USING RAPID GEOMORPHIC ASSESSMENTS TO ASSESS STREAMBANK STABILITY IN OKLAHOMA OZARK STREAMS

Derek M. Heeren  
*University of Nebraska-Lincoln*, derek.heeren@unl.edu

Aaron R. Mittelstet  
*Oklahoma State University, Stillwater*, amittelstet2@unl.edu

Garey A. Fox  
*Oklahoma State University - Main Campus*, gafox2@ncsu.edu

Daniel E. Storm  
*Oklahoma State University - Main Campus*, dan.storm@okstate.edu

Abdulsahib T. Al-Madhhachi  
*Oklahoma State University, Stillwater*

*See next page for additional authors*

Follow this and additional works at: [https://digitalcommons.unl.edu/biosysengfacpub](https://digitalcommons.unl.edu/biosysengfacpub)

Part of the Biological Engineering Commons

Heeren, Derek M.; Mittelstet, Aaron R.; Fox, Garey A.; Storm, Daniel E.; Al-Madhhachi, Abdulsahib T.; Midgley, Taber L.; Stringer, Ashley F.; Stunkel, Kevin B.; and Tejral, Ron D., "USING RAPID GEOMORPHIC ASSESSMENTS TO ASSESS STREAMBANK STABILITY IN OKLAHOMA OZARK STREAMS" (2012). *Biological Systems Engineering: Papers and Publications*. 221.  
[https://digitalcommons.unl.edu/biosysengfacpub/221](https://digitalcommons.unl.edu/biosysengfacpub/221)

This Article is brought to you for free and open access by the Biological Systems Engineering at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Biological Systems Engineering: Papers and Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
ABSTRACT. High streambank erosion and failure rates on streams in the Ozark ecoregion of Oklahoma may be attributed to land use change and degradation of riparian areas. Numerous benefits may be achieved from streambank stabilization, but methods are needed to determine the most critical reaches for investing limited funds. Rapid geomorphic assessments (RGAs) have been used to aid in prioritizing stream reaches. This research (1) applied an existing RGA, the channel stability index (CSI), on several reaches along the Barren Fork Creek and Spavinaw Creek, and (2) modified the existing RGA to create an ecoregion-specific RGA called the Oklahoma Ozark streambank erosion potential index (OSEPI) for larger-order streams in the area. Aerial photography (2003 to 2008) was used to document recent lateral bank retreat for evaluating the RGA scores. Whereas the CSI provided a relatively simple, inexpensive way to identify reaches that should be further evaluated for stability, it failed to disaggregate unstable stream reaches. Limitations included not considering the streambank’s cohesion and the difficulty in assessing some metrics. The OSEPI, which included parameters to account for the streambank’s cohesion and stream curvature, had higher correlation ($R^2 = 0.29$ for all reaches; $R^2 = 0.45$ for reaches with similar soils) with recent streambank erosion. These results indicate promise for its use in prioritizing reaches for future stabilization projects in the Ozark region of Oklahoma. Additional research is needed to further test the generic and ecoregion-specific RGAs and to determine the conditions that necessitate ecoregion-specific indices.

Keywords. Channel stability index (CSI), Rapid geomorphic assessment (RGA), Streambank stability.

and use change can decrease the stability of streambanks and therefore increase mass wasting and stream disturbance (Jacobson and Primm, 1997; Riedel et al., 2005). Streambank failures result in loss of land, increased stream sediment loads, and potentially increased nutrient loads. Excessive sediment is one of the most common surface water pollutants, diminishing water quality and aquatic habitat. Research has demonstrated that streambank erosion can contribute significantly to total sediment loading in streams (Simon and Darby, 1999; Sekely et al., 2002; Evans et al., 2006). In fact, sediment loads and streambank stability have been major concerns for decades, with billions of dollars spent on streambank stabilization (Lavendel, 2002; Bernhardt et al., 2005).

The Ozark ecoregion of Missouri, Arkansas, and Oklahoma is approximately 62,000 km² and is characterized by gravel bed streams that have migrated substantially over time, yielding many paleochannels throughout the ecoregion. Much of the streambank erosion is likely due to the land use changes that have occurred in the ecoregion over the last 200 years as forest and rangeland gave way to pasture and urban areas. These changes affected the hydrology of the region, including increased runoff and decreased riparian erosion resistance (Jacobson and Primm, 1997). The erosion of carbonate bedrock (primarily limestone) by slightly acidic water has left a large residuum of chert gravel in Ozark soils, with floodplains generally consisting of coarse, chert gravel overlain by a mantle (1 to 300 cm) of gravelly loam or silt loam (Heeren et al., 2010, 2011; Mittelstet et al., 2011). Processes of bank erosion include undercutting due to fluvial erosion of the gravel layer as well as geotechnical failure of the loam (Midgley et al., 2012).

Rapid geomorphic assessments (RGAs) provide a quick method for characterizing stream reaches, defined as lengths or segments of a stream with similar streambank characteristics in terms of bank height and stratigraphy, and their degree of stability (Simon and Downs, 1995). One of the most commonly used RGAs is the channel stability index (CSI). The CSI was originally designed for areas that are highly sensitive to erosion, such as bridges (Simon and Downs, 1995). The original CSI required measurements of bed material, bed/bank protection, stage of channel evolution model, percent of channel constriction, number of piers in the channel, percent of blockage, fluvial erosion, meander impact from the bridge, pier skew for each pier,
mass wasting evidence, high flow angle of approach, and percent of woody vegetation cover. When streambanks near bridges are not the subject of a study, the CSI can be modified to eliminate the bridge/pier related criteria (Simon and Klimetz, 2008). Scores from each metric are summed to create an aggregate score, with a higher score indicating greater instability. The aggregate score is used to categorize each stream reach in a stability category: ≤10 is considered stable, between 10 and 20 is considered moderately unstable, and ≥20 is considered highly unstable (Simon and Klimetz, 2008).

An alternative bank hazard index, the bank erosion hazard index (BEHI), has been proposed by Rosgen (1997, 1998, 2001). The BEHI combines several streambank metrics (bank height, bankfull height, root depth and density, surface protection, and bank angle) that indicate erosion by various mechanisms. The BEHI utilizes the concept of channel-forming discharge which, in a healthy stream system, should be related to average morphologic characteristics of the channel (e.g., channel cross-section and meander patterns). However, the Rosgen protocol requires combining BEHI with field observations of the erosion rate determined with at least three years of erosion pin data and a near-bank shear stress (NBSS) metric for a particular soil and geologic type (Rosgen, 2001; van Eps et al., 2004). Such a protocol limits applicability for the objective of rapidly identifying unstable reaches within a stream system.

The overall objective of this research was to conduct rapid assessments for several streambank reaches on Barren Fork and Spavinaw Creeks, located in the Ozark ecoregion of Oklahoma, to help the Oklahoma Conservation Commission determine the most beneficial locations to invest finite financial resources for streambank stabilization projects. The CSI RGA was performed to estimate current bank stability on several reaches at five stream sites following the procedure of Simon and Downs (1995). This RGA was then refined specifically for assessing stability on larger-order streams in the Ozark ecoregion of Oklahoma to determine if a more refined streambank indicator was more applicable to the ecoregion. Scores from the RGAs were corroborated using recent lateral channel migration estimated from a temporal sequence of five years of National Agricultural Imagery Program (NAIP) aerial photographs acquired at a 1 m spatial resolution.

**MATERIAL AND METHODOLOGY**

**SITE LOCATIONS AND STREAM FLOW STATISTICS**

Multiple stable and unstable reaches at five stream sites were assessed in northeastern Oklahoma (fig. 1). One site was located along Spavinaw Creek in Delaware County, and four sites were located along the Barren Fork Creek in Cherokee and Adair Counties. Both watersheds are characterized by cherty soils and gravel bed streams (Heeren et al., 2010, 2011; Mittelstet et al., 2011). Streambank soils are typically cherty silt loams underlain by unconsolidated gravel, and commonly become unstable when erosion of the gravel leads to streambank undercutting (Midgley et al., 2012). These gravel bed streams commonly consist of a critical, steep bank prone to failure on one side of the channel and an expansive gravel deposit on the opposite bank (fig. 2).

Both Barren Fork Creek, a tributary to the Illinois River, and Spavinaw Creek, a source stream for Lake Eucha, provide multiple beneficial uses, including recreation, wildlife habitat, drinking water, and aesthetic value. High streambank erosion and failure rates on these streams may be attributed to land use change and degradation of riparian areas (Jacobson and Primm, 1997; Midgley et al., 2012). The watersheds are characterized by karst topography consisting of low mountains, gently rolling upland hills, and deeply entrenched valleys. Current land use was similar between the two basins: 60% forest, 2% urban, and 38% pasture/rangeteland in Barren Fork Creek watershed, and 51% forest, 2% urban, and 47% pasture/rangeteland in Spavinaw Creek watershed. Primary agricultural practices include cattle grazing and poultry production with land application of litter.

Barren Fork Creek and Spavinaw Creek are fourth-order streams (Strahler, 1964) with historic stream flow rates given in table 1. Flow rates are important in a stream geomorphic assessment because the flow regime is closely related to the changing land forms in and around a stream (Lane, 1955; Dunne and Leopold, 1978). While the shape and dimensions of a stream channel adjust to the entire range of flows that a stream conveys over time, the channel-forming discharge can be used as a surrogate of the full range of flows (Biedenharn et al., 2008). Channel-forming discharge can be estimated by the 1.5-year recurrence interval flow (table 1) or the bankfull discharge (Rosgen, 1996; Biedenharn et al., 2008). Recurrence interval flows for these streams were calculated according to Haan et al. (1994) using the Weibull distribution.

Potential stream stabilization sites were selected by the Oklahoma Conservation Commission based on several factors, with the primary factor being the willingness of the landowner to enroll the riparian area in a long-term program using conservation practices, such as the Conservation Reserve Enhancement Program (CREP). At each site, the stream was divided into homogenous reaches based on visual observations of changes in streambank characteristics (i.e., bank height and stratigraphy). There was no minimum length requirement, and the reaches ranged between 20 and 260 m. Within each reach, a representative cross-section based on the average bank height and typical plant community cover at the top of the streambank was selected for streambank analysis. Both stable and unstable reaches were selected for analysis at all sites.

**CHANNEL STABILITY INDEX (CSI)**

As noted earlier, the Rosgen protocol requires combining BEHI with at least three years of field erosion rate data and a near-bank shear stress (NBSS) metric. Such a protocol limits applicability for the objective of rapidly identifying unstable reaches within a stream system. Therefore, CSI instead of BEHI was the focus of this research. CSI requires measuring the bank height, bank face length, river stage at baseflow, degree of constriction, and average diameter of streambed sediment (fig. 3)
A representative river stage was measured in the thalweg of the stream by placing rod on the streambed and recording the water surface height; care was taken to avoid local scour pools. The river channel width at the cross-section as well as approximately one-quarter of a meander length upstream was measured at the bankfull height. Degree of constriction was the relative decrease in channel width from upstream to downstream. To estimate the average diameter of streambed sediment (gravel, boulder/cobble, or bedrock), the grain size of the average particle from a sample of bed material was measured in the field. Occasionally the difference between gravel and boulder/cobble was split if the streambed particle size distribution contained a large portion of both gravel and cobbles.

Bed protection measured the risk of bed scour or incision. A score of 0 was given for a stream with bed protection (e.g., bedrock or armoring). If the stream had no bed protection, a score of 1 was assigned. If one bank was protected, an additional 2 points were added. If both banks were protected, an additional 3 points were added. As an example, a stream with no bed or bank protection scored 1 point, whereas a stream without bed protection but with both banks protected scored 4 points. A higher score was given for bank protection without bed protection because the energy that is not dissipated on the bank is transferred to the bed (Simon and Downs, 1995).

The degree of incision was calculated from the depth of incision...
water at baseflow ($D$) and the bank height ($BH$), defined as the ratio of the elevation of baseflow to the floodplain elevation, i.e., $D/(BH + D)$. Highly incised channels (low ratio) received a high metric score, and stable channels (high ratio) were scored low. Both banks were evaluated for evidence of fluvial erosion and mass wasting: 0 for no erosion, 1 for fluvial erosion, 2 for mass wasting, and 3 for both mass wasting and fluvial erosion. Scores for the left and right bank were then added together to provide an aggregate score of up to 6 points. Mass wasting evidence included slumping banks, fallen topsoil at the bottom of the bank, and jagged edges at the top of banks. In straight reaches, both banks possibly demonstrated one or more types of erosion, with mass wasting most common on the critical bank. The percentage of the bank that experienced mass wasting was estimated based on a percentage of total reach length.

Table 1. Historic stream flow statistics for potential stream stabilization sites in eastern Oklahoma and nearby U.S. Geological Survey gauge stations. Flows at the potential stream stabilization sites were extrapolated from calculated flows at the U.S. Geological Survey gauge stations based on drainage area.

<table>
<thead>
<tr>
<th>Drainage Area (km²)</th>
<th>Flow Record (years)</th>
<th>Mean Daily Flow (m³ s⁻¹) 1% 25% 50% 75% 99%</th>
<th>Annual Peak Flow (m³ s⁻¹) 1.5-year 2-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spavinaw Creek</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gauge near Sycamore</td>
<td>344</td>
<td>0.11</td>
<td>0.60</td>
</tr>
<tr>
<td>Site A</td>
<td>515</td>
<td>0.16</td>
<td>0.80</td>
</tr>
<tr>
<td>Barren Fork Creek</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gauge at Dutch Mills</td>
<td>106</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Gauge at Eldon</td>
<td>798</td>
<td>0.16</td>
<td>1.40</td>
</tr>
<tr>
<td>Site B</td>
<td>845</td>
<td>0.17</td>
<td>1.50</td>
</tr>
<tr>
<td>Site C</td>
<td>646</td>
<td>0.13</td>
<td>1.10</td>
</tr>
<tr>
<td>Site D</td>
<td>544</td>
<td>0.10</td>
<td>0.90</td>
</tr>
<tr>
<td>Site E</td>
<td>516</td>
<td>0.10</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Figure 3. Data sheet for compiling basic stream channel data and for completing the channel stability index (CSI).
Percentage of the bank reinforced by riparian vegetation was estimated for each bank, and then the two bank scores were added together. Typically, if the canopy of the woody vegetation stretched over the edge of the bank, it was considered to provide support. If woody vegetation was present but the canopy did not reach the streambank, it was not considered to provide support. The general rule of thumb followed was that the extent of roots was approximately equivalent to the canopy crown. Therefore, even though roots may not have been exposed, the presence of canopy above the stream was assumed to provide some geological support through any anticipated failure planes.

The percentage of each bank experiencing accretion (deposition) was estimated based on a percent of reach length that contained signs of accretion. Signs of accretion included gravel or other small sediment bars adjacent to the banks and point bars. Note that when evaluating outside bends, the inside bend was normally a point bar and was scored as depositional.

The reach was then assigned a stage in the channel evolution model using the six-stage model proposed by Simon and Klimetz (2008), which was a modified form of the five-stage channel evolution model developed by Schumm et al. (1984). Each stage had a different point value (Simon and Downs, 1995), with the stage assessed through observations of erosion, deposition, and the condition of riparian vegetation (Simon and Klimetz, 2008).

**Oklahoma Ozark Streambank Erosion Potential Index (OSEPI)**

The Oklahoma Ozark streambank erosion potential index (OSEPI) was developed by modifying CSI to produce an RGA specifically designed for larger-order streams in the area and to minimize the difficulty in determining some parameters and the quantity of materials needed to gather data (fig. 4). Many of the CSI parameters (primary bed material, degree of constriction, and stage of the channel evolution model) were homogeneous throughout the area and therefore were excluded from OSEPI. Similar to CSI, data were entered only for the critical bank (fig. 2). Metrics equivalent to or similar to those in CSI included the bank angle and the percentage of bank that showed evidence of mass wasting. In addition, the percentage of surface protection (bank covered in vegetation, roots, large logs, and boulders) and percentage of the bank with established beneficial woody-vegetative cover was included in OSEPI but given additional weight in the RGA. Field and numerical modeling research has also demonstrated that the addition of roots to streambanks improves stability under a range of hydrological conditions (Wynn et al., 2004; Wynn and Mostaghimi, 2006; Pollen, 2007). Trees straining the bank (overhanging) were not considered beneficial vegetation. It should be noted that there is subjective evaluation included in identifying beneficial vegetation (e.g., how much overhang is considered a strain). The definition of beneficial vegetation could depend on root system shape.
and size as well as lean of a tree; therefore, OSEPI users should carefully consider the impacts of these factors.

Additional metrics added to OSEPI included a specific indicator relative to bank height because bank height represents one factor in the driving force leading to geotechnical failure (Simon et al., 2000). Also included was a metric for the percentage of the bank height with an angle greater than 80° to account for banks with heterogeneous bank angles, which is typical for these Oklahoma Ozark streams (Midgley et al., 2012). Another new metric was an estimate of the percentage of the bank consisting of non-cohesive material. Ozark streambanks may be clean (unconsolidated) or packed with cohesive soil (consolidated). The final new metric was whether the reach was on a meander, shallow curve, or straight section of the stream, since additional boundary shear stresses occur on the outside of meander bends (Crosato, 2007; Papanicolaou et al., 2007).

**Lateral Bank Erosion**

Assuming that future erosion potential is related to recent erodibility, lateral bank erosion for each specific reach during a five-year period was quantified with National Agricultural Imagery Program (NAIP) aerial photographs, acquired at 1 m spatial resolution, to corroborate the scores from both RGAs (fig. 5). It is acknowledged that estimated lateral bank retreat using aerial photography is not as accurate (maximum error estimate of 3 m based on aerial image georeferencing and identification of bank locations due to shading) as actually measuring bank retreat in situ using repeated cross-section surveys, erosion pins, terrestrial photogrammetry, and/or photo-electronic erosion pins (Lawler et al., 1997). However, this information represents the source of bank retreat data most likely to be available for similar studies. The spatial resolution was of sufficient quality to evaluate the RGAs scores.

Using aerial photography to measure lateral channel migration is most appropriate in larger-order streams that are
actively migrating (Pizzuto and Mecklenburg, 1989; EPA, 2011), as are many of the streams in the Oklahoma Ozarks (Harmel et al., 1999a). Jacobson and Primm (1997) illustrated stream channel instability with aerial images of the Ozarks from 1939 to 1993. Researchers would have to rely on other bank erosion measurements, such as bank pins, to detect erosion in heavily forested regions. However, knowing which RGA works best in a specific ecoregion may alleviate the need to measure bank erosion rates to assess current bank stability.

NAIP aerial photographs from 2003 were compared with images from 2008 in ESRI ArcGIS to calculate the quantity of streambank erosion for each reach. Images from 2010 were not yet available at the completion of the study. A polyline was drawn at the streambank profile in 2008, and this polyline was then overlaid onto the 2003 image. A polygon was then drawn showing the difference in the banks from 2003 and 2008 (fig. 5). This area was then calculated and divided by the reach length to estimate lateral bank retreat (m).

Using recent erosion data to evaluate current erosion potential adds an additional source of uncertainty to the analysis. One implicit assumption within this procedure is that RGAs conducted in 2010 at a single time are representative of streambank conditions throughout the 2003 to 2008 study period. Even if the RGAs were performed in 2010 and then future erosion was estimated, uncertainty would still exist in the analysis because an index at a specific moment in time may not adequately represent the most prevalent long-term conditions. Streambank migration is evolutionary and can result in shifts in stability as fluvial erosion undercuts the gravel layers on these streambanks, leading to geotechnical failure of the overlying topsoil (Midgley et al., 2012). No significant land use changes (i.e., installation of riparian buffers) occurred at these sites between 2003 and 2010 that might alter the bank’s future susceptibility to erosion.

Linear regression analysis was performed between the lateral streambank retreat and the composite scores from CSI and OSEPI. Statistical significance of the relationship was assessed through ANOVA, assuming that a p-value less than 0.05 indicated that the composite score from the RGA was corroborated by the lateral bank retreat data. Correlation coefficients were also derived between the individual metrics of each RGA and the estimated lateral bank retreat.

It should also be noted that this research is not suggest-
ing that scores from the RGAs alone should be used to predict future erosion rates. The aim of this research was to assess current stability. In practice, CSI is not used to predict future erosion rates; instead, unstable reaches identified by CSI are further evaluated with bank stability models under various flow scenarios (Simon et al., 2000; Rinaldi et al., 2008; Midgley et al., 2012). Streambank stability models are commonly utilized to investigate the primary mechanisms of bank instability and propose strategies for stabilizing streambanks. One of the most commonly used and most advanced streambank stability models is the Bank Stability and Toe Erosion Model, (BSTEM; Simon et al., 2000). BSTEM consists of two different components: a bank stability module and a toe erosion module. BSTEM has been frequently used to simulate bank stability and lateral retreat for estimating stream sediment loading (Simon et al., 2009), stream rehabilitation projects (Lindow et al., 2009), and research on streambank erosion and failure mechanisms (Cancienne et al., 2008).

RESULTS AND DISCUSSION

One key component of the project was to rank potential reaches for streambank stabilization for the Oklahoma Conservation Commission. Therefore, the scores for the RGAs were used to classify the stability of the banks (table 2). Box and whisker plots of metric scores within CSI and OSEPI are shown in figure 6. CSI scores suggested that all the reaches were moderately unstable (table 2). CSI scores for at least one reach at all the sites were at the upper end of the “moderately stable” classification. Interestingly, all of these reaches experienced significant bank retreat (>9 m) between 2003 and 2008, except for the reach at site C, which is discussed below.

CSI scores among the reaches analyzed were more confined than OSEPI, making differentiation more difficult (fig. 7). Metrics in CSI with the highest correlation to lateral retreat included streambank instability (percentage of each bank failing by mass wasting) and the percentage of established riparian woody-vegetative cover (table 3). It was interesting to note that the streambank instability metric (equivalent to evidence of recent mass wasting in OSEPI) had a correlation coefficient (R) of 0.60 and a coefficient of determination (R²) of 0.37, which is greater than the R² value for any of the aggregate scores for the RGAs (fig. 8). Long-term bank retreat may be better characterized by metrics indicating frequency of bank failures than by metrics indicating geotechnical instability at a single point in time.

OSEPI had nine of the ten most unstable reaches in common with CSI (table 2). As expected due to the use of...
similar metrics, relationships were observed between OSEPI and CSI based on all 23 reaches with an $R^2$ of 0.64 (fig. 7). OSEPI also included similar metrics with the highest correlation coefficients to five-year lateral retreat, including evidence of recent mass wasting and established riparian woody-vegetative cover (table 3).

During the five-year period, the measured lateral retreat ranged from 0 to 55 m (table 2) at the 23 studied reaches. The $R^2$ values between lateral retreat and the RGAs were typical based on previously reported studies for this area (fig. 8). The p-values for both RGAs were less than 0.05 (fig. 8). In previous work investigating streambank erosion in the Illinois River watershed, located in northeast Oklahoma and northwest Arkansas, Harmel et al. (1999b) tested three components of the Rosgen level III stream reach con-

![Figure 6. Box and whisker plots of the scores from each metric of the different rapid geomorphic assessments: (a) CSI = channel stability index and (b) OSEPI = Oklahoma Ozark streambank erosion potential index. The line within the box marks the median, boundaries of the box represent the 25th and 75th percentiles, whiskers (error bars) to each side of the box indicate the 90th and 10th percentiles, and circles represent outliers. Note that parts of the plots are not drawn when unable to compute a percentile point or when percentile points are equivalent.](image)

![Figure 7. Correlations between the two rapid geomorphic assessments used for assessing streambank stability in the Ozark ecoregion of eastern Oklahoma. CSI = channel stability index, and OSEPI = Oklahoma Ozark streambank erosion potential index.](image)
dition assessment for their ability to predict short-term erosion rates (Rosgen, 1998). When integrated, the bank erosion potential (BEP), a precursor to BEHI, and NBSS estimates, which attempt to account for fluvial stresses on the bank, were poor predictors of bank erosion. Harmel et al. (1999b) reported an $R^2$ of 0.16 for the BEP score and an $R^2$ of 0.17 for the Pfankuch score. Simpler RGAs that require 30 min to complete performed equivalently or even better when compared to indices that require three years of bank erosion pin data (Harmel et al., 1999b). Erosion rates were consistent with historical accounts of the Ozark streams where gravel filled in many of the deep pools, thereby changing the channel morphology and converting the stream energy from the streambed to the streambank. Jacobson and Primm (1997) also found that changes in upland runoff can alter the shear stresses applied to the riparian zone, and the removal of riparian vegetation decreases the total shear strength of the streambanks.

Note that in figure 8 there is a point with 55 m of bank retreat that appears as an outlier within these data. However, there is no physical explanation available to support removal of this outlier from consideration. While the RGAs are limited in their range of scores, the potential bank erosion rates are not limited. The linear relationships between the RGAs and lateral streambank retreat underpredicted erosion at site B and overpredicted erosion at site C. The RGAs performed best at sites A, D, and E, which consisted of similar streambank soils and layering (table 2). Reaches 3 and 4 at site C were ranked as moderately unstable by both CSI and OSEPI due to their 5 to 8 m bank heights, yet little erosion actually occurred during the five-year period (table 2). This was likely due to the banks being composed of highly cohesive materials consisting of consolidated loam and gravel, uncharacteristic of most observed reaches within the watersheds. While OSEPI utilized a metric for percentage of non-cohesive material, bank stability at this location was driven primarily by the unusually high cohesiveness compared to other metrics. A detailed bank stability model would account for this, but RGAs by definition are not intended to accurately evaluate every possible scenario. When removing the site C transects with high cohesive streambank material, the $R^2$ value between the RGAs and lateral bank retreat increased, especially for OSEPI, to $R^2 = 0.45$. In addition, the p-value decreased to 0.002 for OSEPI.

The underprediction of erosion at reaches 2 and 3 of site B was likely due to significant gravel bar migration at these reaches during the period and the result of conducting the RGAs at the end of the observation period of estimated lateral bank retreat. These two reaches provided further evidence that a simple one-time RGA cannot account for every variable in a complex stream system, but the RGAs did appropriately identify a number of reaches to be further evaluated for stabilization.

Shields et al. (2008) cautioned that some degree of sedimentation analysis is necessary for any streambank stabilization project. RGAs provide only an indirect and largely qualitative measure of sediment availability and transport. Furthermore, no RGAs consider the likelihood of avulsion in these gravel-dominated streams, which has been observed in the ecoregion (Jacobson and Gran, 1999). A stabilization project may be of little benefit if the stream changes its course after construction. Therefore, RGAs may not be specific enough to identify certain sedimentation problems or avulsion; however, they were designed to serve as rapid assessments that quickly identify reaches that should be evaluated in more detail. Additional evaluation should be devoted to the five to eight reaches that were identified by the RGAs and corroborated by the lateral retreat data from aerial photography as being the most unstable.
It should be noted that the metrics of CSI had the same weight or range of values relative to each other. While there is latitude relative to the range of each metric that corresponds to a given score, the worst (and best case) is valued equally for all categories. As discussed earlier, lower scores are intended to correspond to greater stability. For this process to function appropriately, at least one of two conditions must be met: (1) each metric must contribute equally to stability, or (2) the RGA must be applied in regions where the sources of instability from reach to reach are similar. We can easily accept that the former cannot be universally true. So the latter must be true, and the assumption can be verified. Because of this, RGA scores from different regions are not necessarily comparable.

**SUMMARY AND CONCLUSIONS**

Two RGAs, the channel stability index (CSI) and the newly developed Oklahoma Ozark streambank erosion potential index (OSEPI), were used to assess potential stream stabilization reaches in the Ozark ecoregion of Oklahoma. OSEPI was proposed specifically for the Ozark ecoregion and did not include variables that were relatively homogeneous throughout the region (e.g., streamed material and degree of constriction). Note that stage of the channel evolution model may be required in future applications of OSEPI when assessing streambanks across a range of stream orders. Therefore, OSEPI should not be used outside of this region without further testing. Twenty-three reaches at five sites were assessed and ranked according to each RGA to assess current streambank stability and aid in reach selection for streambank stabilization projects. Both RGAs met their intended purpose; they provided relatively simple, inexpensive, and quick ways to identify reaches that should be further evaluated for instability. The RGA scores from the CSI and OSEPI produced relatively poor relationships with recent lateral bank retreat estimates from aerial photography for all surveyed reaches, with R² of 0.21 and 0.29, respectively. Removing reaches unique in streambank soil type and stratification increased the R² value to near 0.45 for OSEPI. In general, OSEPI had the better correlation to streambank retreat, achieved a broader range of scores, and did not include variables that were relatively homogenous throughout the channel evo-

**ACKNOWLEDGEMENTS**

The authors acknowledge the Oklahoma Conservation Commission for their generous funding and support. The authors also acknowledge Tim Driskill, Dale Turn, Sam Chandler, David Fitzgerald, and Dan Butler for providing access to the alluvial floodplain properties.

**REFERENCES**


