divided mostly by in-channel bars. Anastomosed rivers,
however, have multiple channels that are divided by islands that can persist for decades or centuries and have well established vegetation and stable banks. Island surfaces in anastomosed rivers are at the same elevation (approximately) as the floodplain.

1.2 Island-Forming Processes

Islands form through two processes: growth of channel bars or dissection of a floodplain (Figure 1.1). Bars in a gravel-bed stream develop where gravel and cobble sized material is deposited from the sediment load because of a decline in sediment transport capacity. These are areas of flow divergence (Leliavski, 1955; Keller and Melhorn, 1978) such as apices of channel bends, places where a channel widens, and channel junctions (Church and Jones, 1982). A bar can develop into an island by lateral and vertical accretion while being progressively vegetated. Islands that form by floodplain dissection are the result of channel avulsion (Nanson and Knighton, 1996), where a new channel scours into the floodplain before rejoining the main channel further downstream. These islands are usually large relative to channel size (Knighton and Nanson, 1993) and, because they have once been part of the floodplain, are composed of sediment often much smaller than that of matured channel bars due to slower flow velocities over floodplains during high discharge events.
Figure 1.1 Illustration of two island-forming processes. A: growth of channel bar (modified from Leopold and Wolman, 1957). B: floodplain incision.

Islands that grow from in-channel bars are found either within the channel or at prograding distributary channels within splays or deltas (Nanson and Knighton, 1996). Subaqueous bars in prograding deltas or in wide channels can grow into subaerial bars, which then can develop into semi-permanent islands. Desloges and Church (1987) also noted that medial bars and islands form within the channel upstream of
confluences with major tributary channels in the Bella Coola River in British Columbia. The sediment consisted of cobbles and gravels with sand as thin sheets deposited behind logs or around stable vegetation. Church and Jones (1982) observed that bar formation occurred at channel junctions, at places where the channel widened, and at the apices of channel bends where flow resistance increases and velocity decreases along the convex bank.

Islands that form through channel avulsion are relatively permanent vegetated features (Schumm, 1985), and because they are not mature in-channel bars, their size is not limited to channel width. This can occur in anastomosing (or anabranching) streams, where flow is distinctly divided into individual channels (anabranches) that are separated by large islands. Anastomosing channels are often associated with low flow strength and erosion resistant banks (Knighton and Nanson, 1993). Although the flow is similarly divided into two or more channels, braided streams are more appropriately associated with relatively unstable and sparsely vegetated channel bars rather than islands. Anastomosing rivers form when the channel seeks a new path across the floodplain through avulsion. Makaske (2001) defines avulsion as “the divergence of flow from an existing channel onto the floodplain, eventually resulting in a new channel belt.” Nanson and Knighton (1996) make a clear distinction between channel migration and avulsion in that avulsion is a relatively sudden and major shift of the channel to a new part of the floodplain or an old abandoned channel rather than a gradual lateral migration. According to Slingerland and Smith (2004), avulsion may be full or partial, depending on the size and duration of the avulsion and size and
configuration of the invaded flood basin. Slingerland and Smith (2004) further describe three processes that can cause avulsion: (a) avulsion by annexation, where an existing channel is reoccupied (if abandoned) or appropriated (if active), (b) avulsion by incision, where a new channel is scoured into the floodplain, and (c) avulsion by progradation, where a prograding sediment wedge redirects flow onto a floodplain where a network of distributaries routes flow further away from the parent channel.

Field and laboratory data show that channels may avulse for a variety of reasons. Mohrig et al. (2000) and Jerolmack and Mohrig (2007) found that avulsion occurred when the river channel aggraded to a height above the surrounding floodplain equal to approximately one channel depth. Other studies show that channel aggradation is not always a requirement for a sudden shift. Slingerland and Smith (2004), for example, list frequently occurring floods of high magnitude (Knighton and Nanson, 1993) and over wide, unobstructed floodplains as additional causes. If the floodplain is able to drain down-valley, the surface-water slope from the parent channel to the flood basin may remain high enough during flooding so that flow on the floodplain and preexisting floodplain channels can continue during high discharge events.

Miller (1990) describes an example where flooding causes a stream to avulse onto the floodplain, creating a new channel. The flood of November 1985 in the Central Appalachian region of the Eastern United States proved optimal for floodplain erosion in the South Branch Potomac River and Cheat River basins. After the flood, features such as scour marks, floodplain stripping, floodplain chutes, and channel
widening but also dissection of floodplains by networks of anastomosing channels were recorded on aerial photographs.

Another type of channel shift is similar to avulsion in that the flow finds a new path on the floodplain but involves the creation of a more direct path down valley and occurs only at meanders (Constantine et al., 2010) (Figure 1.2). Naturally occurring dams such as woody debris (Keller and Swanson, 1979) and ice jams (Gay et al., 1998) have been observed to force flow onto the floodplain where, upon returning to the original channel further downstream, an upstream propagating headcut can form a chute channel. Constantine et al. (2010) further list localized bank erosion or embayment at the upstream end of a meander as third cause for cutoffs. These embayments extend across the floodplain during repeated flooding until the river bank of the main channel has been reached and a chute channel is formed. However, cutoffs need to be distinguished from avulsions because no study mentions the formation of islands through cutoffs. After a cutoff, the parent channel is either completely abandoned or the cutoff channel fails to sustain itself.
Vegetation plays a role in the stability of the floodplain because it reduces erosion rates and acts as an obstacle for water flow. Instead of freely flowing across the floodplain, the water must find ways around obstructions. Many studies lack the description of the vegetation along areas of island formation through floodplain incision and images are not clear enough for recognizing certain plant types. For example, aerial photographs by Miller (1990) show no large trees in the vicinity of newly formed channels and the typical flood plain vegetation is not described. The banks of the South River are often vegetated with mature trees and secondary channels flow through highly vegetated areas. Constantine et al. (2010) list the structure of floodplain vegetation as a control for chute cutoffs. Their model predicts that type and
density of vegetation play a role in formation of secondary channels across the
floodplain, and model results show that floodplains vegetated solely with mature trees
are more susceptible to incision than those with small woody plants or brush.
However, floodplains along the South River have both types of vegetation that could
play a role in the formation of secondary channels.

Rivers described in the above studies are easily classified as meandering,
braided, or anastomosing. River features like bars and islands and their formation
appear to be associated with respective river types. For example, channel bars are
associated with braided rivers, anastomosing rivers with islands, and meandering
rivers with cutoffs. If these principles were truly general, simply identifying a river’s
type could provide clues on how islands formed on that river. However, many rivers
do not clearly fit into a category but rather exhibit features from more than one
classification and channel features typical of one type of river can occur in a totally
different type of river. For example, a river can have a fairly straight course with
occasional anabranches and, therefore, have characteristics of both sinuous, non-
meandering rivers and anastomosing rivers. These anabranches could have formed by
a process other than channel bed aggradation. A sinuous river that cannot be classified
as meandering may have formed a fairly straight second channel that could be
characterized as a cutoff across the floodplain. This cutoff, however, does not cause
the parent channel to be abandoned and instead, both channels continue to carry
sufficient flow. Islands along a single river can form through different potential
mechanisms that would normally be associated with specific types of rivers. To
understand how islands form, we must understand channel bar formation and avulsion. Only when we are familiar with the various mechanisms involved in avulsion and bar formation, can we understand how an individual island might have formed.

1.3 The South River

The South River cannot be classified as meandering because its bends do not resemble the typical “loops” of a freely meandering river (Narinesingh, 2010). The South River is also neither braided nor anastomosed, and yet it has frequent isolated and short anabranches throughout its course. This differs from the observed morphology of rivers that have anabranches with lengths of several kilometers. The South River is an interesting place to study because not only does it not fit the profile of an avulsive river, but it also shows islands that have formed through bar development.

This study will focus on island-forming processes through bar growth as well as floodplain incision because a preliminary look at historical aerial photographs shows the formation and growth of gravel bars along the channel and several islands that formed through secondary channel formation on the floodplain. Figure 1.3 shows an island that grew from a gravel bar (left picture) and a river reach with noticeable gravel deposition (right picture). The two images in Figure 1.4 show islands at bends where the vegetation of the islands and floodplain looks similar in density and type (tree cover). Because the South River shows behaviors of anastomosing rivers (anabranches), meandering rivers (floodplain incision at bends), and braided rivers
(bar formation), we need to consider processes of all three river types. In addition, each channel forming mechanism should be investigated while keeping attributes of other processes in mind. For example, a secondary channel at a bend might look like an anabranch commonly found in anastomosing rivers but it could have been formed through mechanisms associated with cutoffs along meandering rivers. Therefore, island formation through floodplain incision along the South River may not be a process that can be compared to that of one specific study of an anabranching river but may include components from other analyses such as cutoff channel formation.

Figure 1.3 2005 aerial photographs showing a large gravel island (A) and a gravel rich section (B).
1.4 Significance of Island Formation in Contaminant Transport

When islands form through floodplain incision, large quantities of sediment are eroded. Rhoades et al (2009) found that 33% of the total area of bank erosion in the South River is related to island formation. Although bank erosion was also associated with migrating bends, straight reaches, former mill dam locations, and tributary confluences, island areas had the highest percentage of the total bank sediment added to the river.

South River sediments are contaminated with mercury due to the unrestricted mercury disposal into the river by the DuPont Company, which used the chemical in the production of Rayon between 1929 and 1950 at Waynesboro, Virginia. The contamination problem was discovered in 1977 and during the last 20 years, a clear
decrease in the level of mercury in fish could not be found (http://www.deq.virginia.gov/fishtissue/mercury.html).

Bank erosion in areas with islands can take place in two ways: (1) When flow creates a secondary channel into the floodplain, large amounts of sediment are added to the river or (2) when a bar grows into a stable island, flow on either side can increase erosion along the banks until the channel has reached a certain width. Understanding the formation and evolution of existing islands may allow for an accurate prediction of future island development and possible sediment sources that may contribute to the continuing mercury contamination of the South River.

1.5 Study Goals

This study has the following objectives:

- Identify islands along the 40 km study reach that have not been influenced by anthropogenic processes.
- Categorize island by type (matured bar vs. detached floodplain).
- Estimate when the islands formed.
- Explain processes that led to island formation.
Chapter 2

STUDY AREA

Figure 2.1  Location of the study area.
2.1 Location and Geologic Setting

The study area along the South River is located in the Shenandoah Valley in Virginia between Waynesboro and Port Republic (Figure 2.1). The river runs northeast along the western flanks of the Blue Ridge from north of Waynesboro to Port Republic in Augusta County, where it joins the North River to form the South Fork of the Shenandoah River.

The Shenandoah Valley is part of Virginia’s Valley and Ridge province that consists of “elongate parallel ridges and valleys that are underlain by folded Paleozoic sedimentary rock.” ([http://web.wm.edu/geology/virginia/provinces/valleyridge/valley_ridge.html](http://web.wm.edu/geology/virginia/provinces/valleyridge/valley_ridge.html)). Most of the river valley north of Waynesboro is underlain by Cambrian carbonate rocks ([http://web.wm.edu/geology/virginia/rivers/potomac-shenandoah.html](http://web.wm.edu/geology/virginia/rivers/potomac-shenandoah.html)). The surficial geology of the South River Valley consists of alluvium, fluvial terrace, and alluvial fan deposits.

2.2 Geomorphic Characteristics

The South River is a relatively stable, single-thread, sinuous, gravel-bed, bedrock river (Skalak and Pizzuto, 2010) and despite having an average sinuosity of just below 1.3 and a maximum sinuosity of above 2.0 in relatively short reaches, it cannot be classified as meandering because its planform does not resemble that of a freely meandering river (Narinesingh, 2010). The average slope is 0.0013 in the upstream section between Waynesboro at relative river mile (RRM) 0 (located at the
footbridge across the South River to the former DuPont plant in Waynesboro) and RRM 13. The average slope increases to 0.0024 in the downstream section between RRM 13 and Port Republic at RRM 24 (Figure 2.2). The bankfull width lies within a range of 20-30 m and bankfull depths range from 2-3 m (Pizzuto et al., unpublished). Bank migration rates range from 0.01 m yr\(^{-1}\) to 0.36 m yr\(^{-1}\) and average 0.04 m yr\(^{-1}\) between 1937 and 2005 (Rhoades et al., 2009).

**Figure 2.2** Longitudinal profile of the South River created from 0.6 m contours generated from a lidar data set acquired in April, 2005 (modified from Pizzuto et al., unpublished).
Several bank and channel stabilizing factors prevent the South River from freely migrating like typical meandering rivers. Large riparian trees along the banks, cohesive bank sediments, and frequent bedrock exposures make bank erosion difficult. Bedrock exposures in the channel and on the banks comprise up to 50% of the study reach (Figure 2.3) and range in height from less than 30 cm to more than 10 m. (Narinesingh, 2010). The bed material consists mostly of grains ranging in size between pebbles and boulders although sand, silt, and clay are locally found as well (Pizzuto et al., unpublished).

Historical aerial photographs show that in the last century the river had been obstructed by 14 dams. All of these dams had been breached by the end of the 1970s. Physical evidence of former dam existence are not observable on photographs with the exception of the former Dooms Dam located at RRM 4.9. This dam had been breached in early 1970s, and 2002 and 2005 aerial photographs indicate that the remaining structure, which is blocking a large part of the channel, continues to degrade (Stotts et al., in revision). Along some parts of the river, remnants of mill races are still visible.
Figure 2.3  Locations of bedrock outcrops (thick black lines). The thin gray line represents the center line of the river. Direction of flow is to the north in all three segments (Narinesingh, 2010).
2.3 Hydrology

The U. S. Geological Survey (USGS) monitors the South River at three gaging stations near Waynesboro, near Dooms, and at Harriston that record daily discharge and gage height. The drainage areas of the South River are 329 km$^2$ at Waynesboro, 383 km$^2$ at Dooms, and 549 km$^2$ at Harriston. Although the gaging station at Harriston has been operating the longest (1925 – present), a measurement interruption from 1951 to 1969 caused an almost 20-year data gap. Similarly, Dooms (1974 – present) shows an interruption from 1996 to 2005. Only the gaging station near Waynesboro has been recording discharge continuously since 1952. Annual average discharges along the river range from 1.05 m$^3$ s$^{-1}$ to 8.84 m$^3$ s$^{-1}$ (4.19 m$^3$ s$^{-1}$ average) near Waynesboro, 2.28 m$^3$ s$^{-1}$ to 8.94 m$^3$ s$^{-1}$ (5.78 m$^3$ s$^{-1}$ average) near Dooms, and 1.98 m$^3$ s$^{-1}$ to 14.60 m$^3$ s$^{-1}$ (7.29 m$^3$ s$^{-1}$ average) at Harriston.

2.4 Islands

Along its 39 km (24 mi) between Waynesboro and Port Republic, islands occur frequently. Within the first 19 km (RRM 0 – 12), islands appear with a frequency of <1/ km, which increases to >2/ km below RRM 12 (Figure 2.4). Locations of islands include former dam sites, bends, and straight reaches. The increase in the number of islands after RRM 12 appears to correlate with the increase of the slope after RRM 13.
RRM 0 is located in Waynesboro.

Figure 2.4  Cumulative number of islands versus relative river mile (RRM) (Pizzuto et al., unpublished). 1 Island/ mile and 4 Is./ mi are referred to as < 1 island/km and >2 islands/km in the text respectively. RRM 0 – 24 extends 39 km from Waynesboro to Port Republic.
Chapter 3

METHODS

3.1 Study Design

A combination of a Geographic Information System (GIS) and field work was used to identify and classify islands. Hydrologic data provided information about past discharges and flood events along the South River. Before any measurements could be collected in the field and evaluated, islands influenced by human activities were eliminated. The remaining islands were located relative to RRM 0.0.

In order to determine whether islands have been formed by floodplain incision or bar growth, the following information was collected (Table 3.1):

- **Upstream Distance to Nearest Tributary:** Tributaries can contribute to the formation islands by adding sediment to the main channel causing deposition of an in-channel bar. An island that is located directly downstream of a tributary might have formed by sediment deposition.

- **Type of Reach:** Dissection of a floodplain is less likely along a straight part of the river where water can flow without restriction. Floodplain islands are more common along bends.

- **Tightness of Bend:** Anabranching is more likely to happen at bends. The number of islands should increase as the tightness of a bend increases.
• **Area:** The surface area of islands can indicate whether an island is a mature bar or a detached floodplain. Islands that formed from floodplain incision are not dependent in size on the channel width. Large islands should be formed by floodplain incision and small islands are more likely to be formed through deposition.

• **Grain Size:** Islands with sediment similar to the channel bed suggests island formation through bar growth. Islands with sediment that is smaller than that of the channel bed and similar to the floodplain indicates an island that was once attached to a floodplain.

• **Topography:** A depositional island is more likely to have a lower elevation than the adjacent floodplain. An island that has formed through avulsion should have the same elevation as the adjacent floodplain. Scour channels should be evident on floodplain islands. Because banks along floodplains are often compacted and difficult to erode, their slope should be close to vertical. Matured bars that have large unconsolidated sediment cannot support a steep bank slope and steeply sloping cutbanks should therefore not exist on islands that develop from bars.

• **Additional Observations:** Any observations that seemed relevant for the determination of the type of island were documented in addition to the information above. Observations could include type of vegetation, location and orientation of large woody debris (LWD), location of bedrock in the channel and on the island, etc.
Table 3.1  List of measurements that helped determine whether an island was once part of the floodplain or whether it has grown from an in-channel gravel bar.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from Nearest Tributary</td>
<td>• Islands close to a tributary could be the result of added sediment to the main channel.</td>
</tr>
</tbody>
</table>
| Type of Reach                            | • A dissected floodplain is more likely to occur at a bend.  
|                                          | • A matured in-channel bar is more likely to be found along a straight part of the river. |
| Tightness of Bend                        | • Anabranching and therefore detached floodplains are more likely at tighter bends. |
| Surface Area                             | • Matured in-channel bars should be smaller than islands separated from the floodplain. |
| Grain Size                               | • Sediment similar to channel bed material indicates a matured bar, while sediment similar to the floodplain indicate a separated floodplain. |
| Topography across Island, Channels, and Floodplain | • Can indicate possible scour channels.  
|                                          | • Steep banks can indicate that the island has been cut off from the flood plain.  
|                                          | • Gradual slopes occur in matured gravel bars.  
|                                          | • A lower elevation of the island can indicate a matured gravel bar.  
|                                          | • Islands that have the same height as the floodplain were most likely once part of that floodplain. |
| Additional Observations                  | • Type of vegetation  
|                                          | • Location and orientation of LWD  
|                                          | • Location of Bedrock |
3.2 Further Explanation for Selection of Islands and Field Study Sites

To find out which islands are the products of human intervention and which formed naturally, historical aerial photographs were examined. Images were available for the years of 1937, 1957, 1974, 1976, and 2005. Photographs from 1976, although clearer than 1974 images, are only available in printed format and were used only for confirmation of unclear images on 1974 photographs. Islands located at former dam sites (Figure 3.1), for example, were not included since their formation could easily be explained and at least 13 sites were eliminated this way. Another island had been created artificially when a new channel was dredged sometime after 1957 to cut off a river bend.

Figure 3.1 Aerial photographs showing an island directly below a dam site. Arrows indicate the location of an intact dam in 1957 (A) and its approximate former location in 2005 (B).
Human influence could not always be easily identified. One example is illustrated in Figure 3.2 where an island is located directly downstream of a mill at RRM 12.1. The picture shows a mill race passing through the mill house before joining the main channel of the South River just downstream. The mill had been built before the first aerial photographs were taken in 1937 and the island also formed before 1937. It is therefore not clear whether the mill race contributed to development of the island somehow by either delivering added sediment to the channel or modifying water flow just downstream of the confluence.

Figure 3.2 Aerial photographs of an island directly downstream of a mill in 1957 (A) and 2005 (B).
A second example illustrated in Figure 3.3 showing an island at RRM 21.7 next to a gravel production company. The island has formed sometime after 1937 and it is not clear whether this was influenced by the close proximity of the company to the channel.

Figure 3.3  Aerial photographs of the river channel next to a gravel production company (arrow in B). Note that the island formed sometime after 1937.

A third example is shown in Figure 3.4. In this case an obstruction is visible in 1974 (Figure 3.4 A) and earlier in 1957 at RRM 6.6. It is unclear whether it is an abandoned man-made dam or a natural obstacle formed by large woody debris (LWD). The 2005 image shows an island that formed at the same location.
Time restrictions did not allow a visit to all islands in the field. Islands with unusually interesting features had priority for field study. For example, an island that was located along a straight reach of the river became subject to further examination in the field. Island formation through avulsion is unexpected at a straight reach because the channel has no need to find a shorter path. Islands at bends where the secondary channel formed at an odd location (i.e. at the apex of the concave bank) or which showed an unusual shape were also considered. Figure 3.5 is an example where the channels split at a high angle to the parent channel at a place that is relatively straight (A) or near the apex of the bend (B). The island in the left image also has an odd shape because the secondary channel does not continue straight down valley but changes direction almost opposite of the valley slope before joining the main channel.
Figure 3.5 2005 images of islands of unusual shape and location. The smaller channel in A splits off at an almost 90 degree angle to the main channel (arrow) and makes another sharp turn further downstream instead of continuing straight towards the main channel. Similarly, image B shows a narrow compound island (arrow) at the apex of the concave bank.

The assumed type of island played a role as well. The initial hypothesis stated that islands at river bends were formed by floodplain incision as the channel searched for a more direct path down valley. On the other hand, islands within straight river sections developed by in-channel bar growth. Aerial photographs showed very few islands along straight reaches and only one could be identified as a true depositional island. Because only a few islands were identified as potential mature gravel bars, all of them had to be visited in the field.

The origin of some islands was clear from aerial photographs because their development began after the first photographs were taken in 1937. Further data collection was therefore not necessary. Only a small number of these islands needed to
be analyzed further. Observations obtained at these sites were used to establish the origins of islands that formed before 1937.

### 3.3 Analysis of Hydrologic Data

Daily mean discharge data were obtained from the USGS (www.usgs.gov). The gaging stations at Harriston and near Waynesboro were used for this study because, unlike the station near Dooms, measurements reach as far back as 1925 and 1952 respectively. This allowed for a long enough time series that includes discharges from when mill dams were still intact. However, a large data gap from 1951 to 1968 in the Harriston measurements required estimation of discharges using data from the Middle River and the following regression equation:

\[
Q_H = 0.7171Q_M + 23.931, r^2 = 0.7292 \quad \text{(Equation 3.1)}
\]

where \( Q_H \) refers to the daily mean discharge at Harriston and \( Q_M \) to the daily mean discharge in the Middle River, which flows in a north western direction west of the South River in Augusta County.

All discharges were ranked from highest to lowest and the recurrence interval (RI) was calculated as
where N is the total number of daily measurements from February 15, 1925 to December 31, 2010, and n represents the rank of each event. Because daily discharges were used instead of annual discharges, the equation is multiplied by 365 days to obtain an annual RI. To see whether high storm discharges along the South River remained the same, increased, or decreased over the past 85 years, all flows with an RI of less than 1.0 were removed to leave only high flows that would occur every other year or less.

3.4 GIS Analysis

Arc GIS was used to measure local channel slope, channel curvature, and area of islands. The channel slope along islands was calculated by dividing the elevation difference or relief between the upstream and downstream ends by the length of the channel section. Elevation data were obtained from 2-foot contours that had been created by converting a digital elevation model (DEM) of the South River into polygons. The DEM was derived from aerial LIDAR data that was collected in 2005. Local elevations were estimated by interpolating points between two contours that crossed the channel upstream and downstream of an island. The channel length was measured using a simple GIS measuring tool. Channel curvature was recorded as the radius of the circle that best followed the curvature of the channel when superimposed.
Area was calculated by the program from a line drawn that followed the outline of an island. The accuracy of the data was largely dependent on the quality of the aerial photographs and the time of the year the photo was taken. Grainy images made the identification of some islands difficult and too much vegetation could conceal the true edges of channels.

Figure 3.6   Circles superimposed onto 2005 aerial photographs to measure channel curvature.

3.5  Field Methods

A total station and auto level were used to survey cross sections across the width of islands, adjacent channels and floodplains when water depths permitted. The auto level proved to be more convenient at sites that could only be accessed by boat or
where channel crossings were more difficult since it was lighter than the total station and easily stowed in a waterproof container. Locations of cross sections were chosen based on the possibility of attaining a clear path across the entire island. The goal was to survey areas where islands had the largest width. This proved to be more difficult during times when vegetation was in full bloom. Places as close to the desired area as possible were then chosen. Multiple cross sections were surveyed on compound islands or on islands that had lengths of more than five channel widths.

The stratigraphy of islands and floodplains was established by coring and examining cut banks. At least two cores on each island and one on the floodplain were taken along the surveyed cross sections using a bucket auger. Grain size was estimated visually. The auger could not penetrate gravel larger than 4 cm. Cores ranged in length from a few centimeters to more than 1 m depending on the elevation of islands and gravel size. When present, cut banks near or on the path of cross sections provided better options for an accurate description of the exposed deposits. Unlike cores, cut banks could show whether gravel existed as an intermittent layer or whether it was the actual channel bed (Figure 3.7). Where sediment consisted of sand and cobbles, cut banks were not available and the auger could not penetrate the surface. In this case a pit was dug and the sediment size and distribution roughly estimated (Figure 3.8).
Figure 3.7  Example of a cut bank. Gravel is absent from this bank.

Figure 3.8  Pit dug into gravel on an island where coring is not possible and cut banks are not available. See hammer on bottom right for scale.
Pebble counts were performed on gravel bars and islands using a gravelometer to obtain surface grain size distributions (GSD) (Figure 3.9). Roughly 100 randomly chosen pebbles were counted on each bar and in the channel at apices of islands where water levels permitted. A larger island was divided into an upstream, center, and downstream part and pebble counts done separately for each part. Sediment that was smaller than or equal to sand size was sampled and analyzed in the lab using a grain size analyzer or camsizer (Figure 3.10). The camsizer provides “reliable measurements for grain sizes ranging from 50 microns to 1 centimeter” (www.sas.upenn.edu/earth/dougi_lab.html) and can quickly produce a precise GSD.

Figure 3.9  Pebble counting on a gravel bar. About 100 pebbles were counted on each site.
Figure 3.10 Side view (A) and top view (B) of the Camsizer (courtesy of the Sediment Dynamics Lab, Department of Earth and Environmental Science, University of Pennsylvania).
Chapter 4
RESULTS

4.1 General Description of Islands

20 islands were identified at 12 sites along the South River with six sites having two or more islands (Table 4.1). Nine islands formed before the first aerial photographs were taken in 1937. Eleven islands formed between 1974 and 2005. The rate of island formation along 39 km from 1937 to 2005 is 0.005 islands/km/yr when calculating using the number of sites (12 sites/39 km/68 years) or 0.008 islands/km/yr when all individual islands were included in the calculation (20 islands/39 km/68 years). Both rates indicate the formation of roughly one island every 5 years, assuming that pre-1937 islands formed within a year before the photographs were taken. It is possible that pre-1937 islands formed many years or even decades before the first pictures were taken. However, no data exist that could prove the possibility of islands being formed much earlier.
Table 4.1  Locations of islands and their approximate time of formation.

<table>
<thead>
<tr>
<th>RRM</th>
<th># of Islands</th>
<th>Reach Type</th>
<th>Distance from Nearest Upstream Tributary, km</th>
<th>Approximate Time of Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.9</td>
<td>2</td>
<td>Straight</td>
<td>0.1</td>
<td>After 1974</td>
</tr>
<tr>
<td>7.0</td>
<td>1</td>
<td>Straight</td>
<td>0.06</td>
<td>Before 1937</td>
</tr>
<tr>
<td>7.15</td>
<td>1</td>
<td>Straight</td>
<td>Next to island</td>
<td>Before 1937</td>
</tr>
<tr>
<td>8.85</td>
<td>3</td>
<td>Bend</td>
<td>0.27</td>
<td>After 1974</td>
</tr>
<tr>
<td>13.0</td>
<td>2</td>
<td>Bend</td>
<td>Next to island</td>
<td>Before 1937, after 1974</td>
</tr>
<tr>
<td>13.4</td>
<td>1</td>
<td>Bend</td>
<td>0.71</td>
<td>After 1974</td>
</tr>
<tr>
<td>14.5</td>
<td>1</td>
<td>Bend</td>
<td>0.37</td>
<td>After 1974 (most likely)</td>
</tr>
<tr>
<td>15.3</td>
<td>1</td>
<td>Bend</td>
<td>0.35</td>
<td>Before 1937</td>
</tr>
<tr>
<td>17.1</td>
<td>2</td>
<td>Bend</td>
<td>1.2</td>
<td>Before 1937, After 1974</td>
</tr>
<tr>
<td>17.7</td>
<td>2</td>
<td>Bend</td>
<td>0.11</td>
<td>Before 1937</td>
</tr>
<tr>
<td>17.95</td>
<td>1</td>
<td>Straight</td>
<td>Next to island</td>
<td>Before 1937</td>
</tr>
<tr>
<td>22.2</td>
<td>3</td>
<td>Bend</td>
<td>3.77</td>
<td>Before 1937(1), After 1974</td>
</tr>
</tbody>
</table>

Similar to other natural rivers, the South River does not have perfectly straight channel sections and frequently changes directions. Some bends, however, are too broad (i.e. have a very large radius) to interpret as such on aerial photographs. In this study, sections that have bends with a radius of more than 20 channel widths have been classified as straight. Figure 4.1A shows the distribution of radii of bend curvature along the South River. The distribution is skewed, with many bends with short radii of curvature and few with long radii of curvature. Figure 4.1A further shows that islands occur over the entire range of observed radii of curvature. Figure 4.1B more clearly shows the distribution of islands with regard to bend radius and Figure 4.2 shows examples of islands at bends and straight reaches. Here it is evident
that islands can form at bends as well as straight reaches. Each bend radius was divided by an average channel width of 26.8 m (Narinesingh, 2010) in order to obtain units of channel widths.

Figure 4.1  Histograms showing radii and occurrence frequency of all river bends with and without islands (A) and only bends where islands have formed (B). Bend radii are normalized by a mean channel width of 26.8 m.
Figure 4.2 Examples of islands at a sinuous reach (A) and along a reach that is classified as straight (B).

Areas of 19 islands were measured (Table 4.2). The average area is 7,043 m² (standard deviation 12,315 m²), with a range of 140 m² to more than 50,000 m². A dimensionless area was determined as well by dividing the island area by the channel area (Table 4.2). Channel areas were calculated using the average channel width for the particular river reach and the length of the channel section occupied by the island. This gives a better indication of the size of an island compared to the channel. An island with a dimensionless area of >1 occupies an area that is larger than that of the river channel. Values below 1 specify islands that are smaller than the channel. Eleven of the 19 islands that were measured (58%) have an area smaller than the channel.
section while seven islands (37%) are larger. One island’s dimensionless area is 1.0 (Table 4.2). The smallest island at RRM 8.85 was not measured because tree cover obscures the location of the shore line on aerial photographs.

Table 4.2 Areas of 19 islands. The abbreviations “sm”, “med”, and “lg” refer to small, medium, and large islands respectively.

<table>
<thead>
<tr>
<th>RRM</th>
<th>Island Area, m²</th>
<th>Dimensionless Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.9 (lg)</td>
<td>1,124</td>
<td>0.5</td>
</tr>
<tr>
<td>5.9 (sm)</td>
<td>320</td>
<td>0.5</td>
</tr>
<tr>
<td>7.0</td>
<td>555</td>
<td>0.5</td>
</tr>
<tr>
<td>7.15</td>
<td>7,139</td>
<td>1.9</td>
</tr>
<tr>
<td>8.85 (lg)</td>
<td>1,125</td>
<td>0.8</td>
</tr>
<tr>
<td>8.85 (sm)</td>
<td>137</td>
<td>0.3</td>
</tr>
<tr>
<td>13.0 (lg)</td>
<td>17,697</td>
<td>1.4</td>
</tr>
<tr>
<td>13.0 (sm)</td>
<td>3,263</td>
<td>1.0</td>
</tr>
<tr>
<td>13.4</td>
<td>16,975</td>
<td>2.2</td>
</tr>
<tr>
<td>14.5</td>
<td>7,603</td>
<td>1.6</td>
</tr>
<tr>
<td>15.3</td>
<td>6,582</td>
<td>0.9</td>
</tr>
<tr>
<td>17.1 (lg)</td>
<td>2,870</td>
<td>0.5</td>
</tr>
<tr>
<td>17.1 (sm)</td>
<td>262</td>
<td>0.1</td>
</tr>
<tr>
<td>17.7 (lg)</td>
<td>2,605</td>
<td>0.5</td>
</tr>
<tr>
<td>17.7 (sm)</td>
<td>139</td>
<td>0.2</td>
</tr>
<tr>
<td>17.95</td>
<td>3,576</td>
<td>1.2</td>
</tr>
<tr>
<td>22.2 (lg)</td>
<td>54,735</td>
<td>5.3</td>
</tr>
<tr>
<td>22.2 (med)</td>
<td>5,535</td>
<td>1.4</td>
</tr>
<tr>
<td>22.2 (sm)</td>
<td>1,568</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>7,043</strong></td>
<td><strong>1.1</strong></td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td><strong>12,315</strong></td>
<td><strong>1.1</strong></td>
</tr>
</tbody>
</table>
About 44 tributaries join the main channel in the 39 km (≈1 tributary/km average) long study reach and all islands, except two, have a tributary joining the river less than 1 km upstream (Table 4.1). Tributaries can be significant sources of sediment that could play a role in channel bar formation. Aerial photographs show that some tributaries that join the South River from the east carry a large amount of sediment. The sediment deposits at or directly downstream of the confluences in the form of deltas or gravel bars. This is due to the channels’ origin in the Blue Ridge Mountains. Tributaries originating from the west do not appear to transport much sediment and some tributaries from both sides appear to be either dry or seasonal.

Large woody debris (LWD) was found on all islands that were visited in the field and is usually positioned perpendicular to flow at apices of islands (Figure 4.3). On some islands LWD exists as smaller clusters throughout the island or parallel to the flow. The size varied from single large trees to clusters of small debris to a combination of large tree trunks and smaller debris. Figure 4.4 shows examples of two islands where LWD is stacked up at the apex as clusters of large and small debris.
Figure 4.3 Sketch illustrating the general positions of LWD on islands.

Figure 4.4 Examples of LWD at island apices at RRM 13.4 (A) and RRM 17.1 (B). Both photographs were taken on the same day when water levels were higher than normal.
4.2 Detailed Description of Selected Islands.

Eight study areas were chosen for field work based on location (bend or straight section), presumed origin (floodplain island or gravel island), time of formation (pre or post-1937), and unexpected characteristics (e.g. multiple islands in same area). At each location, type and density of vegetation, grain size of sediment, and any additional observations were documented. Cross sections were surveyed at 6 locations.

4.2.1 RRM 5.9

The first study reach at RRM 5.9 is located along a straight section of the river 0.10 km downstream from a small tributary from the west. Two islands formed sometime after 1974 (Figure 4.5). The large island to the left has an area of 1,124 m². Steep banks and absence of recent gravel deposits along the left bank of the secondary channel and the right side of the island indicate erosion. Contours show that the island’s highest elevation is similar to that of the floodplain, while the rest of the island’s surface remains below that height.

LWD is found at the apex against trees and is oriented roughly perpendicular to water flow. A large downed tree is also located across the secondary channel (Figure 4.5E). Vegetation is dense with brush covering most of the surface and surrounding large trees. Because the floodplains are used as cattle pastures, the vegetation consists of grass while trees only line the banks. This makes the comparison of the vegetation on island and floodplain as a tool for determining island type untenable.
The smaller island to the right has an area of 320 m$^2$ and an elevation roughly 1.2 m below the highest elevation of the large island. The surface material consists of sediment with a D$_{50}$ of 30 mm. Vegetation is limited to small brush. Some LWD is present parallel to the flow (Figure 4.5E) but it is unclear whether it originated on the island or whether it was deposited during a previous high flow event.

Figure 4.5 Historical aerial photographs showing RRM 5.9 (A-D) and photographs taken in the field showing the apices of both islands (E). Note the LWD on the left island and a downed tree sub parallel to the flow on the smaller island on the right (red arrows in E, below).
4.5 continued.

### 4.2.2 RRM 7.15

![Map showing RRM 7.15 and aerial photographs](image)

**Figure 4.6** 2005 aerial photographs showing RRM 7.15. The white dashed line in B indicates the location of a cross section.
The island at RRM 7.15 formed before 1937 and is located along a straight part of the river (Figure 4.6). A tributary joins the secondary channel west of the $7139 \text{ m}^2$ large island. Erosion is evident through cut banks, which are found on both sides of the island and along the floodplain banks on either side of the channel. The surface elevation decreases towards the secondary channel west of the river (Figure 4.7). The surface sediment consists mostly of muddy sand and vegetation is restricted to mostly trees with some brush. The cross section in Figure 4.7 shows that sediment below the surface is comprised mostly of sand. At a depth of about 100 cm, sand is mixed with gravel. LWD is found as clusters against trees perpendicular to flow across the island but is not significant. This island is next to a cattle pasture and cattle appear to have access to the island.

![Cross section of the island at RRM 7.15 looking downstream.](image)

**Figure 4.7** Cross section of the island at RRM 7.15 looking downstream.
4.2.3 RRM 8.85

Three islands are located at RRM 8.85 along a tight bend ($R = 2.2$ channel widths) and 0.27 km downstream of a large tributary. The formation of these islands is documented in Figure 4.8. The photographs suggest enlargement of the channel through bank erosion after 1974 which could be the cause for the formation of the two smaller islands. No field data were obtained on the smaller islands. Observations in the field show that high cut banks on the right side of the main channel and high flow velocity causes active erosion of the bank sediment near the island furthest downstream.

Figure 4.8 Aerial photographs of RRM 8.85 (A and B). Note the extensive erosion along the right bank of the main channel near the islands. Image C (below) shows a close-up of the three islands and the location of a cross section (dashed line).
The large island has an area of 1,125 m$^2$ and the sediment of the substrate and surface is primarily sand sized and similar to the substrate of the floodplain adjacent to the island (Figure 4.9). A core taken near the secondary channel could penetrate the substrate below the water level due to the absence of large gravel.
Figure 4.9  Cross section of the large island at RRM 8.85 looking downstream. Note the difference in elevation of the island and floodplain.

Steep banks and exposed tree roots along the left bank indicate erosion along the active secondary channel (Figures 4.9 and 4.10A). Vegetation differs from that of the densely vegetated floodplain in that only a small group of trees are located near the main channel while the rest is sparsely covered with small brush (Figure 4.10B). Some LWD is located perpendicular to flow against trees where the secondary channel splits at a roughly 90 degree angle. The surface of the island is very low and even, and evidence such as small plant debris against trees and slanting of small vegetation into the direction of water flow suggests recent inundation.
4.2.4 RRM 13.0

The large island at RRM 13.0 is located along the outside of a large bend ($R = 10.3$ channel widths). It has an area of $17,697 \text{ m}^2$ and its elongated shape follows the curvature of the channel (Figure 4.11). The island has formed before 1937, so its origin is unknown. A large tributary carrying gravel and cobble flows into the
secondary channel from the east and intrudes far into the island. No field data beyond photographs and general observations were collected.

A gravel bar across the parent channel west of the large island detached from the floodplain and matured into an island after 1974. Its formation is documented on historic aerial photographs in Figure 4.11. The aerial photographs in Figure 4.11 further show that the main channel has migrated towards the outside of the bend away from the gravel island.

![Aerial photographs of RRM 13.0. The dashed white lines outline the secondary channel and the solid black lines in B indicate the location of the main channel in 1974.](image)

Figure 4.11  Aerial photographs of RRM 13.0. The dashed white lines outline the secondary channel and the solid black lines in B indicate the location of the main channel in 1974.

Similar to the surrounding floodplain, the large island is heavily vegetated by mature trees and large brush. The surface sediment on the island is mostly sand and the tributary sediment appears to deposit only into the secondary channel. Erosion
along the banks of both sides of the island and the floodplain across the secondary channel is evident by leaning trees and exposed roots (Figure 4.12). The photographs in Figure 4.13 show a layer of compacted fine sediment protruding into the channel below the water surface and gravel is generally absent along this part of the island suggesting that this island might have once been part of the floodplain.

Figure 4.12  Photographs of the secondary channel along the large island at RRM 13.0 looking downstream (A) and upstream (B). Leaning trees and exposed roots indicate erosion along the banks.

Figure 4.13  Pictures of the bank along the main channel. A compacted fine grained layer of sediment protrudes from the island out into the water column.
At RRM 14.5 there is one island at a tight bend with a radius of 2.2 channel widths 0.37 km downstream from the nearest tributary (Figure 4.14). The island has an area of 7,603 m$^2$. The year of its formation is unclear because of the quality of older aerial photographs. Sections of a channel are visible in the 1937 photograph in Figure 4.14, which has the same shape of the current secondary channel. However, it does not appear to connect to the main channel upstream. The channel does not become clearly visible until 2005 due to heavy tree cover in the 1957 and 1974 photographs. Field observations showed that the secondary channel, visible in the 2005 photograph, has slow water flow compared to the larger main channel. It begins upstream of the bend and splits off at an almost 90 degree angle. Before it rejoins the main channel.
downstream of the bend, it changes direction flowing nearly in the opposite direction of the main channel.

The banks of the island and the floodplain to the west are steep and gravel is absent from the island and floodplain except at the island apex and the downstream end where both channels join. The floodplain across the secondary channel has a large area compared to the floodplain across the main channel which is only a few feet wide before the elevation increases rapidly. Contours confirm field observations of a steep floodplain bank west of the island where the secondary channel makes a sharp right turn before joining the main channel. Here, the height of the floodplain increases quickly to at least 0.6 m above the height of the island (Figure 4.15). The vegetation of the island and the floodplain are identical in density and type and consists of mature trees and dense brush. LWD is located perpendicular to flow at the apex of the island.

Figure 4.15  2005 aerial photograph of the island at RRM 14.5 with 0.6 m contours displayed.
The cross section in Figure 4.16 shows a decrease in elevation near the secondary channel and a potential floodplain channel incised into the island. The surface grain size of both island and floodplain is mostly sand with a \(D_{50}\) of 0.45 mm and 0.5 mm respectively (Figure 4.17). Gravel is present within possible floodplain channels on the island. Coring on the floodplain west of the island and cut bank analysis on the island along the secondary channel show similarities in substrate grain size. Small iron nodules found in the core on the floodplain (C1 in Figure 4.16) and in the substrate along the bank of the island across the channel further confirm similarities between the floodplain and the island.

Figure 4.16  Cross section of the island at RRM 14.5 looking downstream.
Figure 4.17 Grain size distribution of floodplain, island, and channel bed at RRM 14.5 showing the similarities in surface sediment between floodplain and island.
The island at RRM 15.3 is similar to the island at RRM 13.0 in that an elongated island with an area of 6,582 m$^2$ follows the curvature of the channel (Figure 4.18). The bend has a radius of 6.7 channel widths and a tighter bend with a radius of 3.2 channel widths is located just downstream at the end of the island. The nearest tributary is 0.35 km upstream. The island formed before 1937 and has not changed. The floodplain across the secondary channel is very narrow and ends abruptly at a steep incline reaching an elevation of more than 6 m above the height of the island. The vegetation is very dense consisting of large trees and thick underbrush.
The sediment consists mostly of sand on the surface and sand and some gravel in the subsurface (Figure 4.19). Sediment becomes slightly finer towards the downstream end of the island. Core 2 along the downstream cross section (Figure 4.19B) was interrupted by a hard object that could have been bedrock or a large cobble.

Figure 4.19  Cross section of the upstream (A) and downstream part (B, below) of an island at RRM 15.3 looking downstream.
Bedrock outcrops dip about 45 degrees west and are visible in the secondary channel and along its banks (Figure 4.20). Bedrock is present in the main channel as well. Some LWD is found at the apex and gravel and cobble block part of the secondary channel at the apex. The secondary channel is also partially filled with gravel and sand bars in some parts and water flow is very slow during base flow conditions.
Figure 4.20  Downstream view of the secondary channel at RRM 15.3 where bedrock outcrops are common. Ovals indicate bedrock.
Two islands that differ from each other in area and grain size, are located along a fairly wide bend (R = 16.5 channel widths) at RRM 17.1 (Figure 4.21). Both islands are located 1.2 km downstream of the nearest tributary and their formation can be followed to an extent on historical aerial photographs (Figure 4.22).

It is likely that the small island has formed before 1937. In both photographs of Figure 4.22, a faint secondary channel can be seen (red dashed lines), however the quality of both images and the tree cover in 1957 make the channel unclear. Comparison of the images in Figure 4.22 with the 2005 photograph reveals that the small island has been eroding since its formation. Steep banks, absence of gravel along
all sides of the island, and rapid water flow in both channels further indicate erosion. The size and location of the modern island is indicated in green and shows the extent of erosion since its formation.

Figure 4.22  Historical aerial photographs of RRM 17.1. The large gravel island is not present. A possible secondary channel (red dashed lines) suggests the existence of the smaller island. The size and approximate location of the modern small island is indicated in green.

The small island has an area of 262 m$^2$ and consists only of fine grained material like muddy sand ($D_{50} = 0.35$ mm) and some gravel as depth increases (Figures 4.23 and 4.24). Vegetation is similar to that of the floodplain. LWD spanning across the secondary channel east of the small island is located at the apex of the island against a group of trees (see Figure 4.4B in section 4.1 for image).

The large island has an area of 2,870 m$^2$ and consists of cobble ($D_{50} = 40$ mm) on the surface and coarse sand and cobble in the subsurface (Figures 4.23 and 4.24).
The root systems of some trees armor the bank along the main channel on the east bank of the island. Although the vegetation consists of mature trees and some brush its density is less than that of the heavily vegetated floodplain. LWD is not very pronounced and consists of a few fallen trees that are oriented in the direction of flow.

Figure 4.23  Cross section across two islands at RRM 17.1 looking downstream. The large island has gently sloping banks unlike the smaller island that has cut banks on all sides.
Figure 4.24  Grain size distribution at RRM 17.1. Note the difference in grain sizes between the two islands.

4.2.8  RRM 17.7

Figure 4.25  2005 aerial photographs of two islands at RRM 17.7. Two cross sections are indicated with white dashed lines (B).
Two islands at RRM 17.7 are located at a bend with a radius of 4.1 channel widths just 0.11 km below a tributary (Figure 4.25). Historical aerial photographs show that both islands were formed before 1937 and differ in size. The channels split at a low angle in the middle of the bend. Two cross sections were produced due to the length of the large island and the location of the small island. The vegetation of both islands is similar to that of the floodplain and each other.

The large island has an area of 2,605 m² and extends well downstream of the bend. The cross sections show that the elevation decreases downstream and grain size increases from sand to very coarse sand and cobble (Figure 4.26) making the island’s grain size distribution appear fine grained at the upstream part and coarse grained at the downstream end. However, because the core on the upstream part could only reach a depth of 0.7 m before reaching large gravel, grain size below this depth is unknown and could be similar to the grain size of the downstream end. Field observations and contours show that the upstream part of the large island is several feet higher in elevation than the downstream part.
Figure 4.26 Cross sections of the upstream (A) and downstream part (B) of RRM 17.7 looking downstream.
Field observations revealed extensive gravel deposition along the island and in the secondary channel. Additionally, a gravel bar in the secondary channel at the downstream end of the island (indicated in Figure 4.28) has migrated downstream past the end of the island since 2005. The comparison of the 2005 image with field observations reveals that even though sediment transport is apparent in and along the secondary channel, no loss or gain of sediment is evident. Figure 4.28 shows the locations of gravel bars where pebble counts were done. Pebble counts on gravel bars along the island and in the secondary channel show that grain size becomes smaller downstream with the exception of the mid channel bar in the secondary channel (Figure 4.27). LWD is absent with the exception of one fallen tree oriented in the direction of flow.

Figure 4.27  Grain size distribution of all gravel bars of the large island at RRM 17.7. The location of each gravel bar is indicated in Figure 4.28 below.
Figure 4.28  Locations of gravel bars at RRM 17.7. Added features outlined in red formed sometime after 2005.

4.3 Shields Parameter

The dimensionless shear stress or Shields Parameter ($\tau^*$) was determined using median grain sizes ($D$) calculated from pebble counts in the main channel, reach average bankfull water depth ($h$), and reach average slope ($S$) obtained from Narinesingh (2010). Using Equation 4.1,

$$\tau^* = \frac{\rho ghS}{(\rho_a - \rho) gD}$$  \hspace{1cm} \text{(Equation 4.1)}
where \( \rho \) and \( \rho_s \) are the densities of water and sediment respectively and \( g \) is the gravitational constant, the average Shields Parameter in the South River is 0.047 (Table 4.3). At threshold of motion, Buffington and Montgomery (1997) suggest \( \tau_{c*} \approx 0.030 \) to 0.073 for gravel-bedded rivers, so bankfull flow is just able to move sediment in the bed of the South River.

Table 4.3  Shield’s Parameter for sites where in-channel pebble counts were done.

<table>
<thead>
<tr>
<th>RRM</th>
<th>Water Depth (h), m</th>
<th>Slope (S)</th>
<th>D_{50}, m</th>
<th>Shield’s Parameter (( \tau^* ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.35</td>
<td>1.9</td>
<td>0.00125</td>
<td>0.0255</td>
<td>0.056</td>
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<td>1.76</td>
<td>0.0023</td>
<td>0.073</td>
<td>0.034</td>
</tr>
<tr>
<td>17.0</td>
<td>1.89</td>
<td>0.0025</td>
<td>0.055</td>
<td>0.052</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td><strong>0.047</strong></td>
</tr>
</tbody>
</table>

4.4 Scour Features

Evidence of scour was found on all field sites in the form of cut banks, scour holes, and scour channels. Figures 4.29 to 4.31 show examples of the latter two types. These features are found on islands as well as adjacent floodplains. Scour channels observed in the field are often several meters in length and width and do not carry any water under base flow conditions. Scour holes are filled with water and appear to have a depth of at least 1 m. Other evidence of scour can be found in the form of large
elongated depressions on islands that are oriented in direction of flow. These are often covered with vegetation and gravel is absent.

Figure 4.29 2005 aerial photographs of two islands that have scour holes (white ovals) nearby (A) or on the island itself (B).

Figure 4.30 2005 aerial photographs showing scour channels (red arrows).
4.5 Hydrologic Data

Between the early 1950s and late 1960s, discharges with an recurrence interval of > 1 year appeared to occur less often than during other years. Plotted high discharges from the Harriston and Waynesboro gages in Figure 4.32 show a similar decrease in occurrences during the same approximate timeframe. Figure 4.32A shows that the South River at Harriston experienced fewer high discharges starting in 1950 before the numbers resumed a pre 1950 slope after 1966. Although discharges were not measured at the Waynesboro gage until 1952 and water discharge data from earlier years are unavailable, similarities in high discharge occurrence before and after 1966 can be seen in Figure 4.32B.
Figure 4.32  Cumulative discharges (RI > 1 year) obtained from Harriston (A) and Waynesboro (B) gages.
Historical aerial photographs show that in some reaches, secondary channels, scour channels, and other features are less pronounced or have disappeared by 1974. In Figures 4.33A and B, for example, the secondary channels (arrows in A) next to the islands at RRM 7.0 and 7.15 are not visible in 1974 and the main channel appears to be smaller in 1974 than in 1937. Similarly, in Figures 4.33C and D, scour channels on the floodplain (arrows in C) at RRM 8.85 have disappeared and like RRM 7.0 and 7.15, the main channel appears smaller. This roughly correlates with the decreased high discharges in the 1950s and 1960s. All faded features had reappeared by 2005 (Figure 4.34).

![1937 and 1974 aerial photographs](image)

Figure 4.33   Historical aerial photographs of the South River at RRM 7.15 (A and B) and at RRM 8.85 (C and D, below). The secondary channel in A and scour features in C (arrows) seem to have disappeared by 1974.
Figure 4.34 2005 aerial photographs of RRM 7.15 (A) and RRM 8.85 (B). All channels and scour features (arrows) have reappeared sometime after 1974.
Chapter 5
DISCUSSION

5.1 Types of Islands

The South River has two types of islands that differ from each other in grain size but are similar in their formation process. 17 islands formed through floodplain dissection and three islands matured from previous bank attached gravel bars. Islands do not form preferentially at bends or straight reaches or downstream of tributaries since islands can be found at straight reaches and along bends. Only three islands have a tributary joining the secondary channel. However, it is clear that the South River’s dominant mechanism for island formation is dissection of its floodplains.

Floodplain islands occur within bends and straight reaches of the South River. The majority (13 out of 17), however, do occur at bends. An approximately equal number of islands has a dominant channel on the outside of the bend while the other half has the main channel located on the inside (Figure 5.1). Channels are considered dominant when the width is larger than that of the secondary channel. Dominant channels also probably carry a faster flow. Secondary channels rarely flow perfectly straight down the valley like chutes, but rather change directions, sometimes flowing perpendicular to the main channel.
Figure 5.1  Examples of islands that have formed through floodplain dissection with the dominant channel on the outside (A) or inside (B) of the bend.

A second group of islands are gravel islands, which have matured from gravel bars. Three gravel islands have formed in the South River. These islands grew from bank attached bars into permanent vegetated features around which a secondary channel has formed. The South River does not have islands that formed from in-channel gravel bars. Historical aerial photographs of gravel bar islands documenting their formation and the rarity of growing in-channel gravel bars in the South River support this hypothesis.

5.2 Features that Contribute to Island Formation

Several features play a role in island formation. While some islands may have formed from one cause alone, other locations may have had multiple causes for secondary channel formation. All 20 islands were formed during flooding events when
water levels reached heights at which channels could either incise on floodplains or when water flow was able to seek a path around a bank-attached gravel bar.

5.2.1 Large Woody Debris (LWD)

The consistent occurrence and location of LWD on nearly all floodplain islands indicates that LWD may play a role in the location of islands because it could influence the position of secondary channels. Large uprooted trees that float down river during a high discharge will eventually be trapped between groups of trees on the floodplain. If enough material accumulates perpendicular to flow, it can form a natural dam preventing future floodwaters from freely flowing across the floodplain. The water is then forced across other areas of the floodplain and may be funneled around the obstruction. Repeated water flow around the new barrier can eventually lead to incision of the floodplain ultimately forming a secondary channel. Figure 5.2 illustrates a hypothetical situation where LWD obstructs the flow causing water to bypass the obstacle during a flooding event.
5.2.2 Scour Features and Local Depressions

Natural low areas and existing scour channels and holes may help the process of channel development by providing paths through which water will find its way back to the main channel downstream during high discharge events. These depressions may cause water to repeatedly seek the same path during subsequent flooding until a secondary channel has been eroded to a depth where water can flow through it during
base flow. Eventually the channel becomes permanent, detaching part of the floodplain and creating an island.

5.2.3 Bank Height at Tight River Bends

Tightness of a bend was shown to not have a large influence in the occurrence of islands since islands occur at bends of different tightness and at straight reaches. However, the bend radius becomes important when the height of the riverbank on the outside of the bend is high enough that water levels do not reach the top of the bank during a flood (Figure 5.3A). In these cases, the channel often flows past a high-level terrace or alluvial fan with an elevation much larger than that of the alluvium-filled floodplain (Figure 5.3B). Four sites show similarities in bend radius and bank height along the outside of the bends. At these sites, the floodplain elevation on the bend inside is at least 1 m below the height of the steep bank along the opposite side of the channel. Additionally, the floodplain on the outside is either only a meter wide or does not exist at all.
Figure 5.3 Island at RRM 17.7 where a high terrace is located along the bend outside (A and B). The white oval in A indicates the approximate location of photographs B and C. Geologic map by Gathright et al. (1978).

A high bank and lack of a floodplain along the outside of a bend allows water to only flood on one side of the bend once the flow capacity of the main channel is exceeded. Over time, a secondary channel is formed cutting off part of the floodplain. Although the secondary channels are calm during low flow periods, leaning trees and bare steep banks show that large water masses occasionally flow through the secondary channels.
Secondary channels remain small relative to the main channel because the majority of the flow will always be directed towards the outside of the bend. Gravel and cobble often partially block the secondary channel at its start preventing enough water to enter. Therefore, these channels have significant water flow only when water levels rise during high discharge events. Because water levels remain at base flow throughout most of the year, the secondary channels do not become active often enough to grow into larger functional channels.

Considering bend radius and bank height could help identify potential sites for new islands. Just downstream of the island at RRM 15.3, the channel makes a tight turn and contours show a steep bank on the outside (Figure 5.4). The contours in Figure 5.4 further indicate that the floodplain on the inside of the bend has developed a faint floodplain channel, which could form into a secondary channel in the future.

![Figure 5.4 2005 aerial photograph of a river section at RRM 15.3 where a new island could soon form. The white dashed line indicates a possible path for a secondary channel.](image)
5.2.4 Tributaries

Tributaries may play a role in the formation of some islands. Their role, however, does not involve gravel bar formation through added sediment at confluences. Aerial photographs provide no evidence that suggests that islands form where tributaries deposit sediment in the main channel. Several large tributaries join the South River; those originating in the Blue Ridge Mountains east of the South River deliver an extensive amount of sediment to the channel. None of these sediment rich tributaries have built an island at its confluence (Figure 5.5).

Figure 5.5 2005 aerial photographs of two large tributaries originating in the Blue Ridge Mountains to the east. Google Earth images of B, taken in 2007, show that sediment is filling the bar in further (oval). The island in B is located at a former dam site and is not part of this study.
Tributaries that join the river next to islands may have contributed to their formation in that they shortened the distance the floodplain had to be eroded to form a secondary channel. Figure 5.6 shows examples of tributaries joining the South River where a secondary channel is joined by a tributary. Tributaries may further help with the existence of islands by keeping the secondary channel occupied, preventing it from filling in.

![Figure 5.6](image)

Figure 5.6 2005 aerial photographs of islands next to tributaries at RRM 7.1 (A) and RRM 17.95 (B). Red arrows indicate tributaries.

### 5.2.5 Changes in High Discharge Occurrence

Aerial photographs show that 11 out of 20 islands have formed after 1974 and none formed between 1937 and 1974. Plotted high discharges (RI > 1 Year) of the South River (Figure 4.32 in Ch 4) show that the number of occurrence decreased
between the early 1950s and late 1960s. The correlation between the low number of discharges and the lack of island formation as well as the apparent temporary disappearance of at least three islands and several scour channels (Figure 4.33 in Ch 4) could indicate that high discharge events play a role in island formation and preservation. Frequent flooding can create secondary channels through floodplain incision as well as prevent existing channels from filling in with sediment.

The change in occurrence of high discharge events is not only visible in the South River. Discharge data from other rivers in the Potomac watershed show the same decreases of the number of high flows around roughly the same time. Cedar Creek near Winchester, about one hour north of Waynesboro, and the North Fork of the Shenandoah River at Mount Jackson show a decrease of high flows between the mid 1950s and late 1960s to early 1970s (Figure 5.7).
Figure 5.7  Cumulative number of discharges (RI > 1 year) of the Cedar Creek near Winchester (A) and the North Fork Shenandoah River at Mount Jackson in Virginia (B). The oval indicates a time interval when high discharges occurred less often than during other years.
5.3 Island Forming Processes

South River’s two types of islands have formed through three processes.

Floodplain islands have formed through either parent channel extension down valley where the main channel changes directions or through the incision of floodplains that are located on the inside of bends. Gravel bar islands formed when mature bank attached gravel bars were detached from the river bank. The processes that formed some islands cannot be identified.

5.3.1 Extension of the Channel Straight Down Valley

Six islands formed when water flow continued down valley, behaving similar to a cutoff channel, instead of following the path of the main channel. The resulting secondary channel either remains on the same straight path until it rejoins the main channel further downstream or it changes its course due to topographic changes before reentering the main channel.

Floodplain islands at RRM 5.9, 13.4, and the small island at RRM17.1 have secondary channels that are similar to chute channels in that they remain relatively straight (Figure 5.8). In all three cases, the secondary channels remain on the previous path of the main channel. A large amount of LWD of several feet in height at island apices suggests possible channeling of water during flooding.
Figure 5.8 2005 aerial photographs of three islands at RRM 5.9 (A), RRM 13.4 (B), and RRM 17.1 (C) where secondary channels continue on the same path as the parent channel. White arrows indicate the parent channel. Red arrows show the secondary channel.

Other islands similarly formed when the secondary channel extended straight down the general path of the river (Figure 5.9). The secondary channels, however, change their course due to topographic changes such as a sudden elevation increase in the floodplain due to a terrace (Figure 5.9B and D) or an alluvial fan. The elevation of
the left bank at the end of the secondary channel at RRM 7.1 increases in elevation and is composed of compacted sediment with a grain diameter of less than 2 mm. Most likely this made it difficult for the secondary channel to continue straight and instead chose an alternative path across the floodplain. The geologic map shows that a terrace flanks the shore line to the west at that location (Figure 5.9B). RRM 15.3 follows the curvature of the main channel because the floodplain on the outside of the bend is very narrow and a steep incline that prevents the channel from flowing farther to the west. The geologic map shows that this incline leads to a high terrace (Figure 5.9D).

Figure 5.9 2005 aerial photographs of islands (A and C) and geologic maps (Gathright et al., 1978) of the respective areas (B and D). Here the secondary channels continue on the path of the parent channel (red arrows in A and C) but topography forces a change in direction before rejoining the main channel.
The island at RRM 13.0 is similar to the island at RRM 15.3 in that the secondary channel follows the curvature of the main channel. A narrow floodplain next to a steep incline also forces the secondary channel to change its course but here, the channel abruptly ends where a large tributary has built a delta that protrudes into the island area. Field observations show that the secondary channel begins as a deep channel with calm water during base flow similar to the main channel (Figure 5.10). Downstream of the tributary, the channel becomes smaller and water flow velocity appears to increase. Because the water from the upstream secondary channel is blocked by the delta, most of the secondary channel carries the flow from the tributary and could therefore simply be an extension of the tributary.
Figure 5.10 2005 aerial photograph showing an island where the secondary channel continues on the path of the main channel (red arrow) but is being partially blocked by a tributary delta (oval).

5.3.2 Creation of a Shorter Path

Seven islands at RRM 8.85, 14.5, 17.7, and 22.2 formed at bends when water was forced across the floodplain on the inside of the bend. Figure 5.11 shows four sites where islands occur on the inside of a tight bend. In this case the river bank on the outside of the bend is high and steep but much lower on the inside. This allows water to flow only onto the inside floodplain but not along the outside of the bend during a flood. The location of the secondary channel depends on topographic features or the location of LWD or both. At all four sites, erosion of the outer river bank was
evident in the form of cut banks. The floodplain on the outside banks is either very narrow or does not exist at all.

Figure 5.11 2005 aerial photographs of islands at RRM 8.85 (A), RRM 14.5 (B), RRM 17.7 (C) and RRM 22.2 (D) where secondary channels formed on the floodplain on the insides of bends.
5.3.3 **Separation of Bank Attached Gravel Bars.**

The development of two gravel islands can be followed on historical aerial photographs (Figure 5.12). The history of the island at RRM 13.0 is the clearest; however, it is unknown what caused the formation of the secondary channel. Most likely the process was similar to that where islands formed when flooding on inside of bends caused the scour of a secondary channel. The island at RRM 17.1 has most likely formed the same way but it is less clear on the historical photographs. The bend at RRM 17.1 is much broader than the bend at RRM 13.0 and water does not have to flow around a tight bend. However, the sediment on gravel bars is not as compacted as on floodplain islands and a secondary channel can incise more easily.

![Figure 5.12](image)

**Figure 5.12** Historical aerial photographs showing the formation of the island at RRM 13.0 (A) and RRM 17.1 (B). The approximate shapes and locations of both islands in 2005 are indicated as white outlines on historical images.
A gravel island at RRM 5.9 does not occur at a bend but may have been separated from the floodplain during high discharge when LWD briefly channeled water along the bank (Figure 5.13). Although sparse small vegetation, gravel and cobble sized sediment, and a low elevation imply that it should be classified as a gravel bar, extensive vegetation coverage evident in historical photographs suggest it to be an island.

Figure 5.13  Aerial photographs showing a gravel island (oval) at RRM 5.9.

5.3.4  Islands with Unclear Formation Processes

The formation process of the island at RRM 7.0 and the small islands at RRM 17.7 and 22.2 is unclear. These islands formed before historical aerial photographs were taken. The secondary channels are neither extensions of the main channel down
valley nor do tight bends and high banks force floodwaters across the floodplains. LWD and/or scour features could be responsible for island formation.

RRM 7.0 is clearly a floodplain island as photographs show in Figure 5.14. However, the secondary channel splits at about 45 degrees within a straight reach of the river. A minor amount of LWD is found at the island apex but it is too small to have an effect on water flow during a flood. However, more substantial LWD is present on the banks within the area. An obstruction could have been present in the past causing short term changes in water flow that resulted in island formation.

Figure 5.14  2005 aerial photograph (A) and images taken in the field (B and C, below) of an island at RRM 7.0.
The small island at RRM 17.7 (Figure 5.15A) could have several factors contributing to its formation. LWD is found at the island apex and along the left bank of the secondary channel (Figure 5.15C). A second factor could be the extensive root matrix that prevents the island from eroding. The small island has only a few trees and
is otherwise completely covered with grass and other small grassy plants. A tightly webbed root system extends about six inches below the surface of the small island while roots of the large island directly across the channel did not reach this deep into the substrate (Figure 5.16). Where the root system began to become thinner, sediment could have been eroded scouring a secondary channel into the surface.

Figure 5.15 2005 aerial photographs (A and B) and image taken on location (C) of a small island at RRM 17.7.
Figure 5.16  Photographs of a bank that is armored with roots (A) and a bank without a deep root matrix (B). Banks are located across each other.

The smallest island at RRM 22.7 (Figure 5.17A and B) could have formed because of a large preexisting scour feature. The 1937 aerial photograph in Figure 5.17C shows that a scour channel existed on the large island before it was further dissected into three separate islands. The channel separating the small islands from each other was most likely once part of the large scour feature on the large island. Repeated flooding could have caused this feature to be scoured further since the water only needed to flow a short distance between two channels.
Figure 5.17  Historical aerial photographs of two small islands that formed after 1974. A scour channel is outlined in white and the approximate location of the smallest island (oval in B) is indicated in C and D.

5.4  Sediment Load Added to the South River

Rhoades et al. (2009) estimated that a total of 160,851 m$^3$ of sediment entered the South River between 1937 and 2005. Sources include channel changes due to island formation as well as erosion associated with meander bank erosion, confluence
gravel deposition, mill dam removal or failure, and erosion due to unknown reasons. After calculating secondary channel areas and measuring their lengths next to the islands (including islands that formed before 1937), a total of 31,067 m$^3$ of sediment was added to the South River through the formation of 3,414 m of secondary channels (Table 5.1). Of the 160,852 m$^3$ of total added sediment estimated by Rhoades et al. (2009), 11,401 m$^3$ (7%) entered the South River at islands between 1937 and 2005.

Unlike Rhoades et al. (2009) who used a combination of LIDAR, GIS and field data to determine the amount of eroded sediment, average bank heights and widths of secondary channels were measured on cross sections that had been produced from field data. The resulting cross sectional areas were multiplied with respective island lengths to determine the volume. Because cross sections were not produced for all study sites, average channel widths and heights of 1.1 m and 7.8 m respectively were assigned for the remaining secondary channels. Average channel height and width determined previously for the South River was not used because secondary channels are generally much smaller than the main channel. This would cause the sediment load to be overestimated.
Table 5.1 Secondary channel lengths and amount of sediment potentially added to the South River. Channel lengths for sites with multiple islands were added together except for RRM 8.85 where only the channel of the large (lg) island was measured.

<table>
<thead>
<tr>
<th>RRM</th>
<th>Channel Length, m</th>
<th>Amount of Sediment Added at Islands, m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>139</td>
<td>1,181</td>
</tr>
<tr>
<td>7.0</td>
<td>60</td>
<td>508</td>
</tr>
<tr>
<td>7.15</td>
<td>181</td>
<td>950</td>
</tr>
<tr>
<td>8.85 (lg)</td>
<td>85</td>
<td>401</td>
</tr>
<tr>
<td>13.0</td>
<td>715</td>
<td>6,056</td>
</tr>
<tr>
<td>13.4</td>
<td>278</td>
<td>2,355</td>
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<td>14.5</td>
<td>201</td>
<td>2,215</td>
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<td>15.3</td>
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<td>4,854</td>
</tr>
<tr>
<td>17.1</td>
<td>237</td>
<td>2,081</td>
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<tr>
<td>17.7</td>
<td>244</td>
<td>2,417</td>
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<tr>
<td>17.95</td>
<td>220</td>
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<tr>
<td>22.2</td>
<td>730</td>
<td>6,188</td>
</tr>
<tr>
<td>Total</td>
<td>3,414</td>
<td>31,067</td>
</tr>
</tbody>
</table>

5.5 Single or Multichannel System?

When comparing aerial photographs from 1937 to those taken in 2005, several added secondary channels indicate that the South River appears to be changing its plan form from a single-thread river to a multichannel river. The South River has previously been described as sinuous but not meandering, and Figure 5.18 shows that the bankfull discharge and slope plot just above those of meandering rivers and near those of straight rivers. Figure 5.18 further supports the observations made on
historical aerial photographs by plotting the South River’s discharge (at Harriston) and slope between “anastomosing” and “braided.”

![Slope discharge plot showing the position of the South River compared to rivers with various channel patterns. Data for braided, meandering and straight rivers are from Leopold and Wolman (1957) and anastomosed rivers have been added from Knighton and Nanson (1993).]

**Figure 5.18** Slope discharge plot showing the position of the South River compared to rivers with various channel patterns. Data for braided, meandering and straight rivers are from Leopold and Wolman (1957) and anastomosed rivers have been added from Knighton and Nanson (1993).

A more recent study by Jerolmack and Mohrig (2007) includes the prediction of anabranching and distributary channels by using relative rates of bank erosion and channel sedimentation to derive a dimensionless mobility number “M”. This mobility number is defined as the ratio of avulsion to lateral migration time scales. When plotted against the Parker stability criterion “ε” (Parker, 1976), rivers cluster into various groups of channel patterns (Figure 5.19). The Parker criterion states that rivers
with $\varepsilon << 1$ are single thread channels while rivers with $\varepsilon \geq 1$ are braided. Table 5.1 shows that the calculated Parker stability numbers in different reaches are less than 1. These results suggest that the South River is a single thread river. With an average aggradation rate of 0.002 m yr$^{-1}$ (Pizzuto, unpublicized presentation) and an average migration rate of 0.04 m yr$^{-1}$ (Rhoades et al., 2009) at a bank height and width of 2 m and 26.8 m respectively, the mobility number is 1.5. With a Parker criterion range of 0.012 to 0.023 (Table 5.2), the South River plots within sinuous transitional systems (Figure 5.19). This supports the hypothesis that the South River may be transitioning into a multichannel system.

### Table 5.2 Reach average Parker criterion for the South River.

<table>
<thead>
<tr>
<th>Reach, RRM</th>
<th>Slope</th>
<th>Width, m</th>
<th>Depth, m</th>
<th>Parker Criterion ($\varepsilon$)</th>
</tr>
</thead>
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<tr>
<td>0.0 – 4.5</td>
<td>0.0013</td>
<td>26.8</td>
<td>1.80</td>
<td>0.015</td>
</tr>
<tr>
<td>4.0 - 9.6</td>
<td>0.0012</td>
<td>26.8</td>
<td>2.03</td>
<td>0.012</td>
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<tr>
<td>9 - 11.9</td>
<td>0.0016</td>
<td>26.8</td>
<td>1.92</td>
<td>0.015</td>
</tr>
<tr>
<td>10.9 - 14.9</td>
<td>0.0020</td>
<td>32.6</td>
<td>1.70</td>
<td>0.023</td>
</tr>
<tr>
<td>14.4 - 17.9</td>
<td>0.0026</td>
<td>27.0</td>
<td>1.82</td>
<td>0.021</td>
</tr>
<tr>
<td>16.9 - 23.9</td>
<td>0.0024</td>
<td>30.4</td>
<td>1.95</td>
<td>0.021</td>
</tr>
</tbody>
</table>
Figure 5.19  Diagram of mobility number and the Parker stability criterion (Jerolmack and Mohrig, 2007) showing the South River among groups of different river systems. Diamonds and circles indicate sinuous (single thread) and braided rivers respectively. White and black symbols are single-channel and branching systems respectively. Gray symbols are transitional systems.

The South River is not braided because it does not have the braided characteristics such as “many many bifurcations, bars, and confluences within a single channel.” However, it does have multiple anabranches which rejoin the main channel further downstream. Even though these secondary channels carry less water flow and are often much narrower with bed elevations above that of the main channel, Studies such as Bertoldi and Tubino (2007) and Edmonds and Slingerland (2008) show that
multichannel rivers with uneven divisions of water flow and sediment transport are stable systems. Based on these findings, it would be reasonable to define the South River as a multichannel system. However, South River’s secondary channels reach a channel length of 500 m or less, while other observed multichannel systems have anabranches with lengths of several kilometers.

The South River may become some type of a multichannel system in the future. For now, the secondary channels may simply serve as accommodation channels during flooding. Many secondary channels are partially blocked at the location of bifurcation preventing enough water to actively flow down the channel. The transition into a multichannel system may be hampered by a narrow valley width. A change into a typical anastomosing river is unlikely because at many locations, the channel is forced to change course because the floodplain is flanked by an alluvial fan or high terrace. This may prevent the development of longer anabranches that are typical of truly anastomosing rivers.
Chapter 6

CONCLUSION

This study focuses on the formation of islands along a 40 km long study section of the South River in Virginia. Described by Skalak and Pizzuto (2010) as a relative stable single-thread, sinuous, gravel-bed, bedrock river, the South River has many islands. The river is subject to extensive research because its sediments are contaminated with mercury. Understanding island formation is important because large amounts of sediments are released into the channel when floodplains are incised during island formation.

Twenty naturally formed islands were identified on 2005 aerial photographs. The rate of island formation during the 20\textsuperscript{th} century is estimated at 0.008 islands/km/yr or one island every 3.5 years along the 40 km study reach. Comparison of historical photographs and data collected in GIS and in the field revealed that 17 islands are the result of floodplain incision, while three islands formed through gravel bar growth. About 7\% of the total volume of sediment eroded along the South River from Waynesboro to Port Republic since 1937 can be contributed to island formation due to the development of secondary channels. Floodplain islands form by incision of the floodplain in two ways: (1) creation of a shorter path through incision of the floodplain on the inside of a bend and (2) extension of the channel down valley where the main channel changes direction. Gravel islands form when bank attached bars
become semi permanent and after a secondary channel has formed around it. All islands formed during flood events and the locations of secondary channels were determined by physical factors such as position of LWD, topography of the floodplain, and location of terraces and alluvial fans.

Although the South River has added several km of secondary channels, it remains a single thread river. A narrow river valley and high terraces and alluvial fans keep channel migration to a minimum and compacted sediments and dense vegetation keep the river relatively stable. Most secondary channels are inactive during base flow but exposed roots along the banks, leaning trees, and steep bare banks suggest frequent erosion in secondary channels during periods of high flow. At this time, secondary channels may simply serve the purpose of accommodating increased water discharge during high flow events. An increase in discharge may change the South River into a multichannel system in the future.
REFERENCES


## Appendix A

### DATA TABLES

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<th>RRM</th>
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<td>1</td>
<td>1</td>
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<td>Straight</td>
<td>Straight</td>
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<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Distance to Nearest upstream Tributary, km</strong></td>
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<td>0.06</td>
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<td>After 1974</td>
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<td>Yes</td>
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<td>555 (0.5)</td>
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<td>Yes</td>
</tr>
<tr>
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<tr>
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<td>Yes</td>
</tr>
<tr>
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<td>N/A</td>
<td>N/A</td>
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<td>------</td>
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<td>1</td>
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<td>13.2</td>
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<td>1. 17,697 (1.4)</td>
<td>16,975 (2.2)</td>
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<tr>
<td></td>
<td>2. 137 (0.3)</td>
<td>2. 3,263 (1.0)</td>
<td>137 (0.3)</td>
</tr>
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<td></td>
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<td>No</td>
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<td></td>
<td>2. N/A</td>
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<td></td>
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<td></td>
<td>2. No</td>
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<tr>
<td>Additional Observations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Channels split at nearly 90° angle</td>
<td>• Fine grained compacted sediment layer extends into main channel below water surface at large island</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Formation is documented in aerial photographs</td>
<td>• Tributary built delta across secondary channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Shape of large island follows curvature of main channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• LWD at island apex</td>
<td></td>
</tr>
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<td>• Formation is documented on aerial photographs</td>
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<td>Yes</td>
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<tr>
<td>Vegetation similar to Floodplain?</td>
<td>Yes</td>
<td>Yes</td>
<td>1. No</td>
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</table>

**Additional Observations**
- LWD at island apex
- Large scour hole at apex
- Possible floodplain channels
- Bedrock exposed in main channel
- Bedrock outcrops along secondary channel
- Very narrow floodplain next to high terrace on bend outside
- Island shape follows curvature of main channel
- LWD at apex of small island
- Erosion of small island evident on historical aerial photographs
<table>
<thead>
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<th>17.7</th>
<th>17.95</th>
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<td>Vegetation similar to Floodplain?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Additional Observations</td>
<td>• Large scour hole on floodplain • Gravel bar migration in secondary channel and around large island</td>
<td>• High terrace next to secondary channel</td>
<td>• Formation of small islands documented on aerial photographs</td>
</tr>
</tbody>
</table>
Appendix B

AERIAL PHOTOGRAPHS OF ISLANDS SORTED BY DISTANCE FROM DOWNTOWN WAYNESBORO (RRM 0.0)

RRM 5.9
RRM 7.0 and 7.15

RRM 8.85
Appendix C

CROSS SECTIONS

[Diagram showing cross sections with labels such as 'Poorly sorted sand', 'C1', 'C2', 'C3', 'Main channel', 'Secondary channel', and legends for clay or silty clay, mud to muddy sand, sand, very coarse sand and fine gravel, gravel and cobble.]

RRM 7.15
Appendix D

GRAIN SIZE DISTRIBUTION

![Graph showing grain size distribution for Channel Bed, Floodplain, and Island. The x-axis represents the grain size in millimeters, ranging from 0.01 to 1000, and the y-axis represents the percent finer in percentage, ranging from 0 to 100. The graph includes data points for each environment.]

RRM 14.5
RRM 17.1

RRM 17.7