TECHNICAL MEMORANDUM

Meander Modeling for the Kopta Slough Flood Damage Reduction and Habitat Restoration Project

Prepared For: DWR Northern Region Office (NRO)

Prepared By: Julia Delphia, Engineer, Water Resources (NRO)

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This memorandum presents the results of the meander modeling effort done in support of the Kopta Slough Flood Damage Reduction and Habitat Restoration Project (Project). One of the primary elements of the Project is to remove rock revetment (revetment) from the right bank (when looking downstream) of the Sacramento River between River Miles 220 and 221 in order to restore natural floodplain functionality and reduce erosive stress on the left bank of the Sacramento River between River Miles 218 and 219. In an attempt to predict the future migration of the river, we ran the Meander Model that was developed by Eric Larsen, Ph. D., of the University of California, Davis, under contract with the FloodSAFE Environmental Stewardship and Statewide Resources Office (FESSRO) of the Department of Water Resources (DWR).

The Sacramento River meander belt is dynamic and constantly changing. Revetment installed by the U.S. Army Corps of Engineers (USACE) and private landowners for erosion control has constrained the river in some locations. Elsewhere, the river is unrestricted in its ability to meander.

According to the Meander Model, removing revetment from the right bank of the Sacramento River between River Miles 220 and 221 would result in the river migrating to the west between River Miles 219 and 221. While it was hypothesized that removal of that revetment would also result in the Sacramento River migrating and moving away from the Woodson Bridge State Recreation Area (left bank) between River Miles 218 and 219, the Meander Model did not show that to be the case. Instead, the erosion and migration of the Sacramento River towards the Woodson Bridge State Recreation Area would be the same with or without removal of the revetment upstream. In addition, the river alignment would remain the same immediately downstream of Woodson Bridge and the City of Corning sewer outfall.

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1. Introduction

The Kopta Slough Flood Damage Reduction and Habitat Restoration Project (Project) is located on the Sacramento River near Vina, between River Miles 218 and 222 (Figure). One of the primary elements of the Project is to remove rock revetment (revetment) from the right bank (when looking downstream) of the Sacramento River between River Miles 220 and 221 in order to restore natural floodplain functionality and reduce erosive stress on the left bank of the Sacramento River between River Miles 218 and 219.

The Meander Model that was used for evaluating the future migration of the Sacramento River was developed by Eric Larsen, Ph. D., of the University of California, Davis, under contract with the FloodSAFE Environmental Stewardship and Statewide Resources Office (FESSRO) of the Department of Water Resources (DWR). Professor Larsen has written several reports on his meander modeling efforts and was contacted several times in person, over the phone, and through email during this effort. When “Larsen” is referred to in this document as a source, it is a general reference, not to a specific report or contact.

The purpose of this document is to discuss the methods and present the results of the meander modeling effort done in support of the Project. In addition, this document includes the historical background of the Project, an overview of the Meander Model and modeling parameters, the results of model calibration, and a sensitivity analysis of the modeling parameters. Meander modeling is the attempt to predict the future migration of the river. This report is not an all-inclusive document. For further details about geomorphology and the science behind the Meander Model, refer to the other consulted reports.

2. Historical Background

The Project area is within the Red Bluff to Colusa reach of the Sacramento River. Within this reach, the Sacramento River meanders over a broad alluvial floodplain. The meander belt is dynamic and constantly changing.

Figure 1 shows the historic channel locations in the Project area that have been mapped since 1896. According to geomorphological studies, the average bank recession rate in the Red Bluff to Colusa reach is 16 feet per year, though some locations may erode in excess of 60 feet per year (DWR 2013).

Over the years, the US Army Corps of Engineers (USACE) and private landowners have installed revetment in order to constrain the movement of the Sacramento River and protect agricultural lands from erosion. USACE installed revetment between 1963 and 1985 as part of the Chico Landing to Red Bluff Bank Protection Project, which was authorized by the Flood Control Act of 1958. The revetment has also been repaired in several locations during and since that time.

In 1986, DWR, the State Reclamation Board (now the Central Valley Flood Protection Board), and USACE installed the Palisades Bank Protection Project (Palisades Project) on the left bank (when looking downstream) of the Sacramento River between River Miles 218 and 219 (DWR 2013). The Palisades Project was unsuccessful in controlling erosion and 90 percent of that project was subsequently removed in 1997. The remaining 10 percent of the project still provides some protection for the bank. The Northern Region Office (NRO) of DWR monitors bank erosion at this location twice a year. Those surveys show an average erosion rate of 11 feet per year, which likely would have been greater had the Palisades Project not been installed.

Figure 1 Project Area

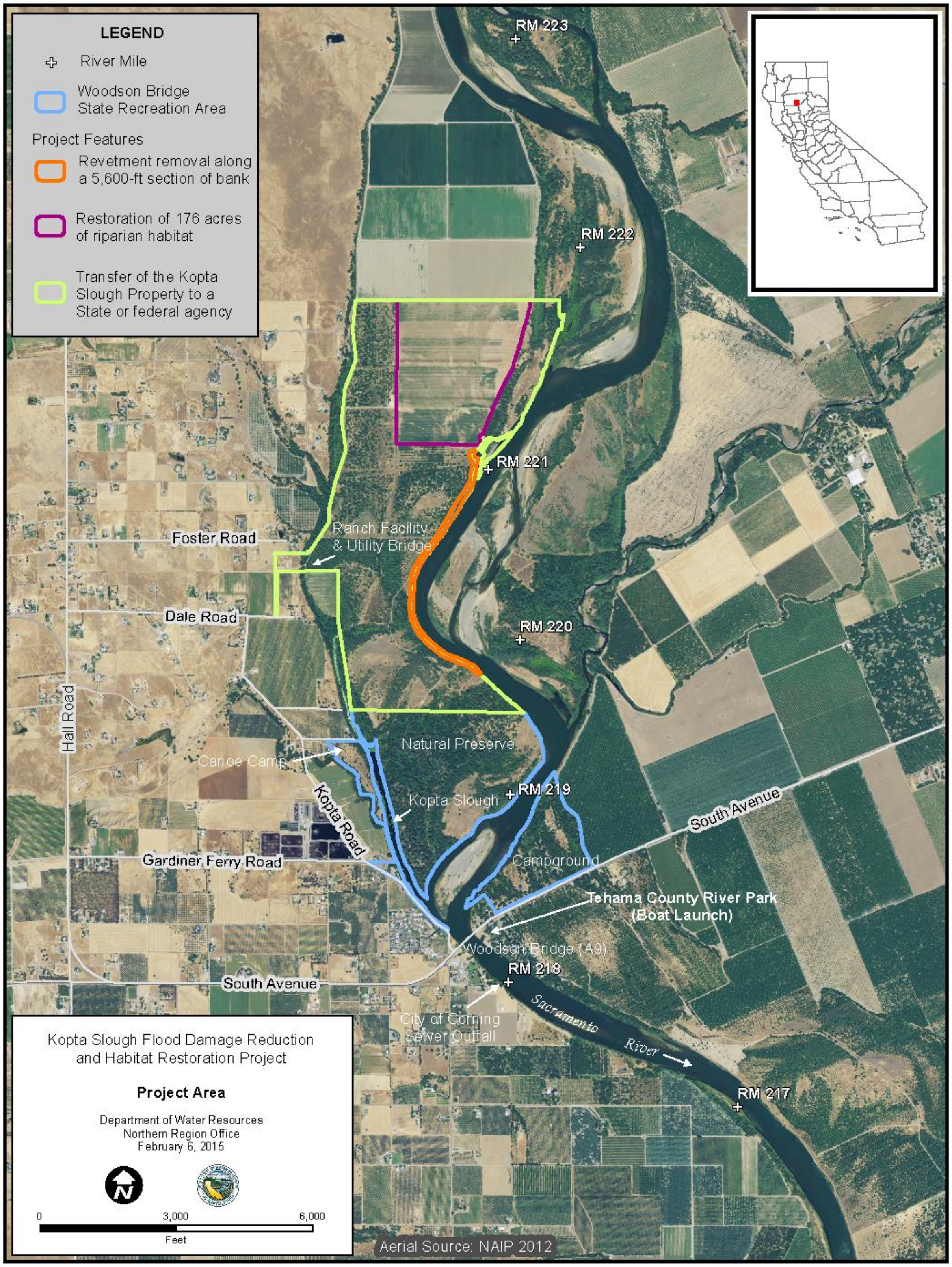
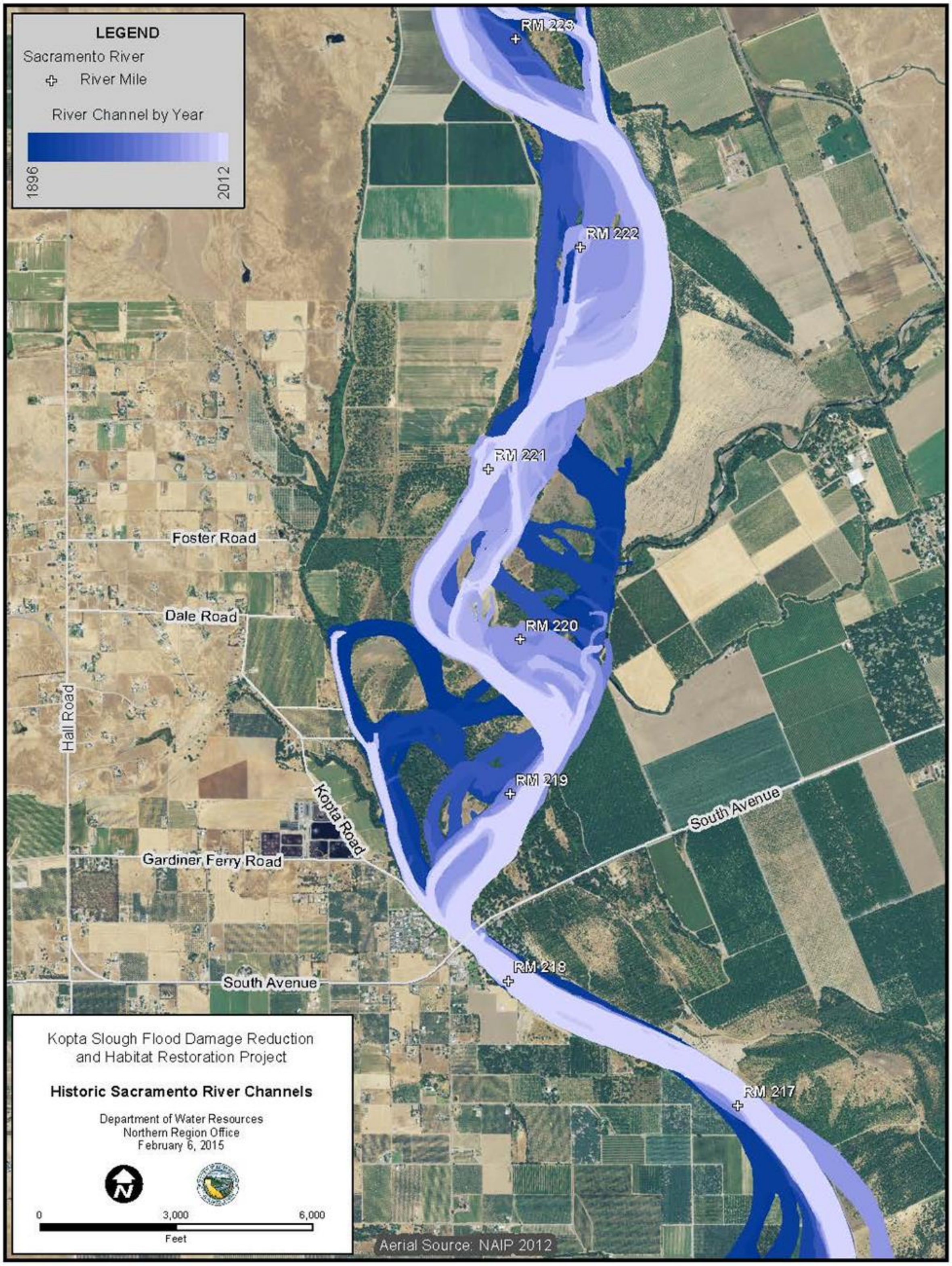


Figure 2 Historic Sacramento River Channels



3. Meander Model

This section presents a brief overview of the Meander Model. For more detailed information about the Meander Model, refer to Larsen's publications.

The Meander Model runs within Matlab (a multi-paradigm numerical computing environment) and is a work in progress. The Meander Model is a tool to predict the trend of a river's meander.

The primary inputs to the Meander Model are:

- Stream Centerline
- Erodibility Surface
- Flow and Geomorphic Parameters

3.1. Stream Centerline

The stream centerline is defined generally in the middle of the inundation area of a 2-year flow event. Using aerial imagery, the centerline of the channel is digitized from upstream to downstream for the full length of the reach being modeled. Two historical centerlines are needed for calibration purposes. Future predictions are run from the most recent river centerline.

3.2. Erodibility Surface

The erodibility surface represents the erodibility potential of the area. It is typically created in a Geographic Information System (GIS) by combining a feature class of geology with a feature class of land cover, including revetment, and converting that to a raster dataset. The raster dataset is exported out as an ASCII text file for use in the Meander Model.

In the original Meander Model code, the erodibility data file contained the coefficient e0, where the greater the value of e0, the greater the potential for erosion. Later, the model code was changed such that the data are now expressed in terms of Fd, which is an inverse of e0, though not strictly 1/e0. Fd can be thought of like a "particle size", where the bigger it is, the less erosion can be expected. So even though the file is called "e0.asc", the data values are actually Fd values.

3.3. Flow And Geomorphic Parameters

The flow and geomorphic parameters for meander modeling are daily flow, channel width, channel depth, channel slope, and grain size. These parameters are discussed below.

3.3.1. Daily Flow

The Meander Model can run either a constant daily flow or a variable daily flow hydrograph. The flows are in cubic meters per second (cms) and should represent a 2-year flow event.

3.3.2. Channel Width, Depth, And Slope

The model needs the average channel width in meters (m), average depth in meters, and average water surface slope of the modeled reach. These values are relative to the 2-year flow event. Ideally, these values are obtained from an existing hydraulic model of the reach.

3.3.3. Grain Size

Grain size is the reach-average median particle size of bed material in millimeters (mm).

4. Meander Modeling For The Kopta Slough Project

This section discusses how the Meander Model was used for the Project and the results of that modeling.

The Project area is within one of the Sacramento River reaches that Larsen analyzed while developing the Meander Model. Larsen has published several reports documenting his modeling results. But according to Larsen, his modeling was more conceptual in nature, rather than being a detailed modeling effort. The emphasis of Larsen's analyses was to show the capabilities of the Meander Model.

For the Kopta Slough Project Meander Model (Kopta Slough Model), NRO decided to develop new input data and run the Meander Model in order to better understand how the model works, its limitations, and its resulting predictive ability. The reach analyzed in the Kopta Slough Model is equivalent to Larsen's modeled reach, between River Miles 198 and 225 (Figure 3). This longer reach allows better calibration of the model because more river meanders are being evaluated, and because model output at any given location depends upon upstream conditions for a distance of about two bends of the river.

4.1. Kopta Slough Model Data

This section describes the primary inputs used in the Kopta Slough Model.

4.1.1. Stream Centerline

Larsen used the 1952 and 1976 centerlines for his calibration when he modeled this reach of the Sacramento River. During this time period, revetment was being installed at different locations at different times. For the Kopta Slough Model, NRO used 1981 and 2013 centerlines for calibration because the revetment was more constant during this time period and because this time period better reflects current and future conditions. The 1981 centerline was obtained from past work done by NRO's Geology-Groundwater Investigation Section. The 2013 centerline was created by first digitizing the banks of the Sacramento River in Google Earth, and then editing with ArcGIS tools.

It is important to note that the1981 and 2013 centerlines actually represent the center of the river at the time of the aerial imagery rather than being an estimate of where the centerline of the 2-year flow event might have been. Estimating the location of the 2-year flow event centerline can be highly subjective with respect to the inclusion of certain features, such as side channels and overflow areas. Also, if the Meander Model is predicting the trend of the river centerline, it is best to ensure that the two centerlines used for calibration are consistent in their representation of the river and that they were developed in the same manner.

4.1.2. Erodibility Surface

The erodibility surface for the Kopta Slough Model was created by importing geology, land use, and revetment features into ArcGIS and clipping each feature to the extent of the Kopta Slough Model area. A new field was added to each feature for the purpose of assigning a relative-erodibility value to each polygon as follows: non, low, moderate, and high. Table 1 and Table 2 show how the relative-erodibility was assigned to each polygon of geology and land use. The ArcGIS union tool was then used to combine the geology and land use features into one erodibility surface feature. Table 3 shows the resulting initial relative-erodibility for the erodibility surface.

Figure 3 Meander Model Area

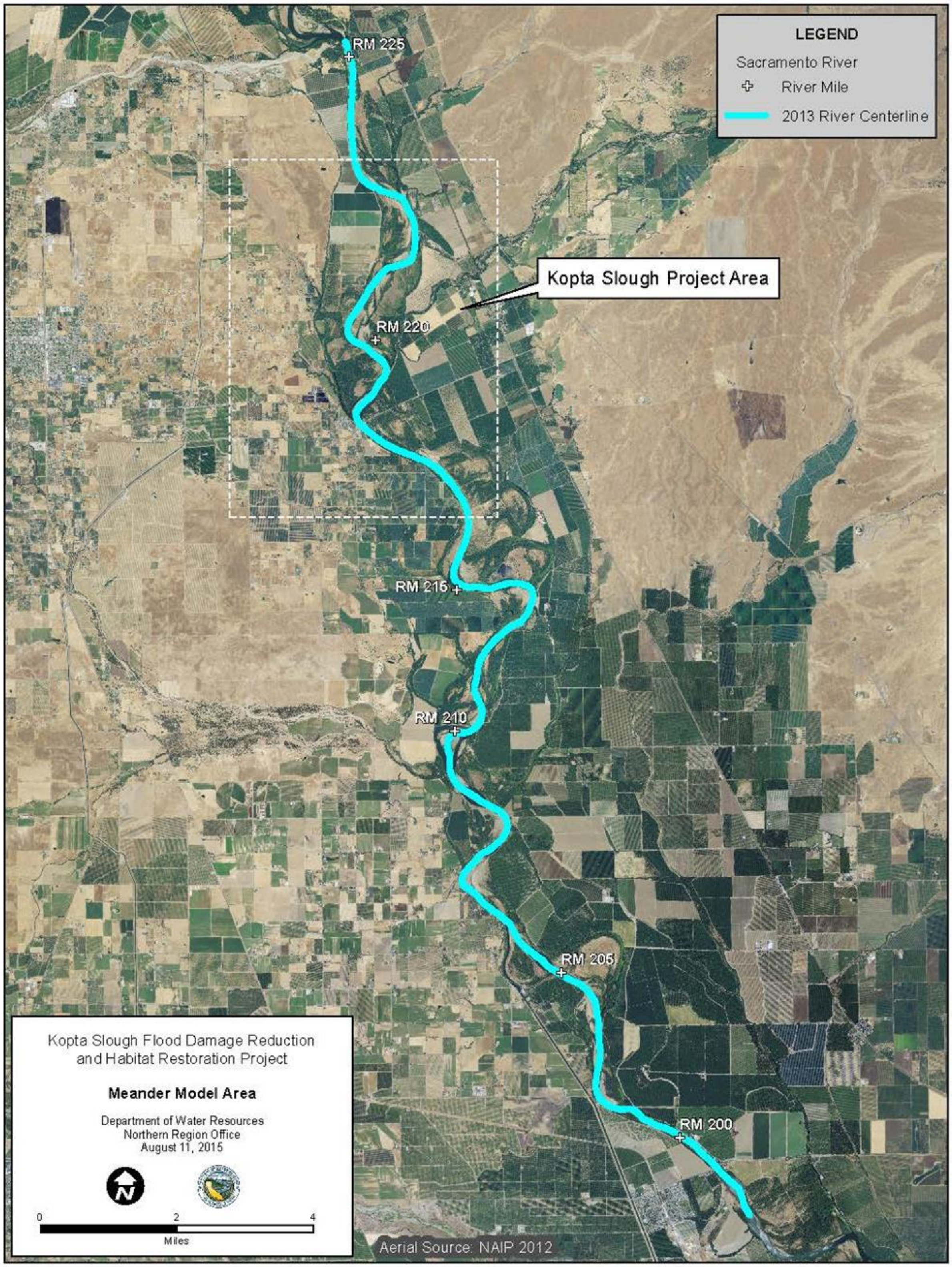


Table 1 Geology

Lithology	Relative-Erodibility
Qa - Alluvium	high
Qar - Rockland Ash Bed	moderate
Qb - Basin Deposits	moderate
Qbdc - Olivine Basalt Deer Creek	low
Qhm - Holocene Alluvium, Medium Grained	high
Qml - Modesto Formation Lower	low
Qmu - Modesto Formation Upper	low
Qrb - Red Bluff Formation	low
Qrl - Riverbank Formation Lower	low
Qru- Riverbank Formation Upper	low
Qsc - Stream Channel Deposits	moderate
Qtog - Older Gravel Deposits	low
Tta - Tuscan Formation Unit A	low
Ttb - Tuscan Formation Unit B	low
Ttc - Tuscan Formation Unit C	low
Ttd - Tuscan Formation Unit D	low
Tte - Tehama Formation	low

In the erodibility surface, another field was then added in order to assign a numeric erodibility value. Larsen's erodibility surface was used as the basis for the typical values. Additional scenarios were also run with the erodibility value held constant for the entire study area in order to determine at what value the centerline stopped migrating. When the erodibility value was equal to 2,000, very little movement of the centerline occurred. Table 4 shows the initial erodibility values that were assigned to each relative-erodibility.

After populating the erodibility values, the erodibility surface was exported to a 30-meter grid raster dataset. The raster dataset was then exported out to an ASCII file to be read by the Meander Model.

4.1.3. Flow And Geomorphic Parameters

The flow and geomorphic parameters for the Kopta Slough Model are the same as those used by Eric Larsen in his analyses (Table 5). The parameters were taken from the USACE and DWR Comprehensive Study of 2002 (Larsen 2014).

Table 2 Land Use and Revetment

Land Use	**Relative-Erodibility**
Agricultural Classes	
C - Subtropical Fruits	moderate
D - Deciduous Fruits and Nuts	moderate
F - Field Crops	high
G - Grain and Hay Crops	high
I - Idle	high
P - Pasture	high
R - Rice	high
S – Semi-agricultural and Incidental to Agriculture	moderate
T - Truck and Berry Crops	high
V - Vineyards	moderate
Urban Classes	
U - Urban	moderate
UC - Urban Commercial	moderate
UI- Urban Industrial	moderate
UR - Urban Residential	moderate
UV - Urban Vacant	moderate
Native Classes	
NB - Barren and Wasteland	high
NC - Native Classes Unsegregated	moderate
NR - Riparian Vegetation	moderate
NV - Native Vegetation	moderate
NW - Water Surface	high
Other	
Revetment	non

Table 3 Initial Relative Erodibility – Union of Geology and Land Use

Geology	Land Use	Union
low	moderate	low
low	high	low
moderate	moderate	moderate
moderate	high	moderate
high	moderate	moderate
high	high	high
any	non	non

Table 4 Initial Erodibility Values

Relative-Erodibility	Erodibility
non	10,000
low	1,000
moderate	250
high	85

Table 5 Flow and Geomorphic Parameters for Calibration

Parameter	Value
Flow (Q)	2,200 cms
Depth (H)	5.01 m
Width (B)	218 m
Slope (S)	0.00045
Grain Size (Ds)	25 mm

Notes: cms = cubic meters per second; m = meters; mm = millimeters

4.2. Kopta Slough Model Calibration

The goal of calibration is to have the modeled centerline align with the actual centerline as much as possible, with consideration of the Meander Model's limitations. If the Kopta Slough Model can be calibrated well to historical events, then the Kopta Slough Model should be able to reliably predict future conditions. As stated above, calibration was done from 1981 to 2013, a total of 32 years. The starting and ending centerlines and the flow and geomorphic parameters were held constant while the erodibility surface was modified based upon the results of each previous run.

The first Kopta Slough Model run results were problematic. Figure 4 shows the initial results for the full modeled reach, and Figure 5 shows the initial results for the Project area, noting that the modeled centerline sometimes crosses over or behind areas designated as non-erodible. According to Larsen, the Meander Model's curve fitting routine can cause the centerline to cross areas defined as non-erodible. In addition, even though the Meander Model uses average channel width and depth data for stream power computations, the channel width is not considered in the determination of the centerline placement.

Initially, the revetment areas were based upon buffering the revetment centerlines by 30 meters. But because of the Meander Model's limitation when applying the model to a spatially-correct erodibility surface, the revetment areas needed to be enlarged further into the river channel so that they would prevent the river from migrating in that direction. Therefore, the revetment centerlines were re-buffered to 60 meters.

The larger revetment areas helped improve the model results by constraining the river centerline migration, but there were still reaches that migrated more or less than what has occurred historically. The next step in the calibration was to change the erodibility values for each relative-erodibility and analyze the results. High erodibility values were modeled up to 250, moderate erodibility values were modeled up to 600, and low erodibility values were modeled up to 2000. From these runs, it was determined that a larger number of erodibility values were needed (Table 6).

Figure 4 **Meander Model Initial Calibration Results, Model Area**

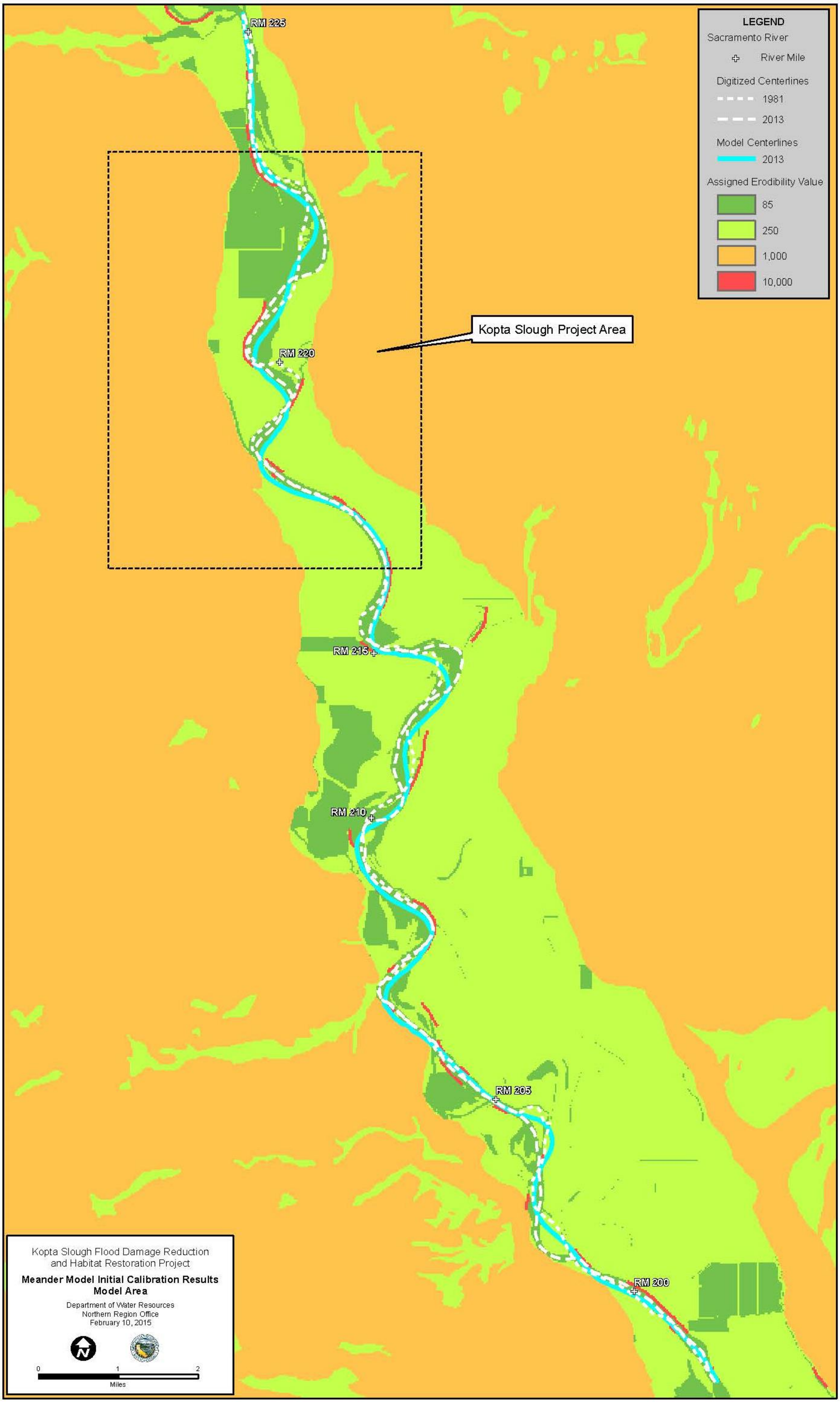


Figure 5 Meander Model Initial Calibration Results, Project Area

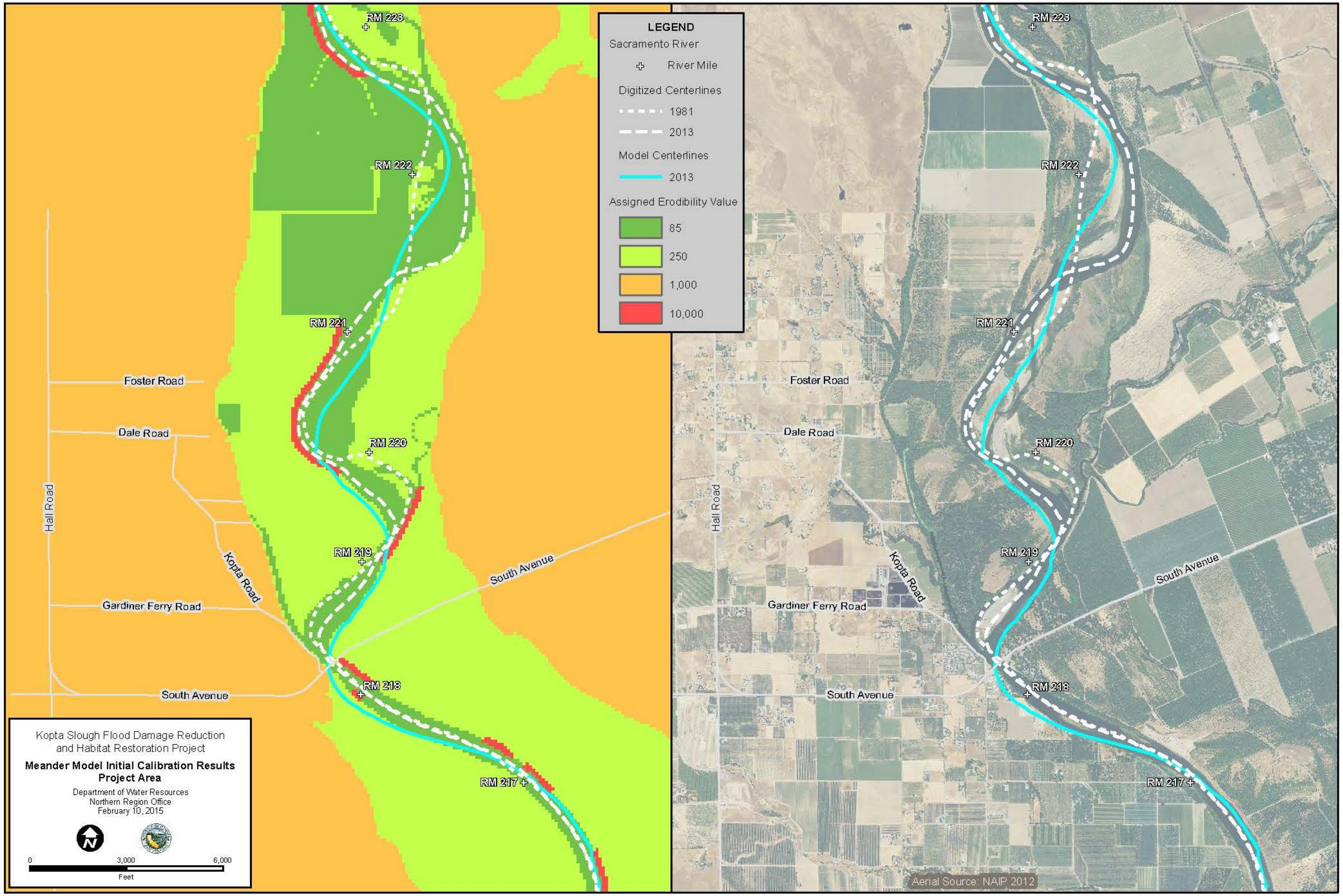


Table 6 Final Erodibility Values

Relative-Erodibility	Erodibility
non	10,000
low	2,000
moderate	400
high3	250
high2	150
high1	85

Assigning an erodibility value for some areas was more complex than simply referencing the geology and land use. While the relative-erodibility methodology is reasonable, it does not and cannot account for all the intricacies involved in what occurs during river erosion and migration processes. Therefore, the erodibility value of some areas was adjusted to whatever resulted in better model results, holding to the six values indicated in Table 6. Adjusting values in this manner is typical in calibrating models.

Another parameter evaluated in the Kopta Slough Model was the Cf factor, which is a coefficient of friction. Larsen recommended setting this to 1 at first, and then changing it to half that or twice that depending on the results. Evaluations showed that a Cf value of 2 gave the best results.

Larsen's erodibility surface was saved as a 30-meter raster grid and an ASCII data file. Initially, the erodibility surface for the Kopta Slough Model was also a 30-meter grid. In an attempt to improve the model results, the erodibility surface was changed to a 10-meter grid. The 10-meter grid did result in a slightly better calibration, most importantly, at the right bank at the Woodson Bridge.

Figure 6 shows the final calibration results for the modeled area, and Figure 7 shows the final calibration results for the Project area. There are still areas where the centerline moved too far or not far enough, but overall, the trend was improved. Because the focus here is on the Kopta Slough Project area, more time was spent trying to calibrate that reach. Figure 7 also shows the initial calibration centerline for ease in seeing the improved calibration. Though the model results show the calibration is fair between River Mile 221 to 223, the calibration results are very good from River Mile 217 to 221. Therefore, the Kopta Slough Model is thought to be well-calibrated and can be used for predicting future river migration.

In addition to visually comparing the centerlines, the area reworked was also evaluated. The area reworked is the area between the starting and ending centerlines. For the 32 years being modeled, the actual area reworked between the 1981 and 2013 centerlines equals 875 acres (about 27 acres per year). From the Kopta Slough Model, the area reworked equals 740 acres (about 23 acres per year). These two values compare relatively well, further verifying the quality of the calibration.

Figure 6 Meander Model Final Calibration Results, Model Area

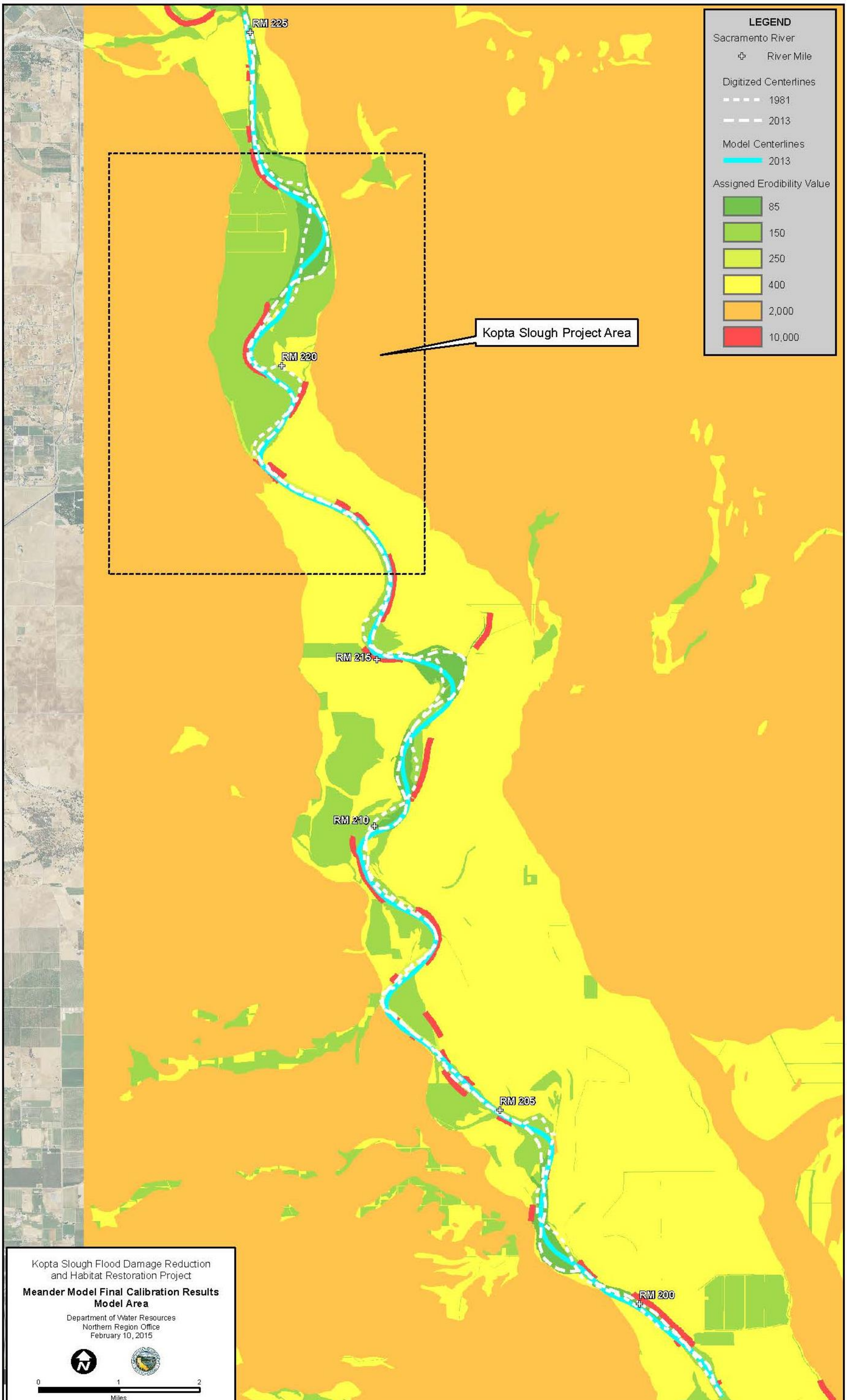
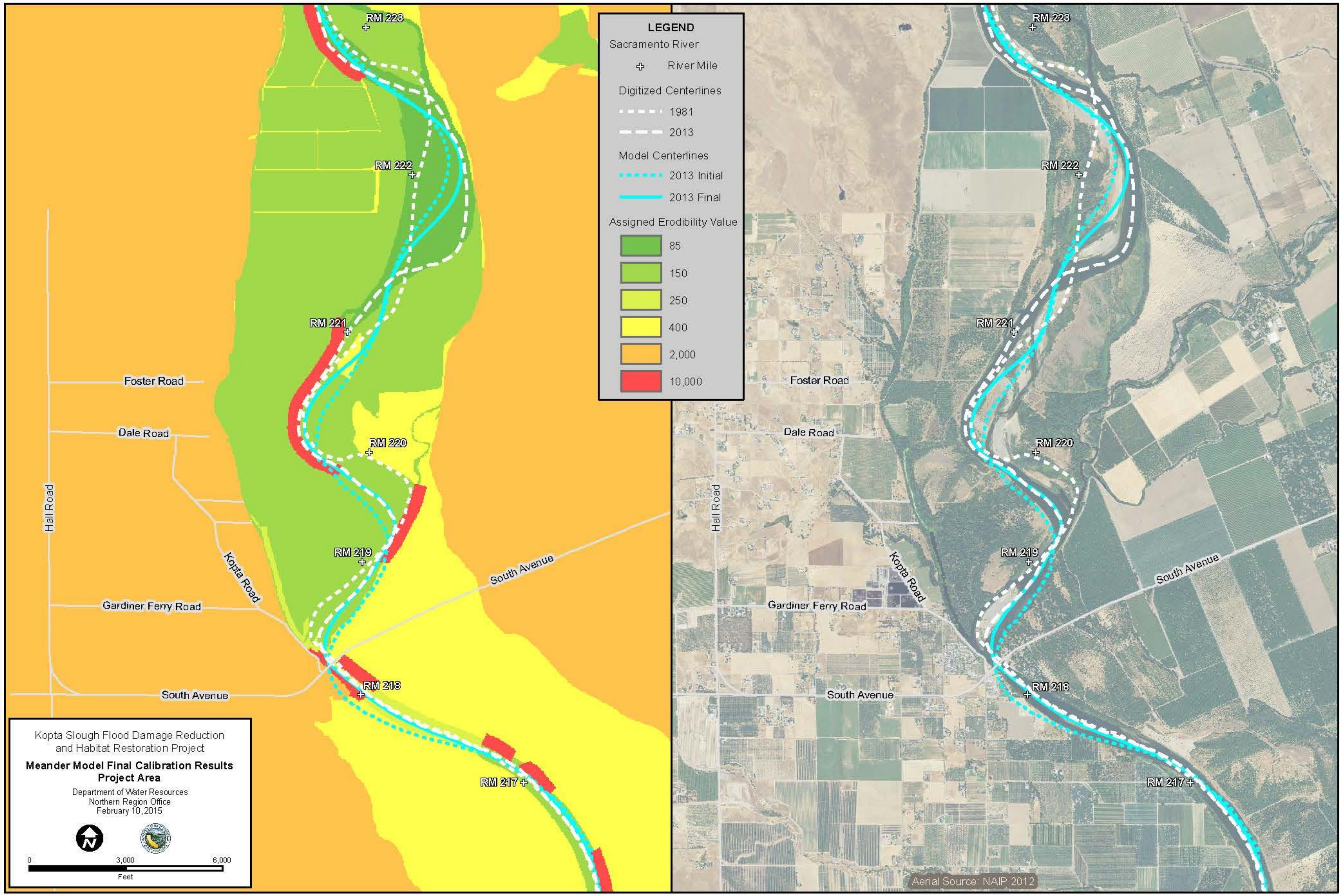


Figure 7 Meander Model Final Calibration Results, Project Area



4.3. Kopta Slough Model Sensitivity Analysis

While it appears that the calibrated Kopta Slough Model is good for evaluating future scenarios, the parameters could be less accurate than were initially thought. To find out how changing the parameters affects the results, a sensitivity analysis was performed. Indicators of sensitivity include the meander centerline alignment and the calculation of area reworked.

As previously stated, all flow and geomorphic parameters (see Table 5) were held constant in order to calibrate the erodibility surface. During that process, a Cf factor of 2 was found to produce the best calibration. The first step of the sensitivity analysis was to determine what effects various erodibility values and Cf factors have on the meander alignment, and thereby, further validate the calibration. The erodibility values (Table 7) and Cf factors (Table 8) were changed one at a time to 80, 90, 95, 105, 110, and 120 percent of their initial values. As shown in

Table 7, Table 10, and Figure 8 through Figure 11, there is, at most, a 15 percent difference in area reworked over the 32 years from 1981 to 2013. This small difference in area reworked indicates that the meander alignment is not that sensitive to minor change in erodibility values or Cf factors, and thus, the results of the calibration are very good.

Table 7 Erodibility (e01) Values Used in the Sensitivity Analysis

Percent of Erodibility (e01)	e01 (non)	e01 (low)	e01 (moderate)	e01 (high1)	e01 (high2)	e01 (high3)
80	8,000	1,600	320	200	120	70
90	9,000	1,800	360	225	135	75
95	9,500	1,900	380	240	145	80
100	10,000	2,000	400	250	150	85
105	10,500	2,100	420	265	160	90
110	11,000	2,200	440	275	165	95
120	12,000	2,400	480	300	180	100

Table 8 Coefficient of Friction Factor (Cf1) Values Used in the Sensitivity Analysis

Percent of Cf1	Cf
80	1.6
90	1.8
95	1.9
100	2
105	2.1
110	2.2
120	2.4

Table 9 Area Reworked (1981–2013) Due to Changes in e01 Values for the Sensitivity Analysis

Percent of e01	Hectares	Acres	Percent Q1 Area	Percent Area Difference
80	343.1	847.8	115	15
90	316.5	782.2	106	6
95	302.7	747.9	101	1
100	299.3	739.5	100	0
105	280.5	693.2	94	-6
110	272.2	672.7	91	-9
120	258.7	639.2	86	-14

Table 10 Area Reworked (1981–2013) Due to Changes in Cf1 Values for the Sensitivity Analysis

Percent of Cf1	Hectares	Acres	Percent Q1 Area	Percent Area Difference
80	315.8	780.5	106	6
90	304.4	752.1	102	2
95	299.3	739.7	100	0
100	299.3	739.5	100	0
105	290.0	716.7	97	-3
110	283.0	699.2	95	-5
120	275.1	679.8	92	-8

Figure 8 Meander Model Erodibility (e01) Sensitivity Results, Model Area

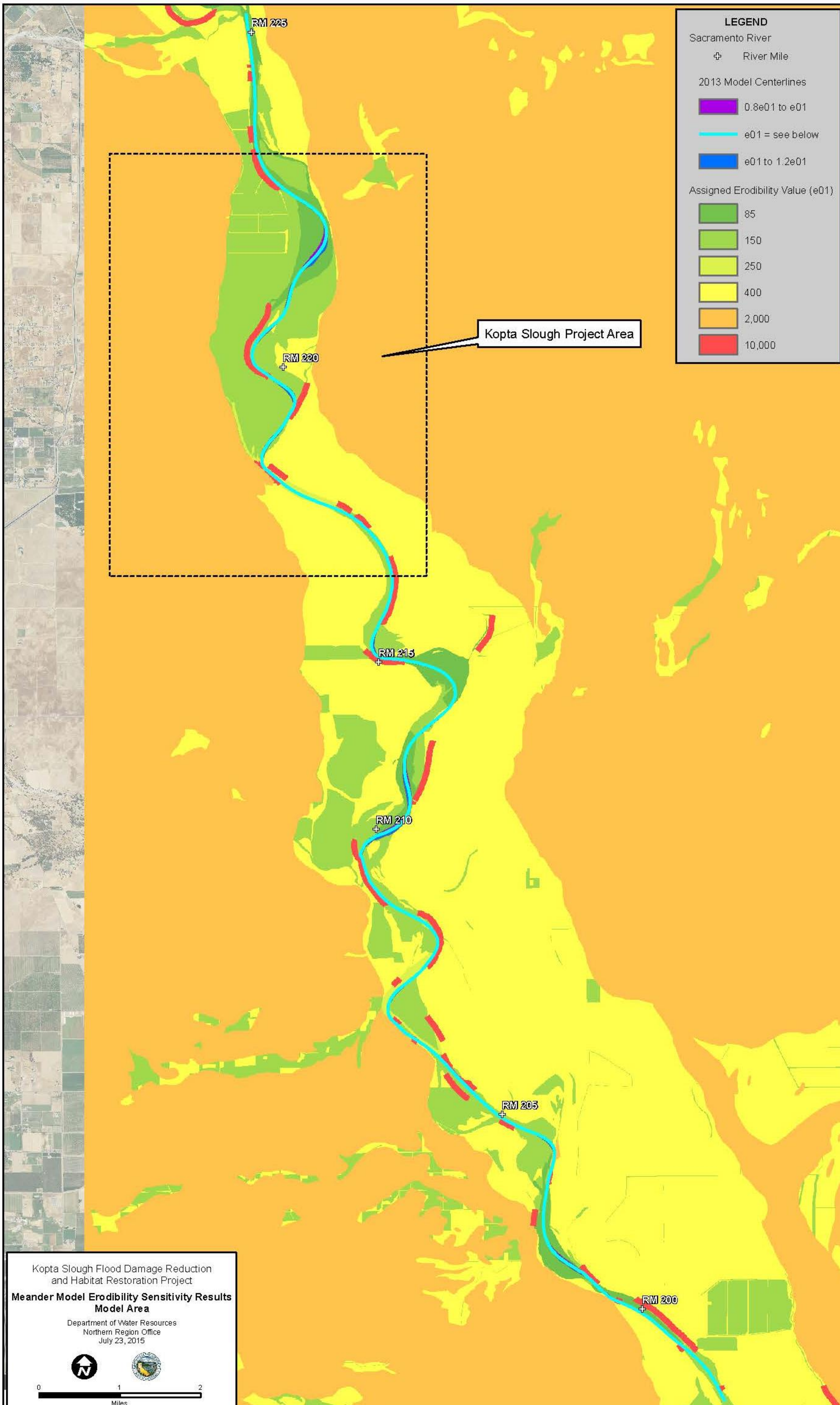


Figure 9 Meander Model Erodibility (e01) Sensitivity Results, Project Area

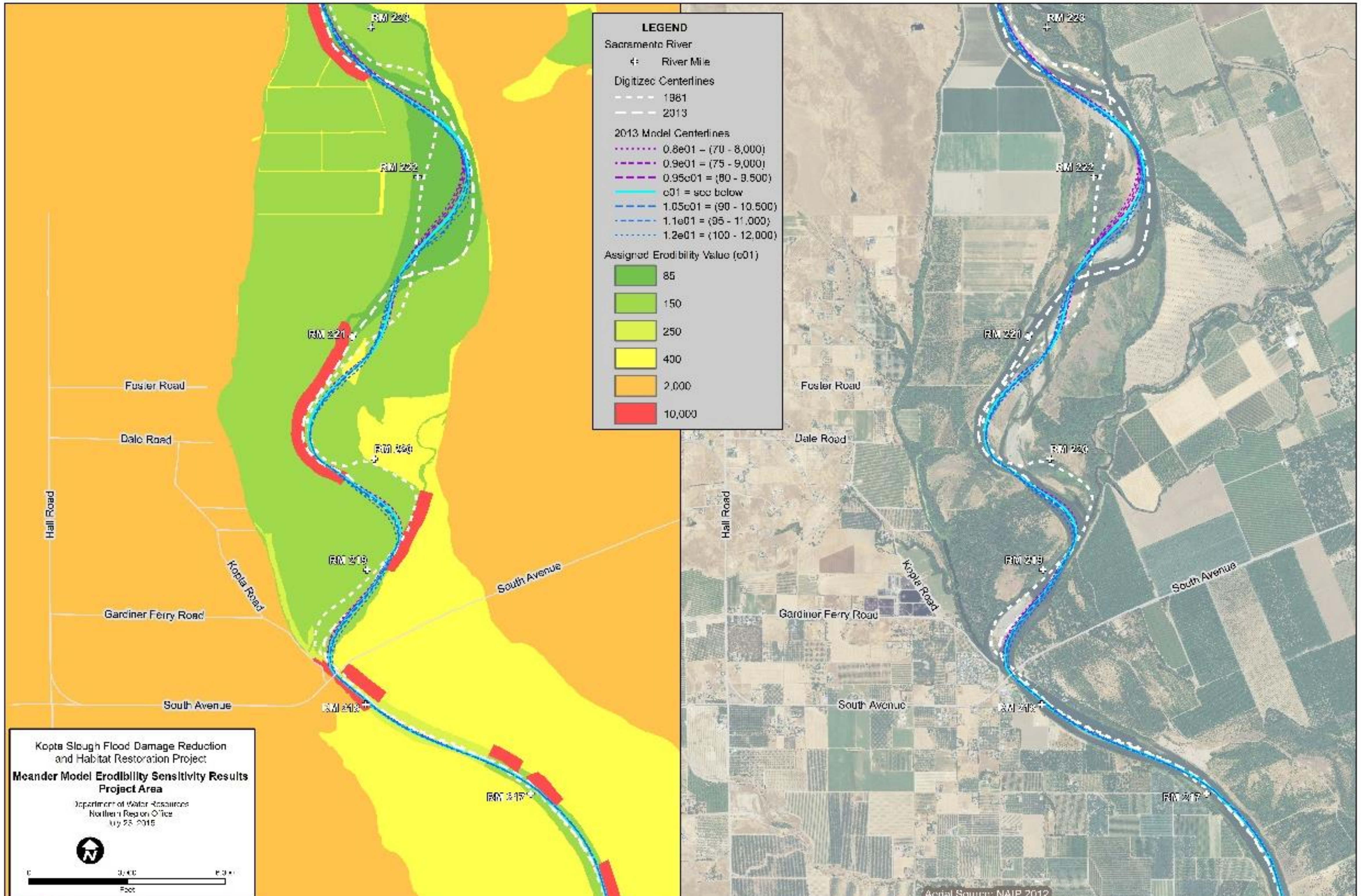


Figure 10 Meander Model Coefficient of Friction Factor (Cf1) Sensitivity Results, Model Area

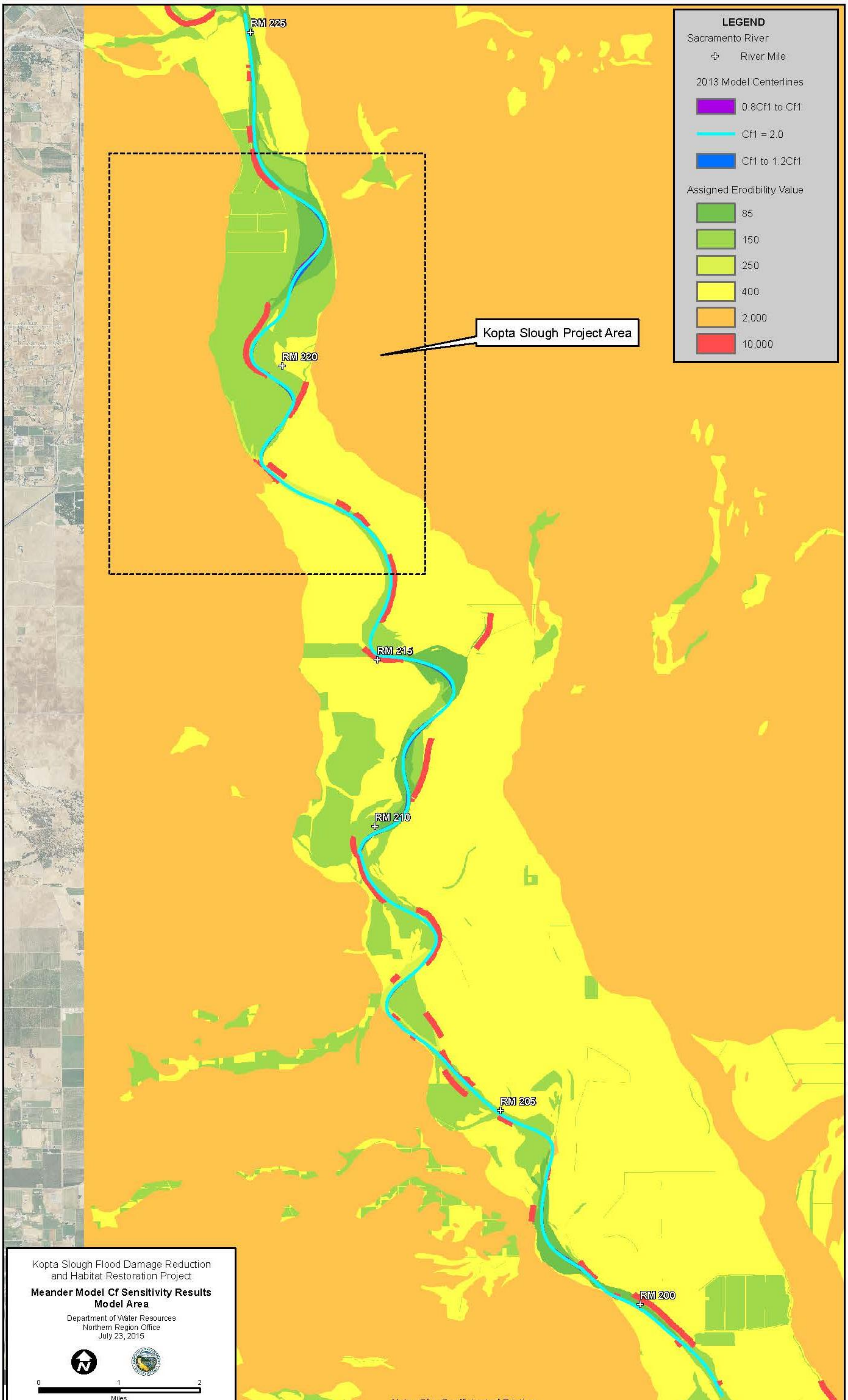
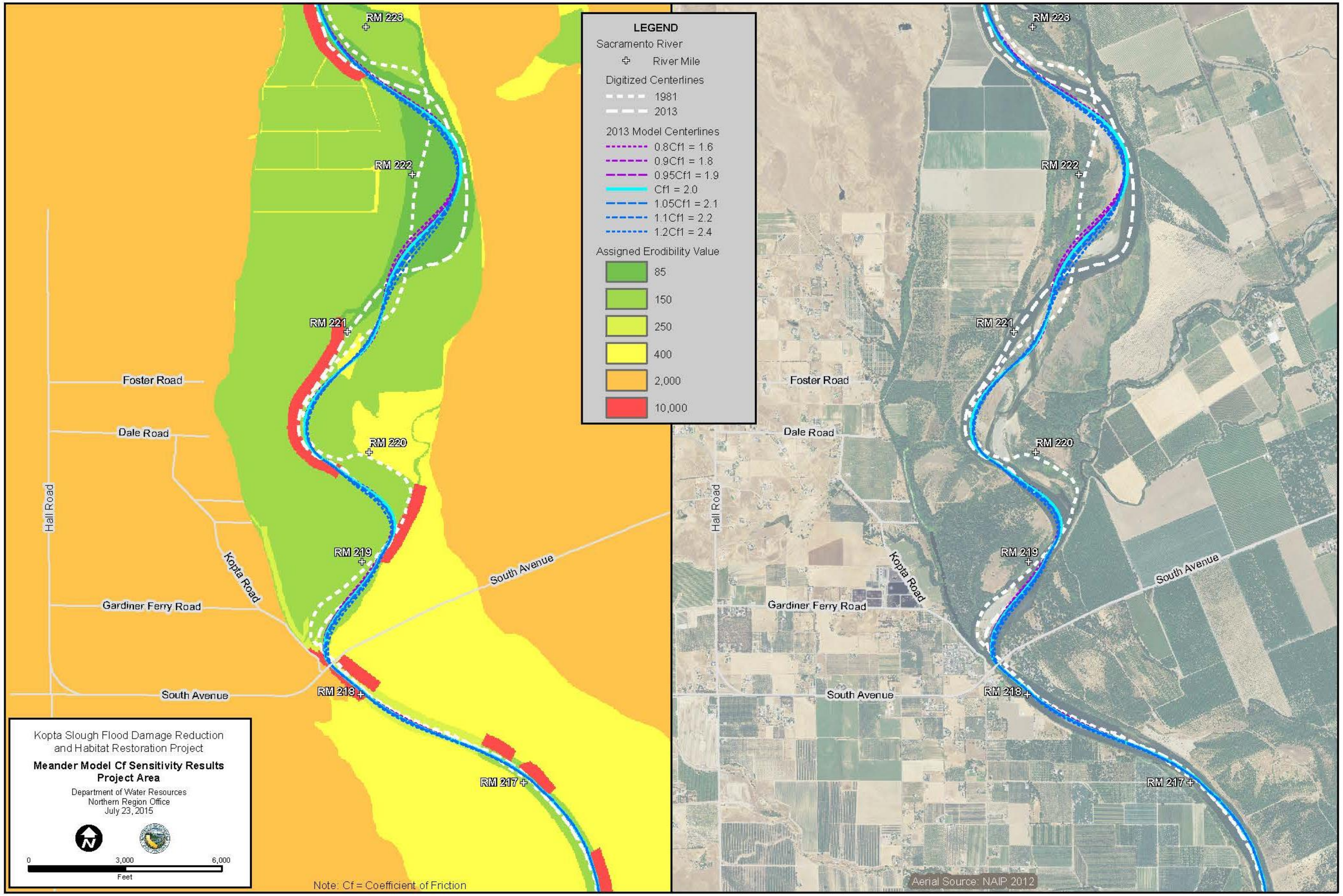


Figure 11 Meander Model Coefficient of Friction Factor (Cf1) Sensitivity Results, Project Area



As previously shown in Table 5, the input flow and geomorphic parameters are flow (Q), width (B), depth (H), slope (S), and particle size (Ds). The input data for the Meander Model is a rectangular flow channel. The Meander Model calculates Manning's equation for flow in cubic meters per second (cms) as follows:

Qcms = (1/n)AR2/3S1/2

Where:

Q = flow, in cms

n = Manning's roughness coefficient (n value)

A = Area = B*H, in square meters

R = hydraulics radius = A/P

S = slope

P = Wetter Perimeter = B+2*H, in meters

(Manning's equation is not a function of grain size)

The Meander Model uses the input parameters to calculate Manning's n value as shown below:

n = (1/u) S1/2 H2/3

Where:

u = velocity = Q/A, in meters per second

The flow and geomorphic sensitivity analysis uses the final erodibility surface (Table 6), a Cf factor equal to 2, and the input parameters (i.e., flow, width, depth, slope, and grain size). The Meander Model was run for the same time period as the calibration, from 1981 to 2013, to allow for easy comparison of results. The sensitivity scenarios involved varying each input parameter one at a time while holding the other parameters constant, allowing Manning's n value to recalculate. The parameters were changed to 80, 90, 95, 105, 110, and 120 percent of their initial values. The results of the scenarios are presented in Table 11 through Table 15 and Figure 12 through Figure 20. Maps for the grain size scenario were not prepared because the change in the meander centerline alignment was so small.

Changes in flow had the largest effect on the alignment of the centerline and the area reworked. A 20-percent change in flow resulted in around a 40-percent change in area reworked. In order of decreasing effect, the parameters are B, H, S, and then Ds.

Table 11 Flow and Geomorphic Parameter Sensitivity Analysis – Area Reworked (1981–2013) Due to Variable Flow (Q)

Percent of Q1	Q (cms)	Q (cfs)	n	Hectares Reworked	Acres Reworked	Percent Q1 Area	Percent Area Difference
80	1760	62,200	0.039	175	431	58	-42
90	1980	69,900	0.034	236	583	79	-21
95	2090	73,800	0.032	271	669	90	-10
100	2200	77,700	0.031	299	740	100	0
105	2310	81,600	0.029	336	829	112	12
110	2420	85,500	0.028	364	899	122	22
120	2640	93,200	0.026	414	1,020	138	38

Notes: Q = flow; cms = cubic meters per second; cfs = cubic feet per second;
n = Manning's Roughness Coefficient

Table 12 Flow and Geomorphic Parameter Sensitivity Analysis – Area Reworked (1981–2013) Due to Variable Width (B)

Percent of B1	B (m)	B (ft)	n	Hectares	Acres	Percent B1 Area	Percent Area Difference
80	174	572	0.025	416	1,030	139	39
90	196	644	0.028	355	876	119	19
95	207	679	0.029	325	804	109	9
100	218	715	0.031	299	740	100	0
105	229	751	0.032	277	685	93	-7
110	240	787	0.034	256	633	86	-14
120	262	858	0.037	220	544	74	-26

Notes: B = width; m = meters; ft = feet; n = Manning's Roughness Coefficient

Table 13 Flow and Geomorphic Parameter Sensitivity Analysis – Area Reworked (1981–2013) Due to Variable Depth (H)

Percent of H1	H (m)	H (ft)	n	Hectares	Acres	Percent H1 Area	Percent Area Difference
80	4.0	13.1	0.021	367	907	123	23
90	4.5	14.8	0.026	337	833	113	13
95	4.8	15.6	0.028	316	780	105	5
100	5.01	16.4	0.031	299	740	100	0
105	5.3	17.3	0.033	279	689	93	-7
110	5.5	18.1	0.036	265	654	88	-12
120	6.0	19.7	0.042	231	572	77	-23

Notes: H = depth; m = meters; ft = feet; n = Manning's Roughness Coefficient

Table 14 Flow and Geomorphic Parameter Sensitivity Analysis – Area Reworked (1981–2013) Due to Variable Slope (S)

Percent of S1	S (m/m)	S (ft/ft)	n	Hectares	Acres	Percent S1 Area	Percent Area Difference
80	0.00036	0.00036	0.028	268	663	90	-10
90	0.00041	0.00041	0.029	287	708	96	-4
95	0.00043	0.00043	0.030	294	726	98	-2
100	0.00045	0.00045	0.031	299	740	100	0
105	0.00047	0.00047	0.032	306	757	102	2
110	0.00050	0.00050	0.032	318	787	106	6
120	0.00054	0.00054	0.034	332	821	111	11

Notes: S = slope; m/m = meters per meter; ft/ft = feet per feet; n = Manning's Roughness Coefficient

Table 15 Flow and Geomorphic Parameter Sensitivity Analysis – Area Reworked (1981–2013) Due to Variable Grain Size (Ds)

Percent of Ds1	Ds (mm)	Ds (in)	n	Hectares	Acres	Percent Ds1 Area	Percent Area Difference
80	20	0.8	0.031	304	750	101	1
90	23	0.9	0.031	301	744	101	1
95	24	0.9	0.031	302	745	101	1
100	25	1.0	0.031	299	740	100	0
105	26	1.0	0.031	300	741	100	0
110	28	1.1	0.031	296	732	99	-1
120	30	1.2	0.031	293	724	98	-2

Notes: Ds = grain size; mm = millimeters; in = inches; n = Manning's Roughness Coefficient

Figure 12 Flow and Geomorphic Parameter Sensitivity Analysis – Area Reworked

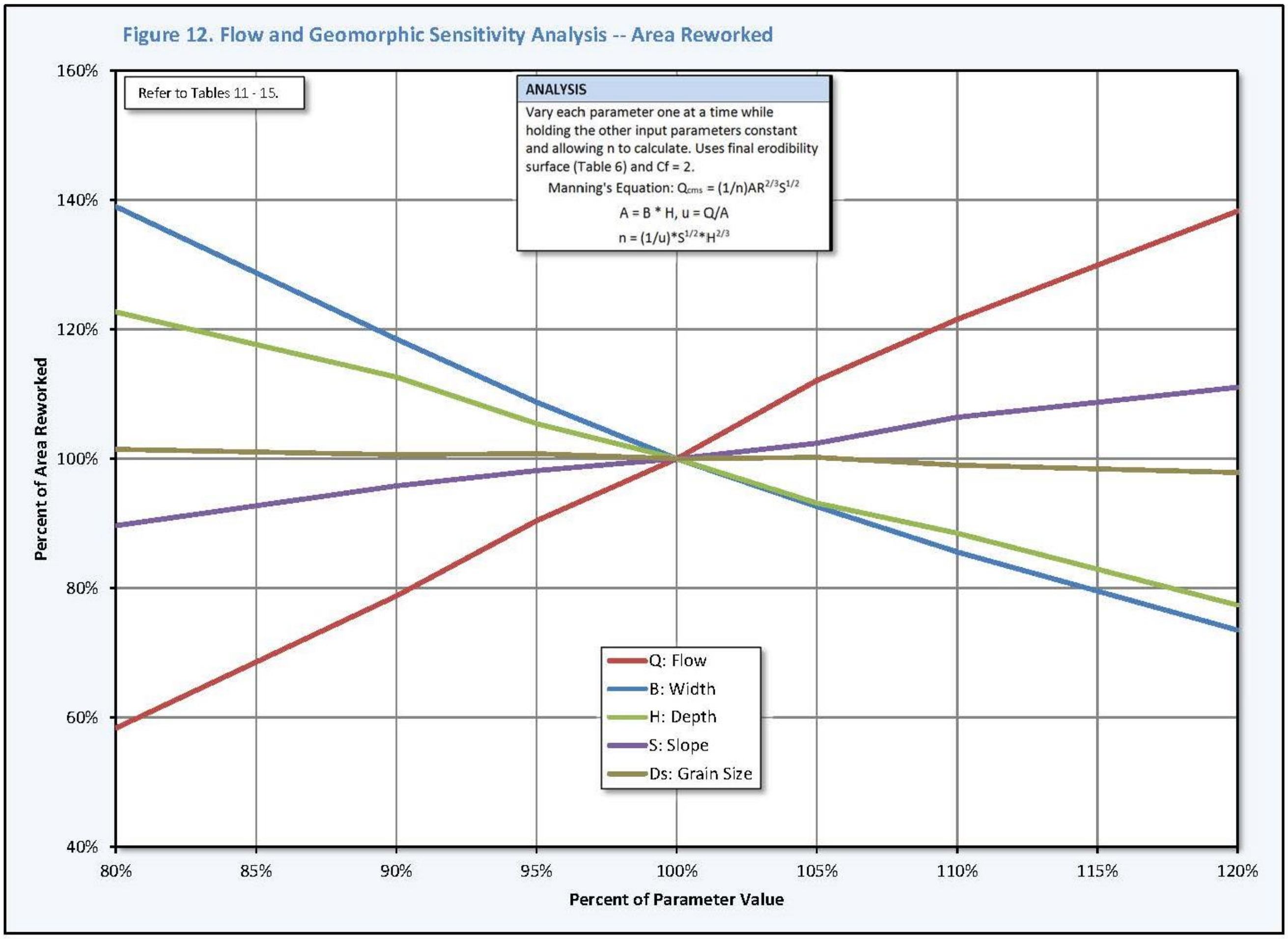


Figure 13 Meander Model Flow (Q) Sensitivity Results, Model Area

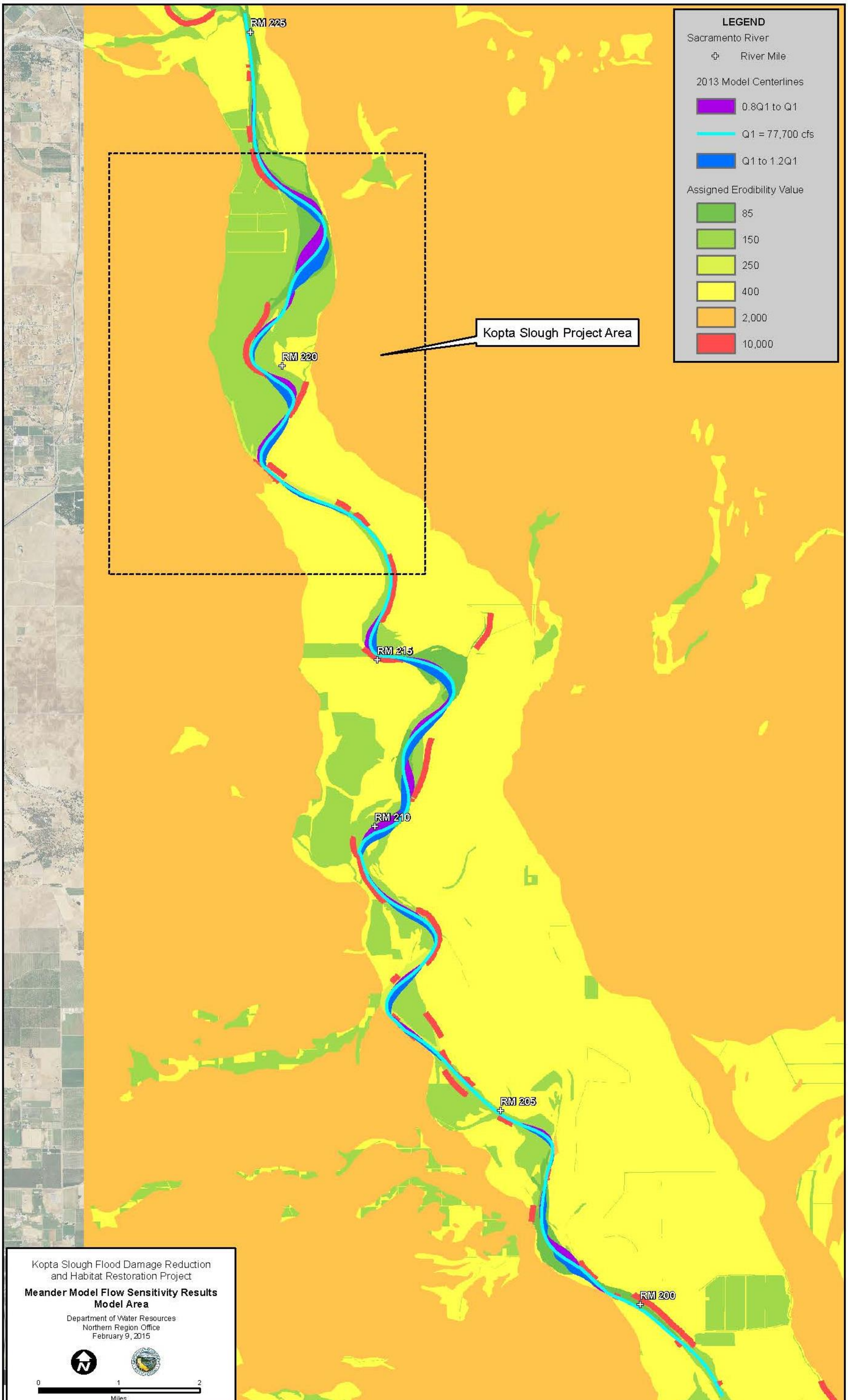


Figure 14 Meander Model Flow (Q) Sensitivity Results, Project Area

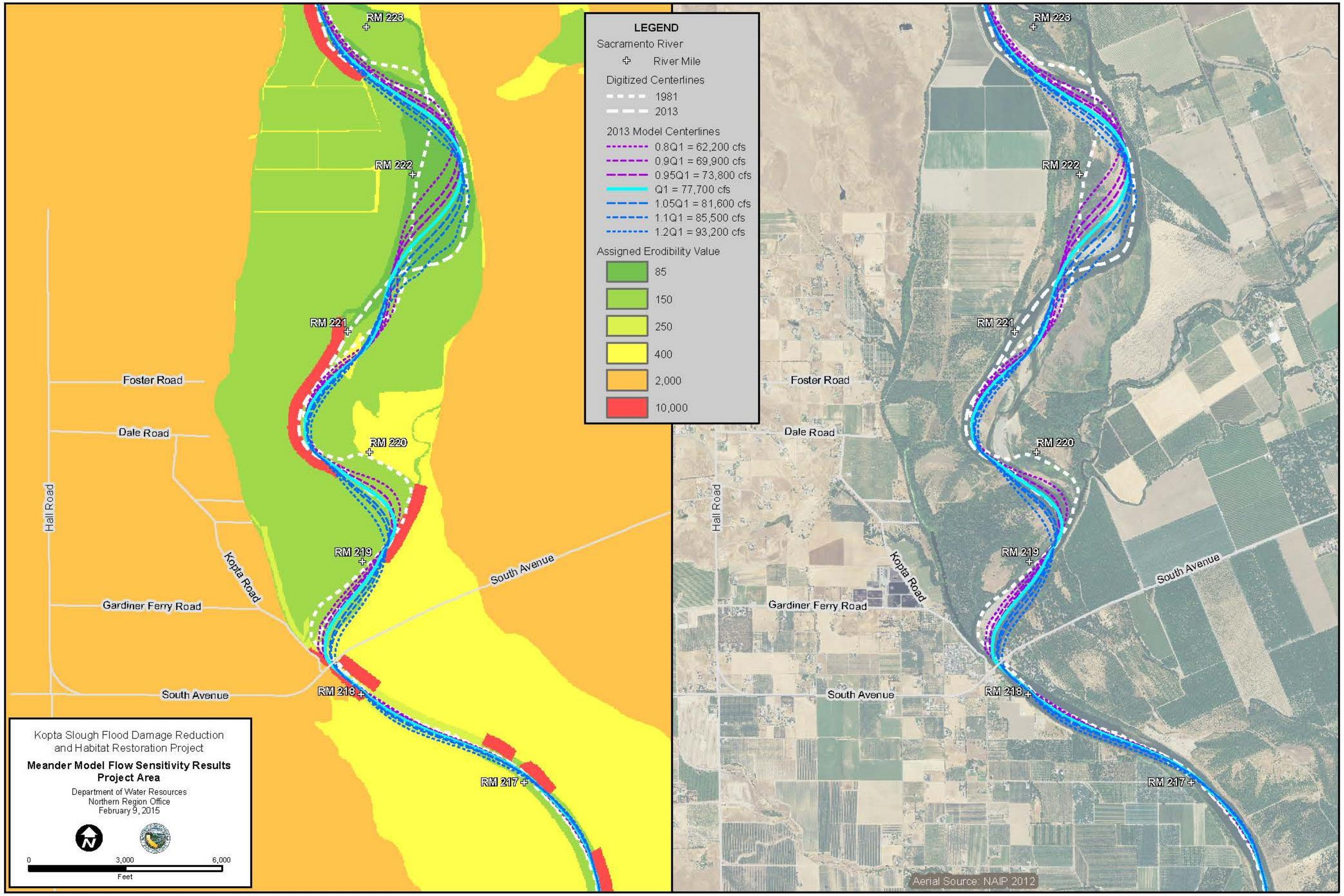


Figure 15 Meander Model Width (B) Sensitivity Results, Model Area

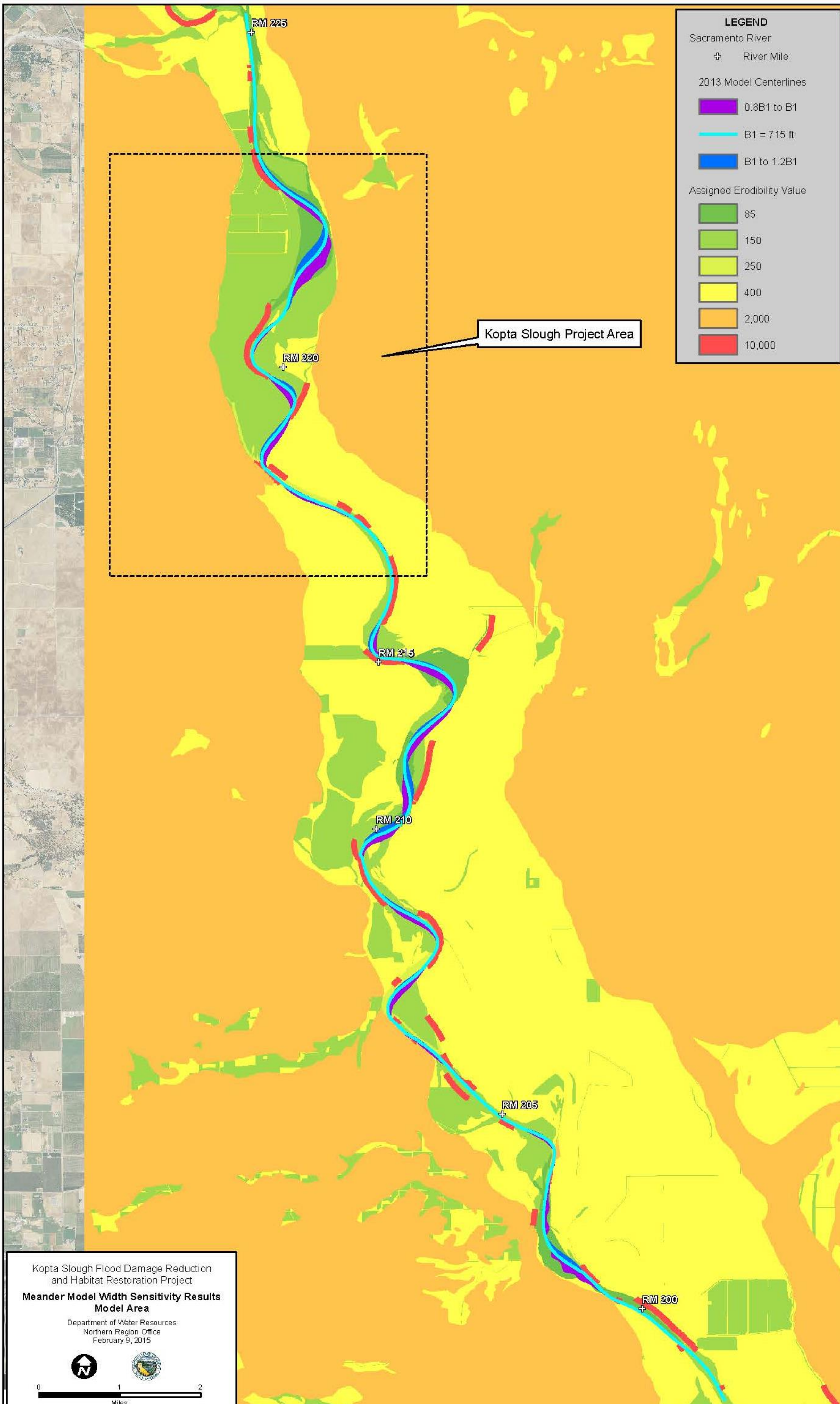


Figure 16 Meander Model Width (B) Sensitivity Results, Project Area

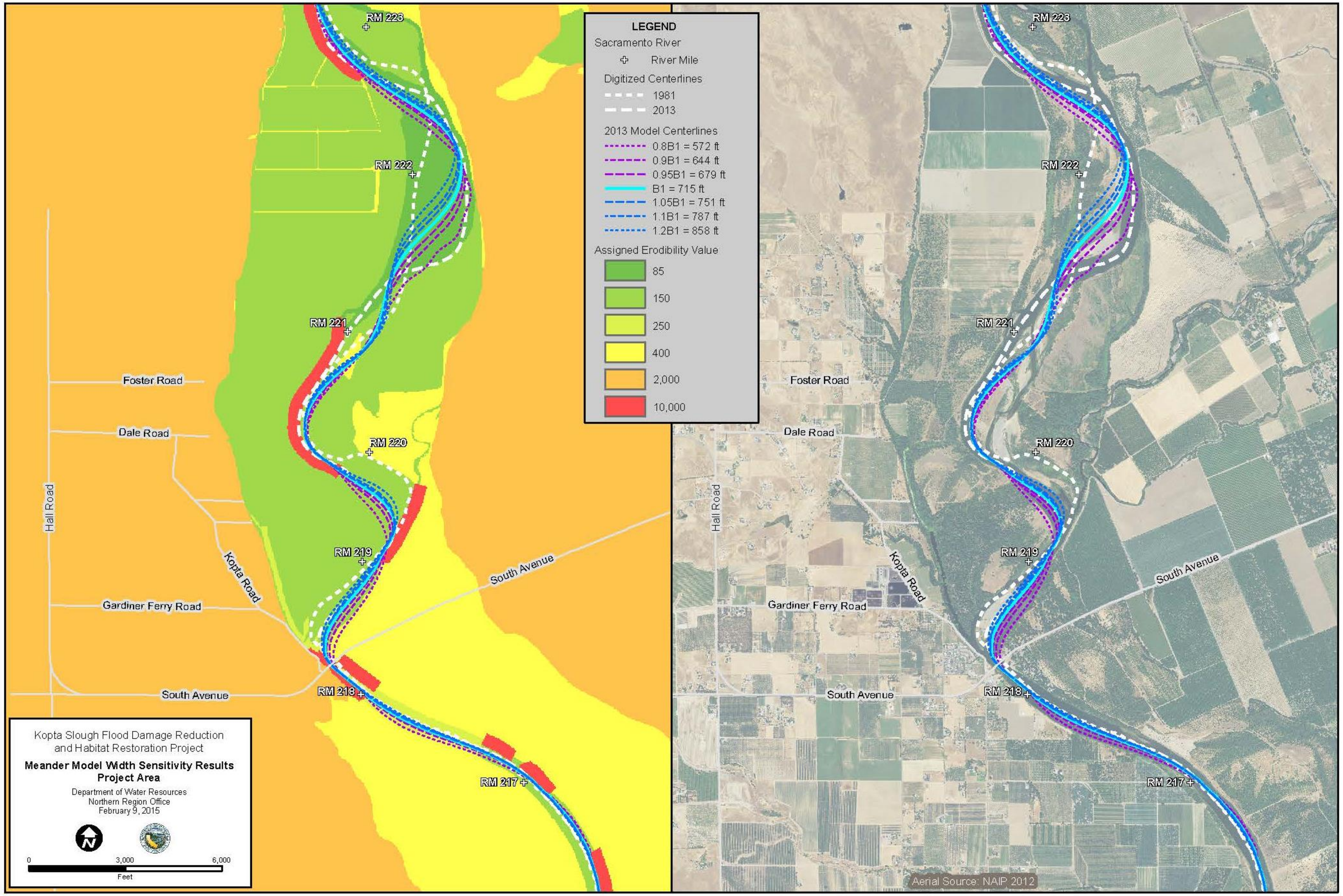


Figure 17 Meander Model Depth (H) Sensitivity Results, Model Area

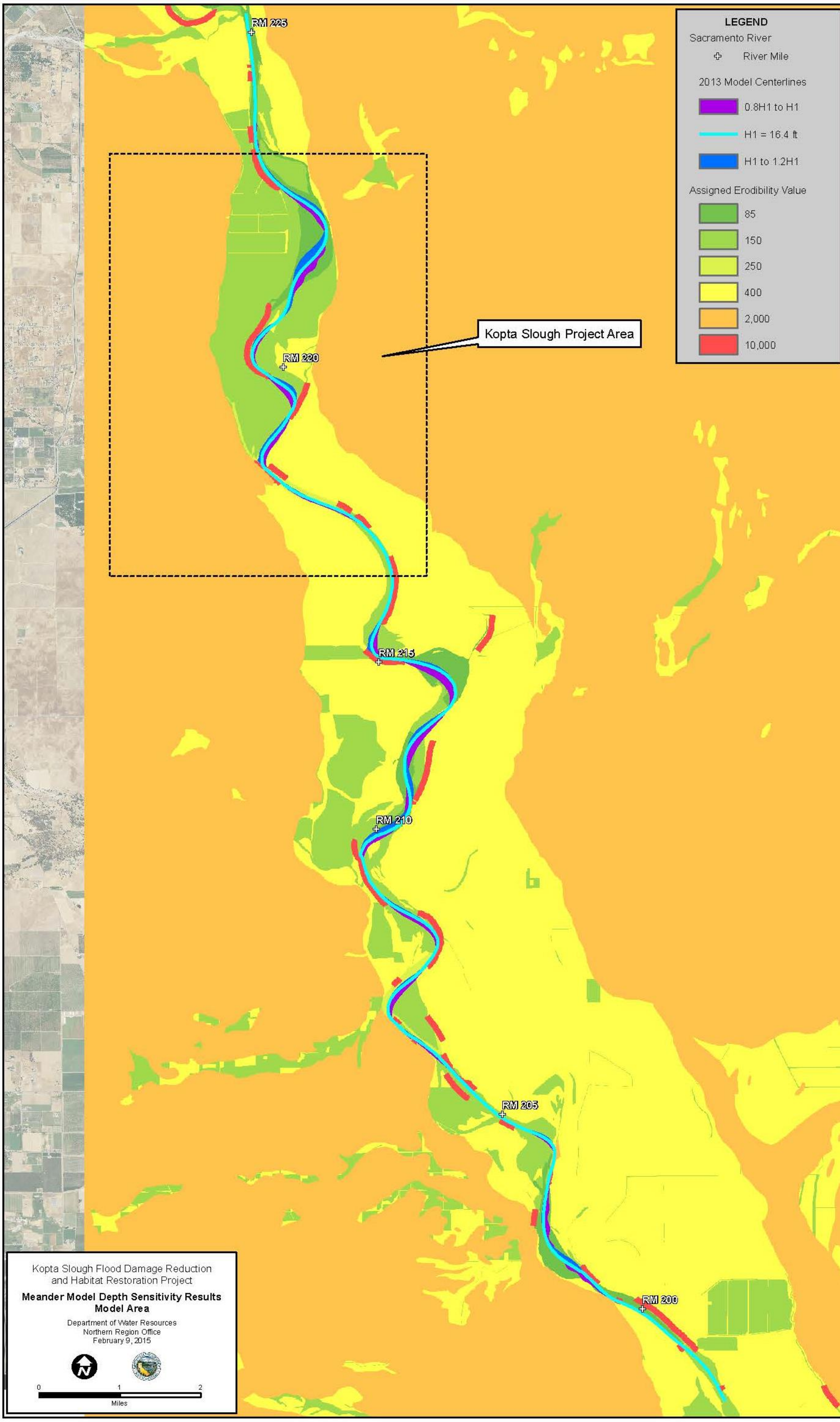


Figure 18 Meander Model Depth (H) Sensitivity Results, Project Area

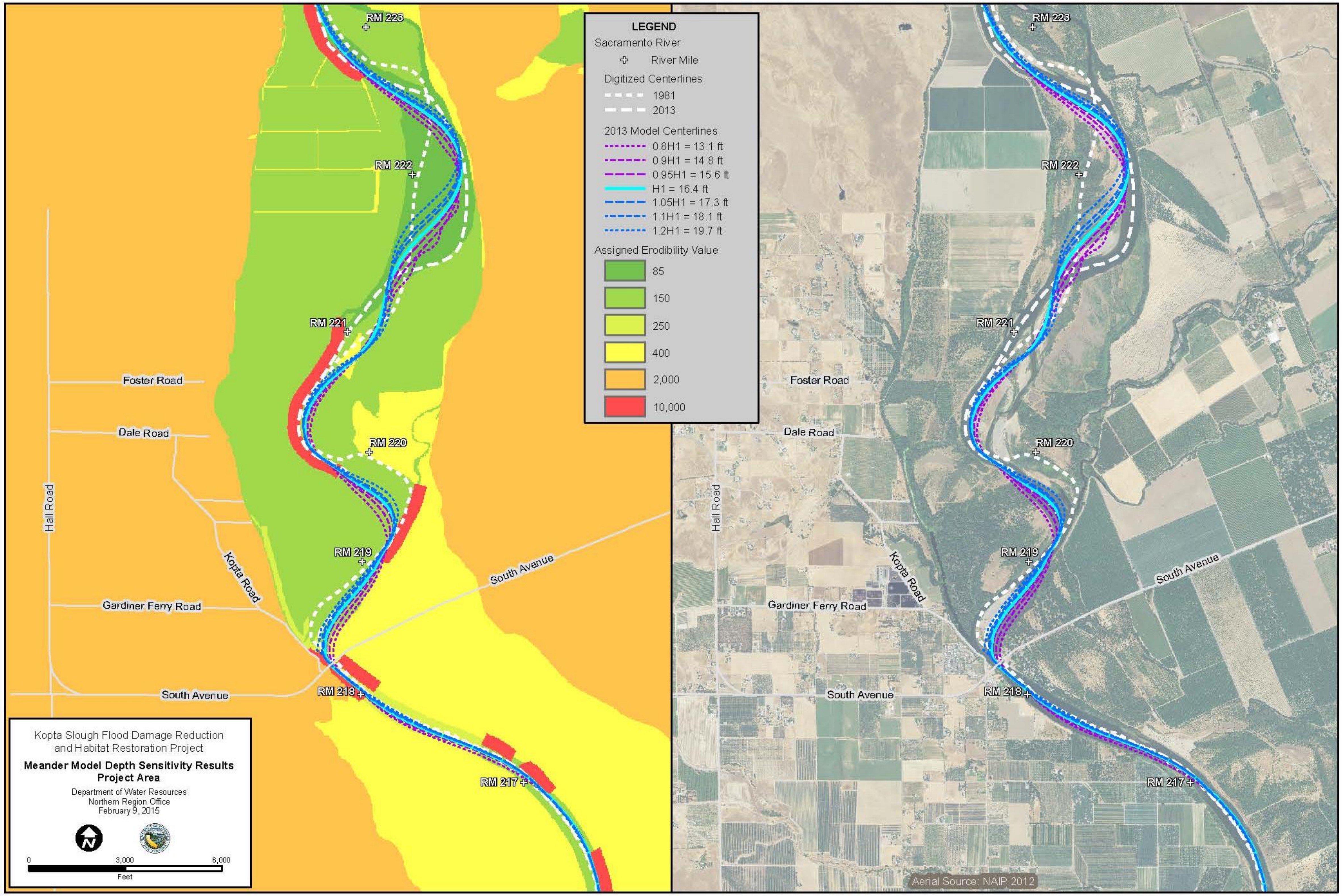


Figure 19 Meander Model Slope (S) Sensitivity Results, Model Area

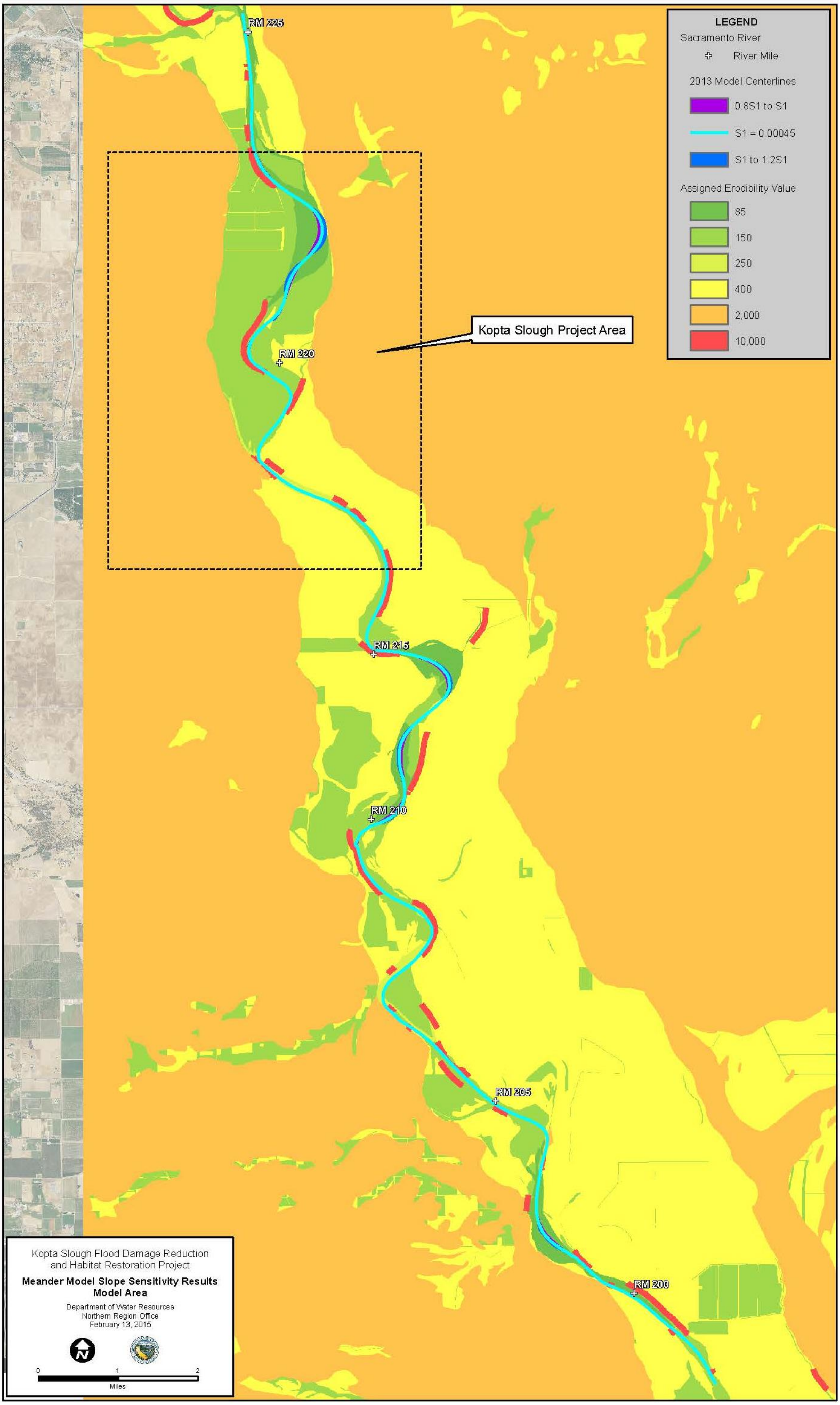
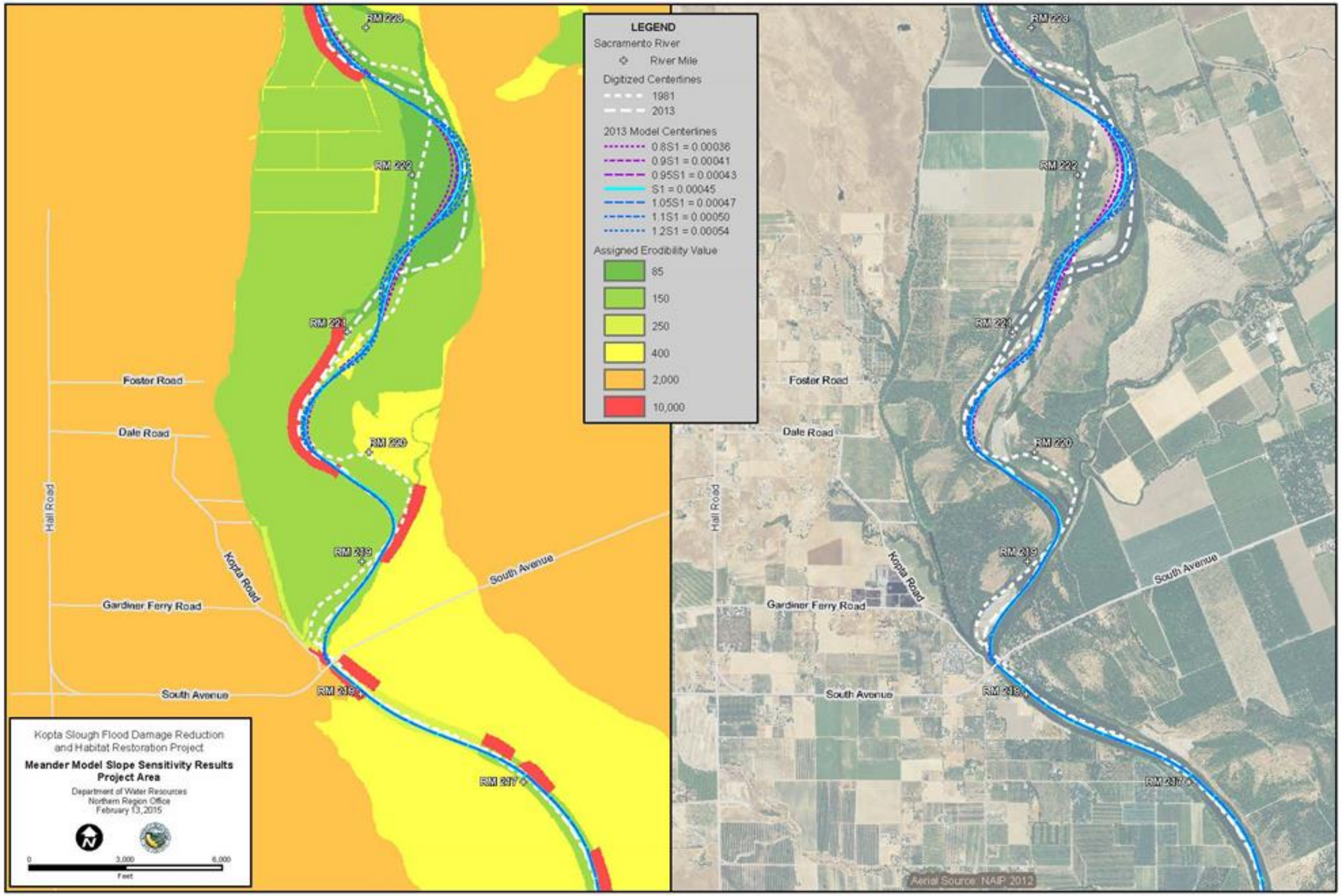


Figure 20 Meander Model Slope (S) Sensitivity Results, Project Area



4.4. Predictive Future Runs Of Kopta Slough Model

After calibrating the Kopta Slough Model and performing the sensitivity analysis, predictive future runs were performed. The Kopta Slough Model was run using the digitized 2013 centerline and the default Meander Model time of 50 years.

The Kopta Slough Model was first run with the final erodibility surface as determined by the calibration process, the results of which are shown in Figure 21 and 22. The Kopta Slough Model shows that by 2063, the centerline of the Sacramento River will continue to trend southeast between River Miles 218 and 219, eroding the left bank of the Sacramento River at the Woodson Bridge State Recreation Area. Over these 50 years, the results show the centerline will move about 650 feet in this reach, or approximately 13 feet per year. This erosion rate is similar to the past surveyed rate of 11 to 16 feet per year.

Next, the Kopta Slough Model was run with the "revetment removed" between River Miles 220 and 221. Revetment removal was done by changing the erodibility value of that area to 150, which is the same value as the surrounding area. The results of this run are shown in Figure 23 and Figure 24. The Kopta Slough Model shows that by 2063, the centerline of the Sacramento River will trend to the west in the area where the revetment was removed, but the centerline will also continue to trend southeast between River Miles 218 and 219, eroding the Woodson Bridge State Recreation Area at a rate similar to the erosion predicted if the upstream revetment remained in place. Table 16 shows the area reworked for both future scenarios.

Table 16 Future Scenario Area Reworked (2013–2063)

Scenario	(Hectares)	(Acres)	No Revetment / Revetment
Revetment	306	756	
No Revetment	331	818	11%

Figure 21 Meander Model with Revetment, Future Results – Model Area

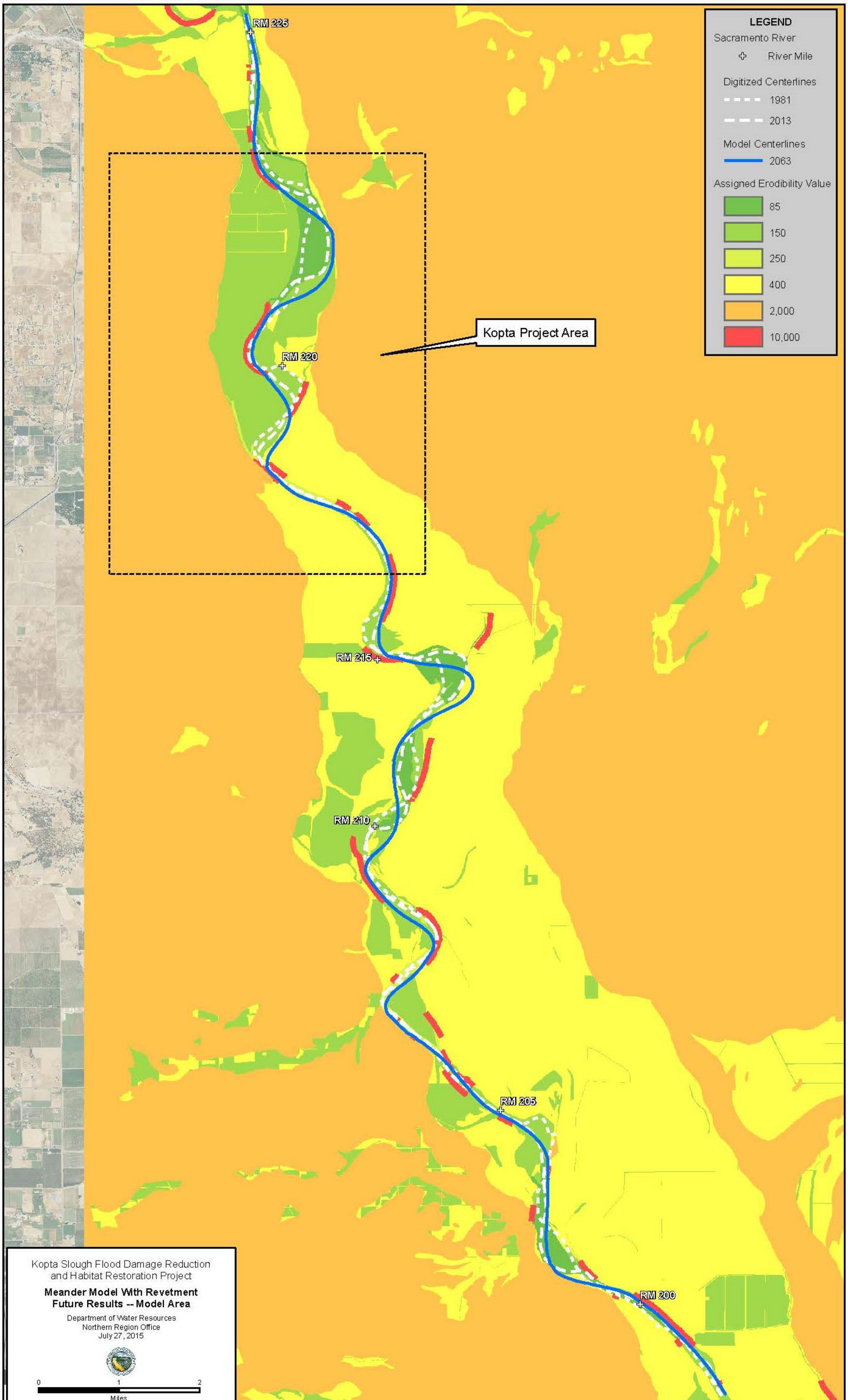


Figure 22 Meander Model with Revetment, Future Results – Project Area

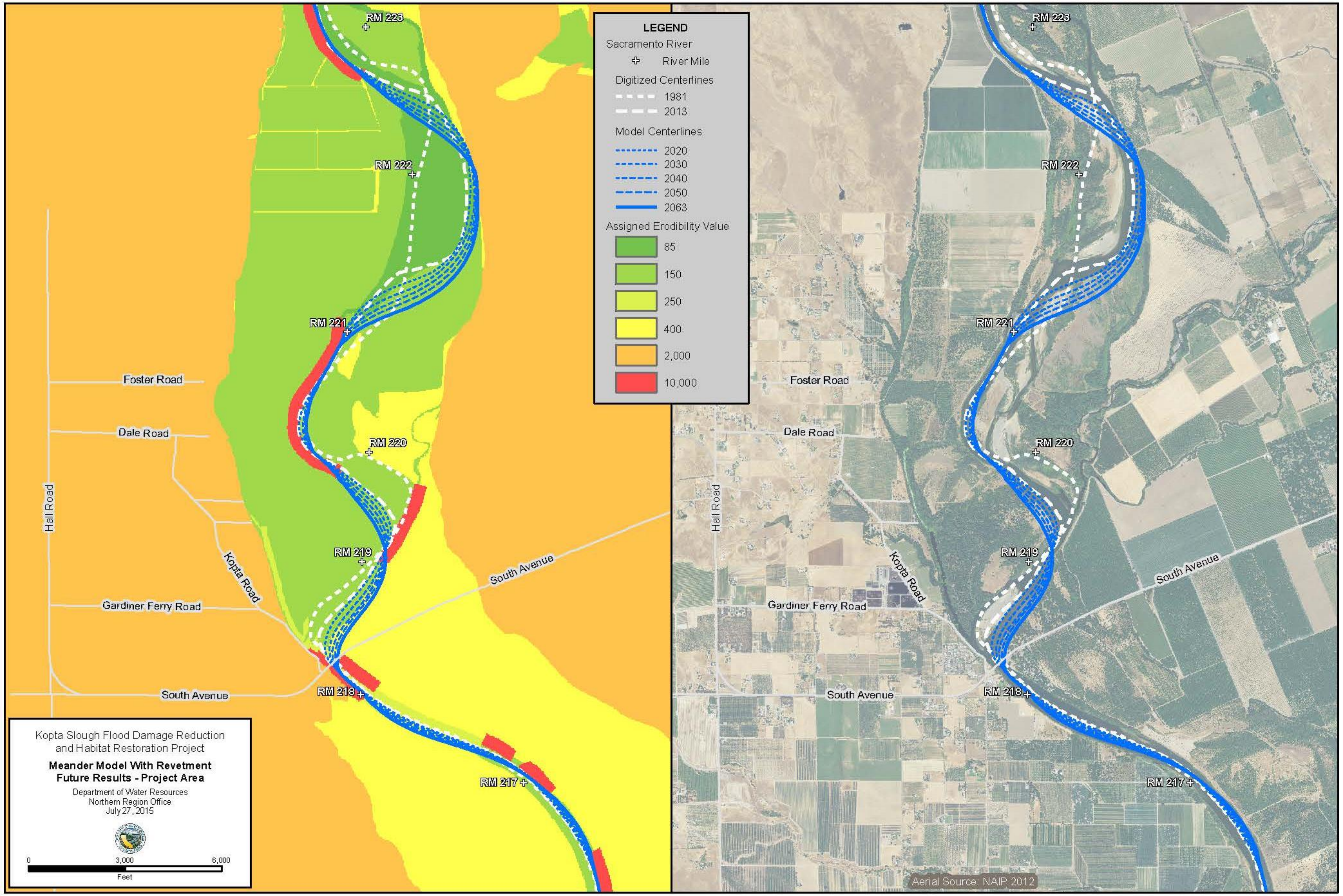


Figure 23 Meander Model without Revetment, Future Results – Project Area

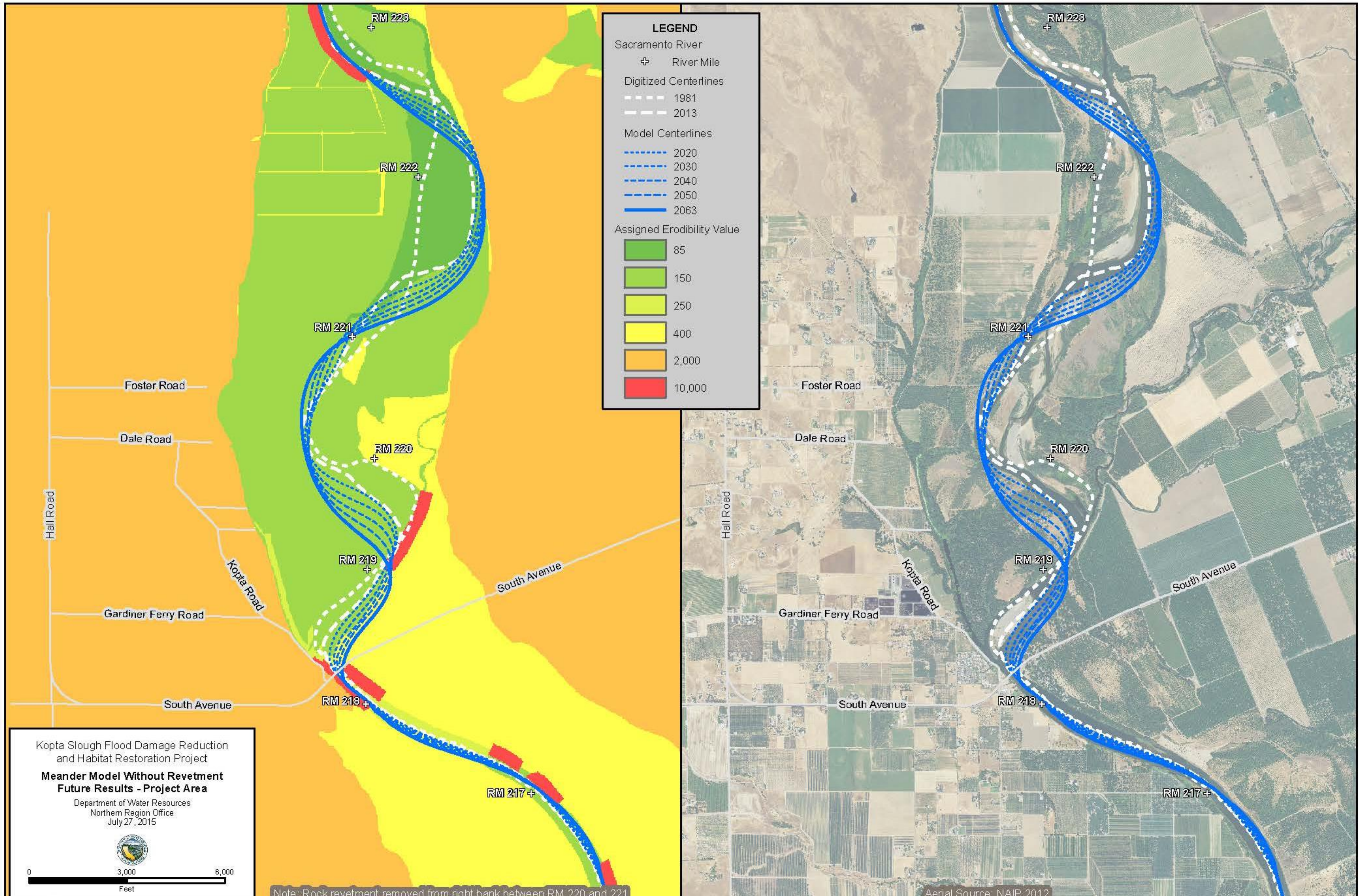
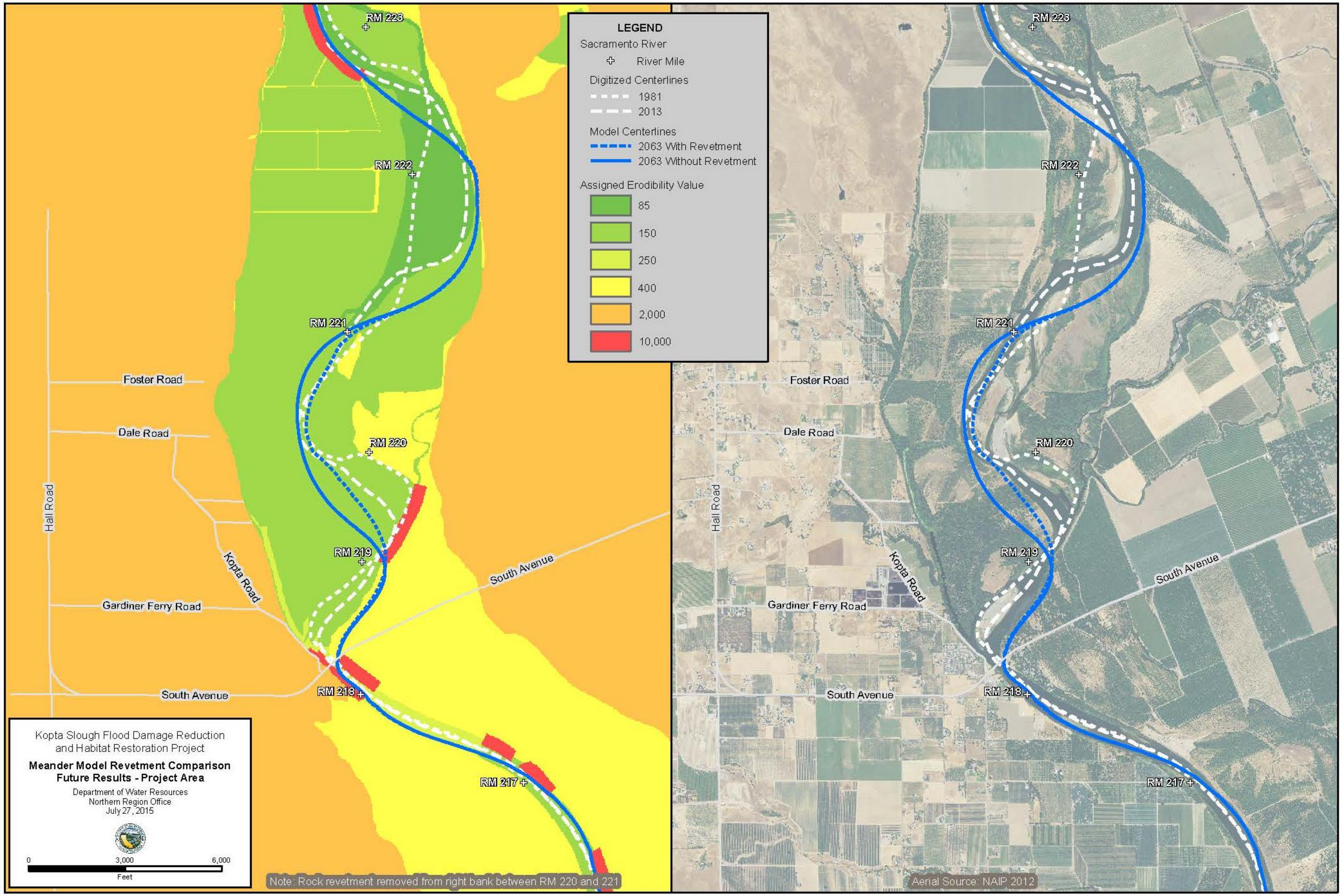


Figure 24 Meander Model Revetment Comparison, Future Results – Project Area



5. Conclusions

The Meander Model is a tool for evaluating the future migration of a stream. The Meander Model cannot predict the exact location of the river centerline in the future, but it can predict the trend of the river meander.

The Meander Model was used for the Project in order to evaluate the effects of removing revetment from the right bank of the Sacramento River between RM 220 and RM 221. According to the results of the Meander Model, revetment removal would allow the river to migrate to the west in that reach, improving natural floodplain functionality and increasing area reworked by 11 percent. While it was initially thought that revetment removal would also allow the Sacramento River to migrate away and thereby reduce erosive stress on the Woodson Bridge State Recreation Area, the meander modeling results did not show this trend (Figure 24). The meander modeling results indicate that the erosion and trend of the Sacramento River towards the Woodson Bridge State Recreation Area would be the same with or without the upstream revetment.

6. References

6.1. References Cited

California Department of Water Resources (DWR). 2013. Draft Kopta Slough Flood Damage Reduction and Habitat Restoration Project Feasibility Study.

Larsen Eric W., David L. Smith, Brian M. Mulvey. 2014. Modeling Meander Migration for Assessing Impacts and Benefits of Channel Management Scenarios, Middle Sacramento River, California. U.S. Army Corps of Engineers, Engineer Research and Development Center (USACE). ERDC/EL TR-1X-DRAFT.

6.2. Personal Communication

Larsen, Eric W. In-person, phone, and email. May 2014 through August 2015.

6.3. References Consulted

Larsen, Eric W. and Steven E. Greco. (2002). "Modeling Channel Management Impacts on River Migration: A Case Study of Woodson Bridge State Recreation Area, Sacramento River, California, USA." Environmental Management. Vol. 30 No. 2, pp. 209-224.

Larsen Eric W. 2007. Sacramento River Ecological Flows Study: Meander Migration Modeling Final Report. The Nature Conservancy.