PRIORITY SITE RANKING FOR CRITICAL EROSION SITES ON THE SACRAMENTO RIVER FLOOD CONTROL LEVEES USING MULTIPLE RANKING METHODOLOGIES

January 16, 2006

Sacramento River Bank Protection Project, California
Contract No. DACW05-02-D-0002, Delivery Order 0009

Prepared For:

U.S. ARMY CORPS OF ENGINEERS
Sacramento District
1325 J Street
Sacramento CA 95814-2922

AYRES ASSOCIATES

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Ayres Associates Project Number: 32-0530.10

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1.0 Introduction and Background

Each calendar year, personnel from the U.S. Army Corps of Engineers (Corps), Sacramento District, and their local sponsor, the California Department of Water Resources (DWR), conduct a field reconnaissance review of the Sacramento River Flood Control System. Since 1997, Ayres Associates has assisted the Corps and their local sponsors with this annual review and inventory of erosion sites. **Figure 1** shows the overall extent of waterways in this field review.

As part of the review, erosion sites are inventoried and any observed changed conditions noted. An annual report is published that includes all of the notes from each review along with a listing of all erosion sites reviewed and those designated as "critical" erosion sites. The designation of "critical" was given to sites where further erosion would encroach near or into the levee crown and may result in a bank failure. These sites were recommended as the highest priority for repair. This designation was based on visual observations in the field and the judgment of the review team. No technical analyses were performed as backup for the ranking in the previous report.

As a part of the 2004 field reconnaissance scope of work, Ayres Associates was tasked to develop a more objective, technically based ranking methodology for further evaluating the erosion sites that were in the critical and potentially critical categories. Based on the ranking methodology, a site priority list was to be developed.

Based on the 2004 inventory, there are 185 eroding sites, with 40 classified as critical or potentially critical. Given this large number of sites, it is not economically feasible to fix all of them in the immediate future. This report points out the highest priority sites, and ranks the sites based on the methodologies described further in this report.

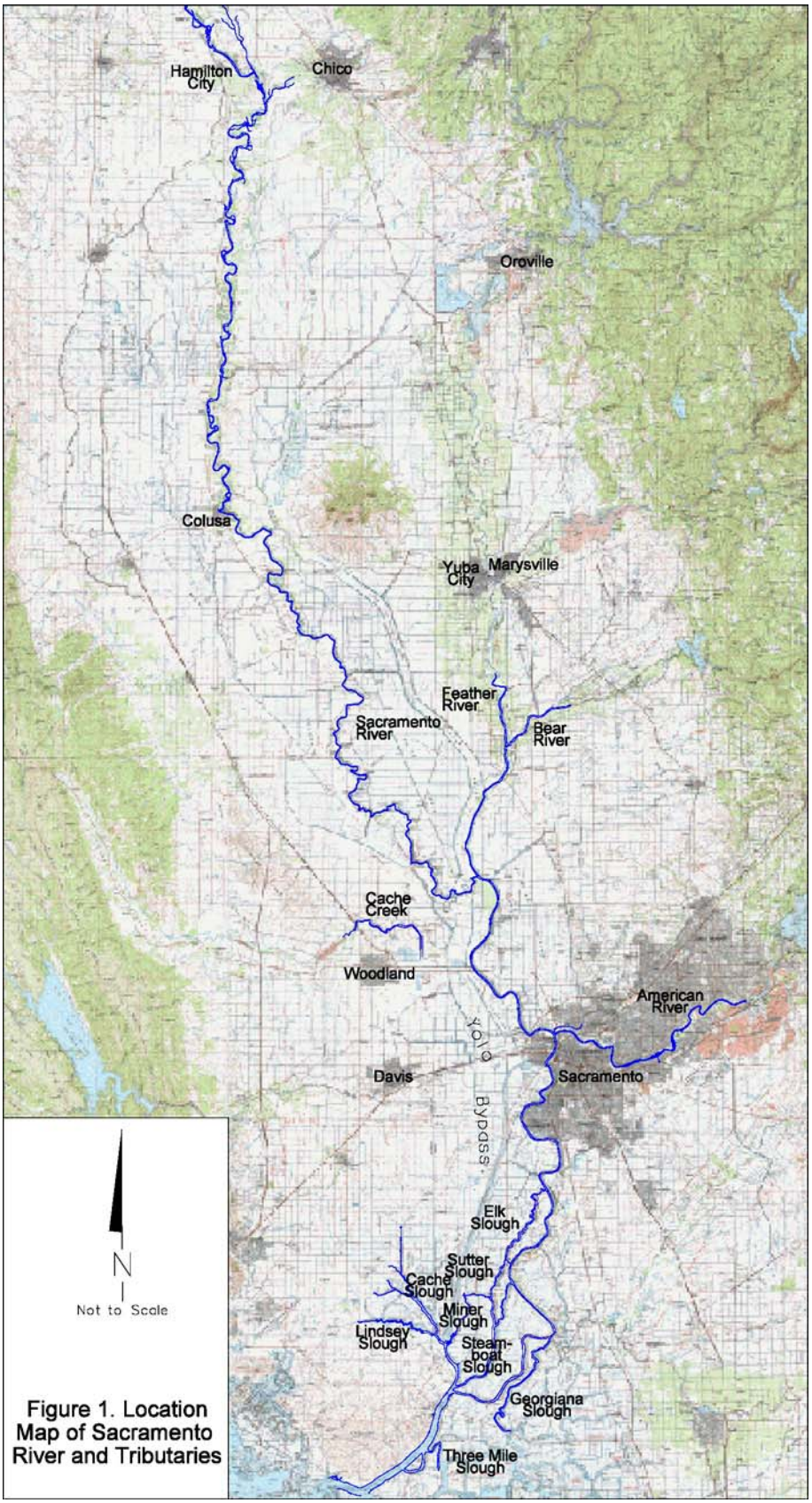

Figure 1. Location Map of Sacramento River and Tributaries

2.0 Field Reconnaissance Inventory Project Area

The following list of rivers and sloughs make up the coverage for the annual reconnaissance inventory and are all part of the Sacramento River Flood Control System and are also shown in Figure 1.

- Sacramento River, RM 4 (Collinsville) to RM 199 (Chico Landing)
- Bear River
- Cache Creek
- Cache Slough
- Elk Slough
- Feather River, RM 0 to RM 25
- Georgiana Slough
- Lindsey Slough (portions)
- Lower American River
- Miner Slough
- Steamboat Slough
- Sutter Slough
- Threemile Slough

3.0 Project Authorization and Scope

This scope was authorized by the U.S. Army Corps of Engineers (USACE) under contract number DACW05-02-D-0002, Delivery Order 0009, dated July 21, 2004. The point of contact at USACE is Mr. Richard Torbic, P.E., in the Engineering Division, Civil Design Section. The project manager for Ayres Associates Inc is Mr. Thomas Smith, PE, GE.

The project scope required the development of a ranking methodology that could be used to assist in the establishment of a priority list of which critical sites should be fixed first. Surveyed levee cross sections were to be provided as a part of the back up data. As of the date of this report, the surveys have not been completed.

The final determination on which sites to rank was developed jointly by USACE personnel and Ayres. The final list included 34 sites, 29 sites on the Sacramento River, 2 on Cache Slough, 1 on Elk Sough, 1 on Sutter Slough, and 1 on Georgiana Slough. The specific sites are listed below:

Sacramento River				
8L	42.8R	85.6R	154.5R	Cache Slough
10.8L	43.3R	96.2L	164R	21.2R
22.7L	55.8R	99.3R		21.8R
26L	56.7L	99.5R	Elk Slough	
26.1R	69.9R	123.5L	0.7	Georgiana Slough
26.5L	71.7R	125.8L		10.3L
26.9L	72.2R	130L	Sutter Slough	
32.5R	73R	130.8R	25.1R	
34.5R	78L	141.4R		

4.0 Ranking Methodologies

4.1 Discussion of Reviewed Methodologies

Four different methodologies were reviewed in the development of the site priority lists. The methodologies differ in the number of physical factors considered and some include economic considerations of the damage due to a levee failure. The methodologies are listed below. Detailed descriptions are provided in the following sections.

- Methodology 1: 16 Physical Factors with One Economic Factor
- Methodology 2: 10 Physical Factors and no Economic Factor
- Methodology 3: 5 Physical Factors with Revised Economic Factor
- Methodology 4: 5 Physical Factors and no Economic Factor

4.2 Methodology 1: 16 Physical Factors and One Economic Factor

Methodology 1 was the first attempted at ranking erosion potential at each site and takes into account a total of 17 different factors. These factors are as listed below:

- Bank Slope
- Berm Width
- Length of Erosion
- Location of Erosion
- Bank Stability
- Rc/W
- Site Relative to Bend
- Geomorphologic Processes
- Vegetative Cover
- Tree Hazard
- Soil Type
- Velocity
- Wave Action (Wind/Boat)
- Economic Factor
- Human Usage
- Seepage Potential
- Tidal Fluctuation

The definitions for the rating factors included in Methodology 1 are follows:

Bank Slope – The bank slope is the horizontal to vertical ratio of the eroding slope. (Estimated since actual cross sections were not completed at the time of this report.)

Berm Width – The berm width is the horizontal segment of the bank that extends from the levee toe to the top of the riverbank. (Estimated since actual cross sections were not completed at the time of this report.)

Length of Erosion Site – The length of erosion is the full length along the river over which the erosion occurs.

Location of Erosion – The location of the erosion is the position in the vertical direction where the erosion occurs, the lower on the slope, the greater the potential for failure.

Bank Stability – The bank stability criterion identifies any observed instabilities in the bank, such as near vertical slopes and animal caves.

Rc/W- This factor is the radius of the meander bend divided by the top width length at bank full.

Site Relative to Bend – This factor relates to where within a mender bend an erosion site is located.

Geomorphologic Processes – This criterion takes into account the active erosion and deposition patterns of the channel.

Vegetative Cover – This criterion relates to how much vegetation exists on the site and its role in providing erosion protection.

Tree Hazard – While vegetation can be helpful, large trees can put excessive weight on banks and can result in failures, therefore the older and larger trees result in a higher stability hazard.

Soil Type – Based on the Unified Soil Classification System.

Velocity – The velocity for the Sacramento River sites has been obtained from the existing UNET hydraulic model using the 100-yr discharge, where available. For other sites not in the UNET model, computing velocity from a normal depth determination may be adequate.

Wave Action – The wave action accounts for natural (wind) and unnatural (boats) waves that impact the banks.

Economic Factor – This economic factor is based primarily on the estimated population within the potential inundation areas.

Human Usage - The human usage criterion takes into account how much the site is used by humans and accounts for site damage from such usage.

Seepage Potential – The seepage potential takes into account any documented history of seepage.

Tidal Fluctuation – Reaches of the river that are affected by tides have a lower bank zone that is usually devoid of vegetation and more susceptible to erosion.

Each factor can score from 0 points to 5 points, with the exception of velocity, which can score up to 6 points. Five of the most significant factors relating to erosion (bank slope, berm width, soil type, velocity, and economics) are weighted by a factor of 2. The scores are summed resulting in a total in the range of 0 to 107, with 0 meaning no erosion hazard and 107 being the greatest potential erosion hazard. The values and corresponding score definitions are provided in **Figure 2**.

Criteria	Score Definition
Bank Slope (*2)	0 - 3:1 or Greater Slope; 1 - 2.5:1 Slope; 2 - 2:1 Slope; 3 - 1.5:1 Slope; 4 - 1:1 or Less Slope; 5 - Vertical Slope
Berm Width (*2)	0 - Berm Width of 30 ft or Greater; 1 - 20 to 29 ft of Berm; 2 - 10 to 19 ft of Berm; 3 - 5 to 9 ft of Berm; 4 - 1 to 4 ft of Berm; 5 - No Berm Width
Length of erosion	0 - Less than 10 ft; 1 - 10ft to 100ft; 2 - 101ft to 500ft; 3 - 501ft to 1000ft; 4 - 1001ft to 1500ft; 5 - Greater than 1500 ft
Location of erosion	0 - Upper Bank; 1 - Middle Bank; 2 - Lower Bank; 3 - Toe; 4 - Toe and Bank; 5 - Toe and Underwater
Bank Stability	0 - No Vertical Sections or Caves; 1 - Beaver Burrows at Toe (1 to 4 ft in length); 2 - Vertical Slope Sections (less than half the slope height); 3 - Beaver Burrows at Toe (greater than 4 ft); 4 - Vertical Slope Sections (greater than half the slope height); 5 - Both Vertical Sections and Beaver Burrows
Radius of Curvature (R_c/w)	0 - Greater than 5 or No Curve; 1 - 4 to 5 Range; 2 - 3 to 4 Range; 3 - Less than 3; 4 - 2 to 1 Range; 5 - Less than 1
Site Relative to Bend	0 - Inside of Bend; 1 - Straight Reach; 2 -Just Downstream of a Bend; 3 - Outside of Bend (greater than 90 degrees interior angle); 4 - Outside of Bend (90 degree turn); 5 - Outside of Tight Bend (less than 90 degree interior angle)
Geomorph	0 - No Channel Migration Expected; 2 - Channel Migration Potential on one side, opposite bank; 3 - Channel Migration Potential on one side, erosion side; 5 - Channel Migration Potential on both sides
Vegetation Cover	0 - Dense vegetation (100 - 80% cover); 1 - Medium to Dense Vegetation (80 - 60% cover); 2 - Medium Vegetation (60 - 40% cover); 3 - Slight to Medium Vegetation (40 - 20% cover); 4 - Slight Vegetation (up to 20% cover); 5 - No vegetation
Tree Hazard	0 - No or Small Trees; 1 - Young Trees (with potential to be large); 2 - Medium Trees; 3 - Large Trees; 4 - Trees with Visible Roots; 5 - Trees wth Visible Roots and Leaning
Soil Type (*2)	0 - Cemented Soils; 1 - All Clays; 2 - Clays and Silts; 3 - Sands; 4 - Silty Sands; 5 - All Silt
Velocity (*2)	0 - Less than 2.0 ft/s during high flow event; 1 - 2.0 to 4.0 ft/s; 2 - 4.0 to 4.5 ft/s; 3 - 4.5 to 5.0 ft/s; 4 - 5.0 - 6.0 ft/s; 5 - Greater than 6 ft/s **(If eddy currents are observed, add an additional point)**
Wave Action (Wind/Boat)	0 - Calm Water; 1 - Occassional Wave ; 2 - Low Wave Action; 3 - Moderate Wave Action; 4 - Heavy Wave Action; 5 - Heavy Wave Action with Cargo Ships passing through
Economic Factor (*2)	0 - Parks/No Habitable Structures; 1 - Farms; 2 - Small Town (100+ population); 3 - Rural (5,000+ population); 4 - Suburban (20,000+ population); 5 - Major Metropolitan (100,000+ population)
Human Useage	0 - No or Rare Usage; 1 - Occasional Usage; 2 - Seasonal Usage; 3 - Monthly Usage; 4 - Weekly Usage ; 5 - Daily Usage
Seepage Potential	0 - No Seepage History; 5 - Seepage History
Tidal Fluctuation	0 - Not tide, upstream of RM 80; 1 - Between RM 60 and RM 80; 2 -Between RM 45 and RM 60; 3 - Between RM 30 and RM 45; 4 - Between RM 15 and RM 30 ; 5 - Between RM 0 and RM 15

Figure 2. Score Sheet for Methodology 1.

4.3 Methodology 2: 10 Physical Factors and no Economic Factor

This methodology uses the previously discussed methodology but removes selected physical based factors and any economic considerations based on review comments received from California DWR on the Ayres Associates' draft ranking methodology report (Ayres Associates, December 15, 2004). The factors that make up Methodology 2 are:

- Bank Slope
- Berm Width
- Location of Erosion
- Bank Stability
- Site Relative to Bend
- Vegetation Cover
- Tree Hazard
- Soil Type
- Velocity
- Human Usage

The definitions for the factors are the same as described in Section 4.2 and the scoring is as shown in **Figure 3**.

The general reasoning given for the removal of the seven factors was as follows: The economic factor was removed because it was not a physical criteria for determining severity. While economics may be a factor in allocation of funding, DWR thought it should not be included when deciding severity. The wave action, tidal fluctuation, and geomorphology were removed since they tend to be reach-specific factors. Length of erosion was removed as it was felt that length did not contribute to failure risk. Radius of curvature was removed since it was believe the site relative to bank would be more useful for erosion and that it was a double count. Seepage potential was removed since it could be considered in the bank stability and the method of assessing seepage history may require extensive levee boring work.

4.4 Methodology 3: 5 Physical Factors with Revised Economic Factor

After further reviews and comments, the initial ranking was revised to utilize the minimum number of factors. The purpose of this revised methodology was to emphasize the major causes of failure in the Sacramento River Levee System and to place increased emphasis on the economic value of the areas protected by these levees.

Methodology 3 takes into account a total of 6 ranking factors for every site. The criteria used to classify and score the erosion hazard at each site are as follows:

- Bank Slope
- Berm Width
- Soil Type
- Velocity
- Bank Stability
- Economic Factor

Criteria	Score Definition
Bank Slope (*2)	0 - 3:1 or Greater Slope; 1 - 2.5:1 Slope; 2 - 2:1 Slope; 3 - 1.5:1 Slope; 4 - 1:1 or Less Slope; 5 - Vertical Slope
Berm Width (*2)	0 - Berm Width of 30 ft or Greater; 1 - 20 to 29 ft of Berm; 2 - 10 to 19 ft of Berm; 3 - 5 to 9 ft of Berm; 4 - 1 to 4 ft of Berm; 5 - No Berm Width
Location of erosion	0 - Upper Bank; 1 - Middle Bank; 2 - Lower Bank; 3 - Toe; 4 - Toe and Bank; 5 - Toe and Underwater
Bank Stability	0 - No Vertical Sections or Caves; 1 - Beaver Burrows at Toe (1 to 4 ft in length); 2 - Vertical Slope Sections (less than half the slope height); 3 - Beaver Burrows at Toe (greater than 4 ft); 4 - Vertical Slope Sections (greater than half the slope height); 5 - Both Vertical Sections and Beaver Burrows
Site Relative to Bend	0 - Inside of Bend; 1 - Straight Reach; 2 -Just Downstream of a Bend; 3 - Outside of Bend (greater than 90 degrees interior angle); 4 - Outside of Bend (90 degree turn); 5 - Outside of Tight Bend (less than 90 degree interior angle)
Vegetation Cover	0 - Dense vegetation (100 - 80% cover); 1 - Medium to Dense Vegetation (80 - 60% cover); 2 - Medium Vegetation (60 - 40% cover); 3 - Slight to Medium Vegetation (40 - 20% cover); 4 - Slight Vegetation (up to 20% cover); 5 - No vegetation
Tree Hazard	0 - No or Small Trees; 1 - Young Trees (with potential to be large); 2 - Medium Trees; 3 - Large Trees; 4 - Trees with Visible Roots; 5 - Trees wth Visible Roots and Leaning
Soil Type (*2)	0 - Cemented Soils; 1 - All Clays; 2 - Clays and Silts; 3 - Sands; 4 - Silty Sands; 5 - All Silt
Velocity (*2)	0 - Less than 2.0 ft/s during high flow event; 1 - 2.0 to 4.0 ft/s; 2 - 4.0 to 4.5 ft/s; 3 - 4.5 to 5.0 ft/s; 4 - 5.0 - 6.0 ft/s; 5 - Greater than 6 ft/s **(If eddy currents are observed, add an additional point)**
Human Useage	0 - No or Rare Usage; 1 - Occasional Usage; 2 - Seasonal Usage; 3 - Monthly Usage; 4 - Weekly Usage ; 5 - Daily Usage

Figure 3. Score Sheet for Methodology 2

The definitions for these ranking criteria are as follows:

Bank Slope – The bank slope is the horizontal to vertical ratio of the eroding slope.

Berm Width – Measured from the toe of the levee slope to the top of the riverbank.

Soil Type – Classified using the Uniform Soil Classification System.

Velocity – The velocity for the Sacramento River sites has been obtained from the USACE's existing UNET hydraulic model using the 100-yr discharge, where available. The velocity score is based on the 100-yr event, which might not be the most damaging event on the banks and levees. The 10-yr event and a bankfull event should be looked at also. The event that causes the greatest velocities on the banks should be used.

Bank Stability – The bank stability criterion accounts for observed instabilities in the exposed riverbank and levee. The instabilities are tension cracks, slumping, tree hazard, beaver holes or caves, and seepage history.

Economic Factor – The economic factor is difficult to rate and will likely be highly debated. The ranking system for Methodology 3 is based on an estimated cost of damage, so a flood occurring in a large area will be more expensive than a flood in a smaller area. Land use is also important to consider since a square mile of urban area will be more costly than a square mile of agriculture. The ranking was established by first dividing the entire Sacramento River basin into potential flooded areas, based on if a levee failure occurs what land would be flooded. The basin was divided into 26 sub-basins; these sub-basins are shown in **Figures 4** and **5**, with the name and area displayed. A land use weighted factor was developed based on the percentage of each land use. The land uses in the Sacramento Valley are primarily urban and agricultural (annual crops and orchards). Since the cost of rebuilding is different for these land uses, the urban areas were weighted at 10 times that of annual crops. The orchards were ranked as twice the value of annual crops. The weighted factor was then multiplied by the area of the overbank to establish a ranking order. **Table 1** shows the sub-basins, their size, percent of each land use, the weighted factor, and the final ranking score.

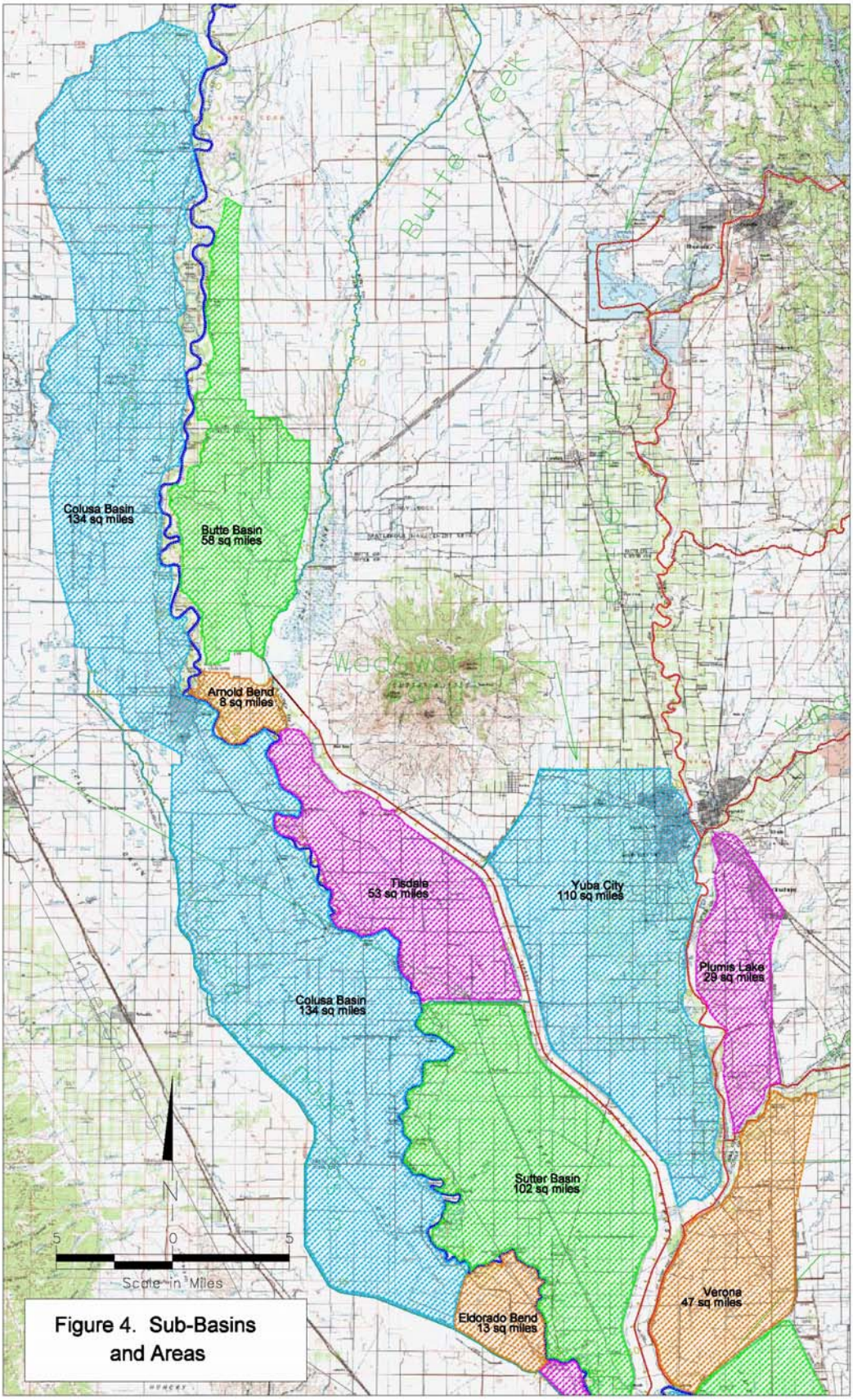

Figure 4. Sub-Basins and Areas

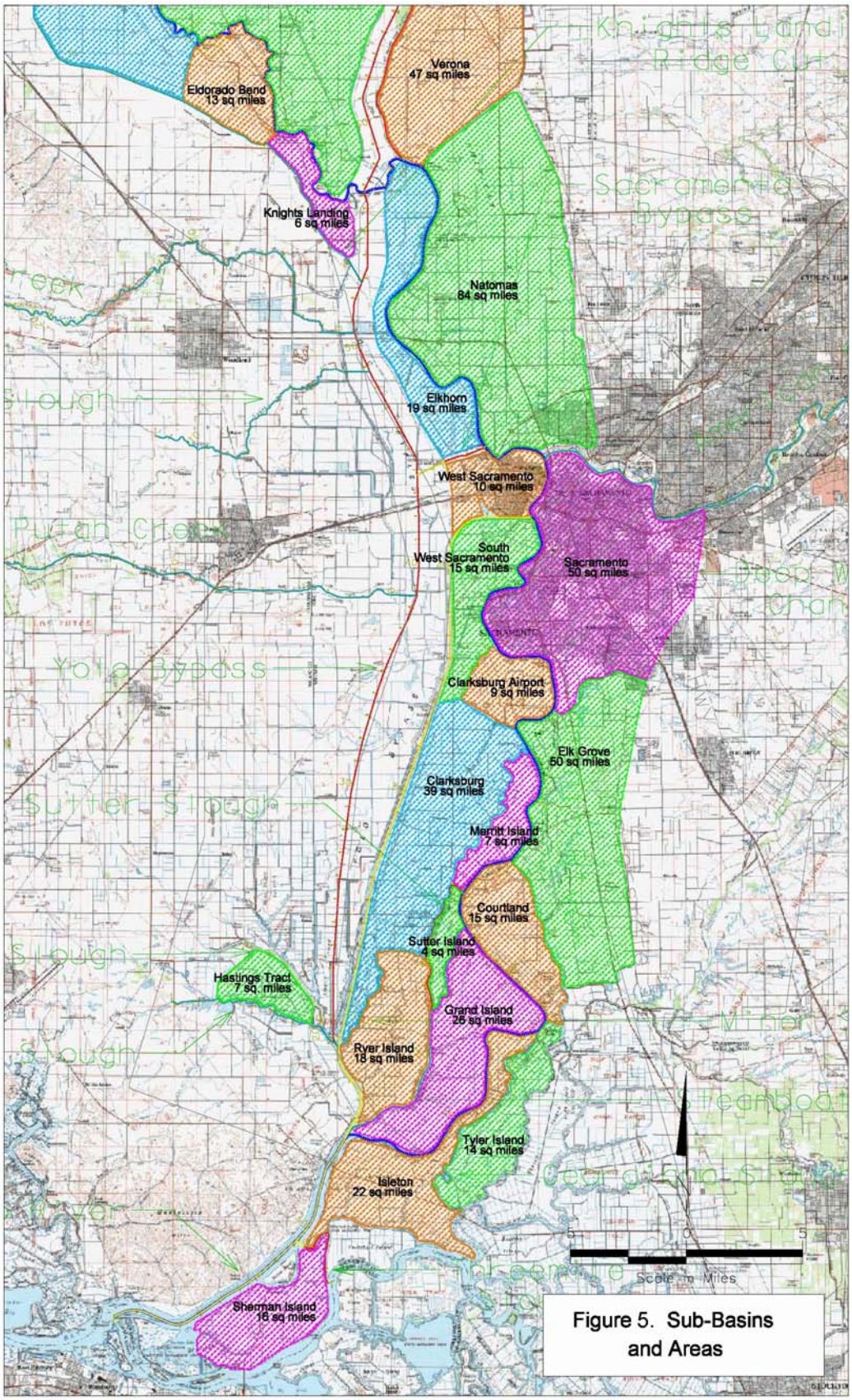

Figure 5. Sub-Basins and Areas

Table 1. Ranking for Revised Economic Factor

Overbank Name	Area (miles^2)	% urban	% agriculture (orchards)	% agriculture (crops)	Land Use weighted factor	Score	Ranking Factor
Sherman Island	16	0	0	100	1	16	4
Isleton	22	5	5	90	1.5	33	7
Tyler Island/ Walnut Grove	14	5	5	90	1.5	21	5
Grand Island/ Walnut Grove	26	5	10	85	1.55	40	8
Ryer Island	18	0	0	100	1	18	4
Sutter Island	4	0	30	70	1.3	5	1
Courtland	15	5	10	85	1.55	23	6
Merritt Island	7	0	10	90	1.1	8	1
Clarksburg	39	10	5	85	1.95	76	12
Elk Grove	50	35	5	60	4.2	210	16
Clarksburg Airport	9	5	0	95	1.45	13	3
South West Sacramento	15	40	5	55	4.65	70	11
West Sacramento	10	90	0	10	9.1	91	13
Sacramento	60	95	0	5	9.55	573	20
Natomas	84	45	0	55	5.05	424	18
Elkhorn	19	0	20	80	1.2	23	6
Verona	47	5	0	95	1.45	68	10
Knights Landing	6	10	0	90	1.9	11	2
Sutter Basin	102	0	0	100	1	102	14
Eldorado Bend	13	0	0	100	1	13	3
Colusa Basin	300	5	5	90	1.5	450	19
Tisdale	53	0	10	90	1.1	58	9
Arnold Bend	8	0	10	90	1.1	9	1
Butte Basin	58	5	10	85	1.55	90	13
Yuba City	110	15	40	45	2.75	303	17
Plumas Lake	29	35	40	25	4.55	132	15
Hastings Tract	7	0	0	100	1	7	1

The proposed rating system presented here can result in a range of values from 0 to 48, with 0 meaning no erosion hazard and 48 being the greatest possible erosion hazard. The sites with the highest erosion hazard score should be the highest priority for repair.

The factors are not all equally weighted. For instance, since the economics of a failure which depends on the size and land use surrounding the Sacramento River can vary so greatly, it has a higher score range than the other values. The velocity and bank stability factors have a maximum score of one point higher than the remaining factors. The velocity score can be increased if eddies are present, since in addition the potential erosion the velocity can cause, the eddy will intensify its effect. For the bank stability factor, the score is raised if you have a combination of seepage or slumping and additional stability issues.

All factors are evaluated at each site and given a ranking score based on the definitions provided in **Figure 6**. The values for each site are combined arithmetically and summarized on a score sheet.

4.5 Methodology 4: 5 Physical Factors with no Economic Factor

Methodology 4 uses the same factors described in Section 4.4 but does not include any economic factor. This places increase emphasis on the factors that will cause failure and disregards the value of the area it will flood. This rating system can result in scores of 0 to 28, with a score of 28 representing the most severe site and most likely to fail. The definitions for the factors are described in Section 4.4 and the score sheet is shown in **Figure 7.**

Criteria	Score Definition
Bank Slope	0 - 3:1 or Greater Slope; 1 - 2.5:1 Slope; 2 - 2:1 Slope; 3 - 1.5:1 Slope; 4 - 1:1 or Less Slope; 5 - Vertical Slope
Berm Width	0 - Berm Width of 30 ft or Greater; 1 - 20 to 29 ft of Berm; 2 - 10 to 19 ft of Berm; 3 - 5 to 9 ft of Berm; 4 - 1 to 4 ft of Berm; 5 - No Berm Width
Soil Type	0 - Cemented Soils; 1 - All Clays; 2 - Clays and Silts; 3 - Sands; 4 - Silty Sands; 5 - All Silt
Velocity	0 - Less than 2.0 ft/s during high flow event; 1 - 2.0 to 4.0 ft/s; 2 - 4.0 to 4.5 ft/s; 3 - 4.5 to 5.0 ft/s; 4 - 5.0 - 6.0 ft/s; 5 - Greater than 6 ft/s **(If eddy currents are observed, add an additional point)**
Economic Factor	1 - Arnold Bend, Merritt Island, Hastings Tract, and Sutter Island; 2 - Knights Landing; 3 - Eldorado Bend and Clarksburg Airport; 4 - Ryer Island and Sherman Island; 5 - Tyler Island; 6 - Elkhorn and Courtland; 7 - Isleton; 8 - Grand Island; 9 - Tisdale; 10 - Verona; 11 - South West Sacramento; 12 - Clarksburg; 13 - Butte Basin and West Sacramento; 14 - Sutter Basin; 15 - Plumis Lake; 16 - Elk Grove; 17 - Yuba City; 18 - Natomas; 19 - Colusa Basin; 20 - Sacramento
Bank Stability	0 - No Stability issues; 1 - Tree Hazards; 2 - Beaver Holes or Caves; 3 - Tension Cracks; 4 - Slumping; 5 - Seepage History; 6 - Combination of Seepage/Slumping and one additional stability issue; 7 - Combination of Seepage/Slumping and two additional stability issues

Left Bank		Right Bank	
Location	**Overbank Area**	**Location**	**Overbank Area**
Elk Slough	Merritt Island	Cache Slough, RM 20 - 25	Hastings Tract
Feather River, RM 0 - 12	Verona	Elk Slough	Clarksburg
Feather River, RM 12 - 22	Plumis Lake	Feather River, RM 8 - 22	Yuba City
Georgiana Slough	Tyler Island	Georgiana Slough	Isleton
Miner Slough	Ryer Island	Miner Slough	Clarksburg
Sacramento River, RM 3 - 9	Sherman Island	Sacramento River, RM 15 - 32.4	Grand Island
Sacramento River, RM 9 - 26.5	Isleton	Sacramento River, RM 32.4 - 34	Sutter Island
Sacramento River, RM 26.5 - 28	Tyler Island	Sacramento River, RM 34 - 41.8	Merritt Island
Sacramento River, RM 28 - 36.5	Courtland	Sacramento River, RM 41.8 - 43	Clarksburg
Sacramento River, RM 36.5 - 45	Elk Grove	Sacramento River, RM 43 - 49.5	Clarksburg Airport
Sacramento River, RM 45 - 60	Sacramento	Sacramento River, RM 49.5 - 57.5	South West Sacramento
Sacramento River, RM 60.5 - 79	Natomas	Sacramento River, RM 57.5 - 63.5	West Sacramento
Sacramento River, RM 79 - 80	Verona	Sacramento River, RM 63.5 - 81.5	Elkhorn
Sacramento River, RM 84.5 - 118.5	Sutter Basin	Sacramento River, RM 84 - 90	Knights landing
Sacramento River, RM 118.5 - 138.5	Tisdale	Sacramento River, RM 90 - 98.5	Eldorado Bend
Sacramento River, RM 138.5 - 176	Butte Basin	Sacramento River, RM 98.5 - 184	Colusa Basin
Steamboat Slough	Grand Island	Sevenmile Slough	Isleton
Sutter Slough	Sutter Island	Steamboat Slough, RM 15 - 22	Ryer Island
Threemile Slough	Sherman Island	Steamboat Slough, RM 22 - 27	Sutter Island
		Sutter Slough, RM 22 - 24	Ryer Island
		Sutter Slough, RM 24 - 28	Clarksburg
		Threemile Slough	Isleton

Figure 6. Score Sheet for Methodology 3

Criteria	Score Definition
Bank Slope	0 - 3:1 or Greater Slope; 1 - 2.5:1 Slope; 2 - 2:1 Slope; 3 - 1.5:1 Slope; 4 - 1:1 or Less Slope; 5 - Vertical Slope
Berm Width	0 - Berm Width of 30 ft or Greater; 1 - 20 to 29 ft of Berm; 2 - 10 to 19 ft of Berm; 3 - 5 to 9 ft of Berm; 4 - 1 to 4 ft of Berm; 5 - No Berm Width
Soil Type	0 - Cemented Soils; 1 - All Clays; 2 - Clays and Silts; 3 - Sands; 4 - Silty Sands; 5 - All Silt
Velocity	0 - Less than 2.0 ft/s during high flow event; 1 - 2.0 to 4.0 ft/s; 2 - 4.0 to 4.5 ft/s; 3 - 4.5 to 5.0 ft/s; 4 - 5.0 - 6.0 ft/s; 5 - Greater than 6 ft/s **(If eddy currents are observed, add an additional point)**
Bank Stability	0 - No Stability issues; 1 - Tree Hazards; 2 - Beaver Holes or Caves; 3 - Tension Cracks; 4 - Slumping; 5 - Seepage History; 6 - Combination of Seepage/Slumping and one additional stability issue; 7 - Combination of Seepage/Slumping and two additional stability issues

Figure 7. Score Sheet for Methodology 4

5.0 Site Priority Ranking Results

In late summer of 2005, Ayres Associates personnel performed a field inspection of each of the designated erosion sites (see list in Section 3.0) and collected data to complete an erosion hazard data sheet for each site and each methodology. The ranked order for the reviewed erosion sites, from greatest hazard potential to least, is shown in **Figure 8** for each of the four methodologies.

The top ten sites from Methodology 1 have been highlighted in separate colors for ease of locating their relative ranking within the other methodologies. The erosion site at RM 125.8L on the Sacramento River is listed at the bottom of each list with an N/A because during the field visit it was found to be repaired. Complete erosion hazard data sheets are provided in **Appendices A – D** for each of the four methodologies.

Nine (9) of the highlighted erosion sites show up in the top 10 ranking for methodologies 1, 2 and 4, which are the methods without a strong emphasis on the economics associated with a failure. This demonstrates that these nine sites should be the highest priority sites if the economics of failure is not a consideration. However, if the economics of a levee failure is considered, then the ranking in Methodology 3 may be more appropriate for setting priorities.

The winter storm event of late December 2005 – early January 2006 tested the flood control levees and a number of locations showed some distress (bank erosion at RM 56.8R, personal photograph and sand boils near Clarksburg, Sacramento Bee, for example). The fact that damage occurs for a moderate event (10- to 30-year frequency, Sacramento Bee) could be an indicator of inherent weaknesses within the system.

Methodology 1		
1	Sacramento River, RM 43.3R (Clarksburg Airport)	76
2	Sacramento River, RM 26.9L (Tyler Island)	70
3	Sacramento River, RM 78L (Natomas)	69
4	Sacramento River, RM 56.7L (Sacramento)	68
5	Sacramento River, RM 32.5R (Sutter Island)	67
6	Sacramento River, RM 55.8R (South West Sacramento)	65
7	Sacramento River, RM 26.5L (Tyler Island)	63
8	Sacramento River, RM 26L (Isleton)	62
	Sacramento River, RM 85.6R (Knight's Landing)	62
	Sacramento River, RM 10.8L (Isleton)	62
11	Sacramento River, RM 8L (Sherman Island)	55
	Georgiana Slough, RM 10.3L (Tyler Island)	55
13	Sacramento River, RM 34.5R (Merritt Island)	54
14	Sacramento River, RM 72.2R (Elkhorn)	53
15	Sutter Slough, RM 25.1R (Grand Island)	52
	Sacramento River, RM 22.7L (Isleton)	52
17	Sacramento River, RM 26.1R (Grand Island)	51
18	Sacramento River, RM 69.9R (Elkhorn)	50
	Sacramento River, RM 130.8R (Colusa Basin)	50
	Sacramento River, RM 42.8R (Clarksburg)	50
21	Sacramento River, RM 71.7R (Elkhorn)	49
	Sacramento River, RM 141.4R (Colusa Basin)	49
	Sacramento River, RM 99.5R (Colusa Basin)	49
24	Sacramento River, RM 154.5R (Colusa Basin)	48
25	Sacramento River, RM 130L (Tisdale)	46
26	Sacramento River, RM 96.2L (Eldorado Bend)	45
27	Cache Slough, RM 21.8R (Hastings Tract)	44
28	Sacramento River, RM 164R (Colusa Basin)	43
29	Elk Slough, RM 0.7 (Clarksburg)	42
30	Sacramento River, RM 99.3R (Colusa Basin)	41
31	Sacramento River, RM 73R (Elkhorn)	40
	Cache Slough, RM 21.2R (Hastings Tract)	40
33	Sacramento River, RM 123.5L (Tisdale)	38
34	Sacramento River, RM 125.8L (Tisdale)	N/A

Methodology 2		
1	Sacramento River, RM 43.3R (Clarksburg Airport)	58
2	Sacramento River, RM 26.9L (Tyler Island)	56
3	Sacramento River, RM 32.5R (Sutter Island)	53
4	Sacramento River, RM 26L (Isleton)	49
5	Sacramento River, RM 26.5L (Tyler Island)	48
6	Sacramento River, RM 78L (Natomas)	46
	Sacramento River, RM 56.7L (Sacramento)	46
	Sacramento River, RM 85.6R (Knight's Landing)	46
9	Sacramento River, RM 55.8R (South West Sacramento)	45
10	Sacramento River, RM 10.8L (Isleton)	44
	Sacramento River, RM 34.5R (Merritt Island)	44
12	Sacramento River, RM 72.2R (Elkhorn)	43
13	Sacramento River, RM 71.7R (Elkhorn)	41
14	Sacramento River, RM 8L (Sherman Island)	40
	Sacramento River, RM 22.7L (Isleton)	40
16	Sacramento River, RM 69.9R (Elkhorn)	39
	Sacramento River, RM 42.8R (Clarksburg)	39
18	Georgiana Slough, RM 10.3L (Tyler Island)	38
	Sutter Slough, RM 25.1R (Grand Island)	38
	Sacramento River, RM 26.1R (Grand Island)	38
	Sacramento River, RM 130.8R (Colusa Basin)	38
22	Sacramento River, RM 99.5R (Colusa Basin)	37
23	Sacramento River, RM 141.4R (Colusa Basin)	35
24	Sacramento River, RM 154.5R (Colusa Basin)	34
	Sacramento River, RM 96.2L (Eldorado Bend)	34
26	Sacramento River, RM 130L (Tisdale)	33
	Sacramento River, RM 164R (Colusa Basin)	33
	Elk Slough, RM 0.7 (Clarksburg)	33
	Sacramento River, RM 99.3R (Colusa Basin)	33
	Sacramento River, RM 73R (Elkhorn)	33
31	Sacramento River, RM 123.5L (Tisdale)	32
32	Cache Slough, RM 21.8R (Hastings Tract)	29
	Cache Slough, RM 21.2R (Hastings Tract)	29
34	Sacramento River, RM 125.8L (Tisdale)	N/A

Methodology 3		
1	Sacramento River, RM 56.7L (Sacramento)	42
2	Sacramento River, RM 78L (Natomas)	37
3	Sacramento River, RM 99.5R (Colusa Basin)	35
	Sacramento River, RM 99.3R (Colusa Basin)	35
5	Sacramento River, RM 55.8R (South West Sacramento)	33
	Sacramento River, RM 141.4R (Colusa Basin)	33
	Sacramento River, RM 164R (Colusa Basin)	33
8	Sacramento River, RM 154.5R (Colusa Basin)	32
9	Sacramento River, RM 130.8R (Colusa Basin)	30
10	Sacramento River, RM 26L (Isleton)	29
	Sacramento River, RM 96.2L (Eldorado Bend)	29
12	Sacramento River, RM 26.9L (Tyler Island)	28
	Sutter Slough, RM 25.1R (Grand Island)	28
	Elk Slough, RM 0.7 (Clarksburg)	28
15	Sacramento River, RM 42.8R (Clarksburg)	27
16	Sacramento River, RM 22.7L (Isleton)	26
17	Sacramento River, RM 43.3R (Clarksburg Airport)	26/25
18	Sacramento River, RM 26.5L (Tyler Island)	25
	Sacramento River, RM 10.8L (Isleton)	25
	Sacramento River, RM 69.9R (Elkhorn)	25
21	Sacramento River, RM 32.5R (Sutter Island)	24
	Sacramento River, RM 72.2R (Elkhorn)	24
	Sacramento River, RM 130L (Tisdale)	24
	Sacramento River, RM 123.5L (Tisdale)	24
25	Sacramento River, RM 26.1R (Grand Island)	23
	Sacramento River, RM 71.7R (Elkhorn)	23
27	Sacramento River, RM 85.6R (Knight's Landing)	22
28	Georgiana Slough, RM 10.3L (Tyler Island)	21
	Sacramento River, RM 34.5R (Merritt Island)	21
30	Sacramento River, RM 8L (Sherman Island)	20
31	Sacramento River, RM 73R (Elkhorn)	19
32	Cache Slough, RM 21.8R (Hastings Tract)	13
33	Cache Slough, RM 21.2R (Hastings Tract)	12
34	Sacramento River, RM 125.8L (Tisdale)	N/A

Methodology 4		
1	Sacramento River, RM 26.9L (Tyler Island)	23
	Sacramento River, RM 32.5R (Sutter Island)	23
3	Sacramento River, RM 43.3R (Clarksburg Airport)	23/22
4	Sacramento River, RM 56.7L (Sacramento)	22
	Sacramento River, RM 55.8R (South West Sacramento)	22
	Sacramento River, RM 26L (Isleton)	22
7	Sacramento River, RM 26.5L (Tyler Island)	20
	Sacramento River, RM 85.6R (Knight's Landing)	20
	Sacramento River, RM 34.5R (Merritt Island)	20
10	Sacramento River, RM 78L (Natomas)	19
	Sacramento River, RM 22.7L (Isleton)	19
	Sacramento River, RM 69.9R (Elkhorn)	19
13	Sacramento River, RM 10.8L (Isleton)	18
	Sacramento River, RM 72.2R (Elkhorn)	18
15	Sacramento River, RM 71.7R (Elkhorn)	17
16	Sacramento River, RM 8L (Sherman Island)	16
	Georgiana Slough, RM 10.3L (Tyler Island)	16
	Sutter Slough, RM 25.1R (Grand Island)	16
	Sacramento River, RM 99.5R (Colusa Basin)	16
	Elk Slough, RM 0.7 (Clarksburg)	16
	Sacramento River, RM 99.3R (Colusa Basin)	16
22	Sacramento River, RM 26.1R (Grand Island)	15
	Sacramento River, RM 42.8R (Clarksburg)	15
	Sacramento River, RM 130L (Tisdale)	15
	Sacramento River, RM 96.2L (Eldorado Bend)	15
	Sacramento River, RM 123.5L (Tisdale)	15
27	Sacramento River, RM 141.4R (Colusa Basin)	14
	Sacramento River, RM 164R (Colusa Basin)	14
29	Sacramento River, RM 154.5R (Colusa Basin)	13
	Sacramento River, RM 73R (Elkhorn)	13
31	Cache Slough, RM 21.8R (Hastings Tract)	12
32	Sacramento River, RM 130.8R (Colusa Basin)	11
	Cache Slough, RM 21.2R (Hastings Tract)	11
34	Sacramento River, RM 125.8L (Tisdale)	N/A

Figure 8. Site Priority Ranking Results

6.0 Conclusions

Based on our fieldwork and a review of the priority ranking methodologies, we offer the following conclusions:

1. While finalizing work on a ranking methodology is important, it shouldn't delay repair work on the existing critical erosion sites as they are continuing to deteriorate even under low and moderate flow events.

2. The slopes of the eroding banks and the underwater cross section configuration are important factors affecting bank stability, however no surveyed cross sections are available at the critical sites and these slopes and shapes have been estimated for this evaluation. Field surveyed levee and underwater cross sections will provide additional credibility for these factors.

3. Methodology 1, 2 and 4 yield similar results when comparing the top 10 erosion sites on each list. Nine (9) common sites are included in each list (not necessarily in this order) and are as follows:

    - RM 26.9L – Tyler Island Basin
    - RM 32.5R – Sutter Island Basin
    - RM 43.3R – Clarksburg Basin
    - RM 56.7L – Sacramento Basin
    - RM 55.8R – South West Sacramento
    - RM 26.0L – Isleton Basin
    - RM 26.5L – Tyler Island Basin
    - RM 85.6R – Knight's Landing Basin
    - RM 78.0L – Natomas Basin

4. Including the economics of a levee failure as demonstrated in Methodology 3, alters the ranking order, however 4 of the erosion sites listed above still remain in the top 10 ranking. Those four site are:

    - RM 56.7L – Sacramento Basin
    - RM 78.0L – Natomas Basin
    - RM 55.8R – South West Sacramento
    - RM 26.0L – Isleton Basin

7.0 Recommendations

Based on our conclusions above, we offer the following recommendations:

1. As work continues on the development of a criteria for setting site priorities, attention should also be focused on the continued inspection, maintenance and/or repair of the erosion sites.

2. Since the bank slope and the shape of the underwater cross section are critical factors, field cross sections should be taken at each of the designated critical sites and the methodologies recomputed.

3. Since Methodology 1, 2 and 4 yield similar results when comparing which site are within the top 10, we recommend that Methodology 4 be used for evaluation when economics are not used as an evaluation factor since it provides comparable results and requires fewer evaluation factors.

4. Since the economic evaluation of a potential failure can make a significant difference in the site rankings, it is recommended that all sites also be evaluated with an economic factor. We recommend Methodology 3 for this evaluation.

5. The following 9 erosion sites rank within the top 10 for Methodology 1, 2 and 4 (minimum or no emphasis on economics) and those in bold print are in the top 10 for Methodology 3 (economics as a significant factor) and are recommended as the highest priority for repair:

    - RM 26.9L – Tyler Island Basin
    - RM 32.5R – Sutter Island Basin
    - RM 43.3R – Clarksburg Basin
    - **RM 56.7L – Sacramento Basin**
    - **RM 55.8R – South West Sacramento**
    - **RM 26.0L – Isleton Basin**
    - RM 26.5L – Tyler Island Basin
    - RM 85.6R – Knight's Landing Basin
    - **RM 78.0L – Natomas Basin**

6. A field review of the critical erosion sites should be performed as soon as low water allows to inspect for damage from the most recent December-January storm event. Signs of site damage may be useful in validating erosion methodologies.

APPENDIX

A.
Erosion Hazard Data Sheets
for
Methodology 1: 16 Physical Factors and One Economic Factor

B.
Erosion Hazard Data Sheets
for
Methodology 2: 10 Physical Factors and no Economic Factor

C.
Erosion Hazard Data Sheets
for
Methodology 3: 5 Physical Factors and Revised Economic Factor

D.
Erosion Hazard Data Sheets
for
Methodology 4: 5 Physical Factors and no Economic Factor