Lower Hassayampa Watercourse Master Plan
Phase II

Lateral Erosion Hazard Zone Delineation

by the

Engineering Application Development and River Mechanics Branch
Engineering Division
Flood Control District of Maricopa County

August 2011

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Table of Contents

INTRODUCTION 1

OVERVIEW OF NEW GUIDELINE 1

DATA COLLECTION 2

ASSUMPTIONS MADE IN THE ANALYSIS 4

USE OF MAXIMUM SINGLE EVENT CHANGE FROM PHASE I 4

FLOW RATES AND MAIN CHANNEL 5

CROSS SECTION LINEAGE AND DEVELOPMENT 6

CALCULATION OF THE LATERAL EROSION DISTANCE 10

TOTAL SCOUR 10

MAXIMUM SINGLE EVENT EROSION DISTANCE 11

RIVER BENDS 12

RESULTS 13

FIELD VERIFICATION 13

CONCLUSIONS 19

RECOMMENDATIONS 23

REFERENCES 25

APPENDIX 26

Introduction

In Phase I of the Lower Hassayampa River Watercourse Master Plan (LHWCMP), the existing condition of the Hassayampa River was evaluated and documented. Three lateral erosion hazard zones were also delineated as a part of Phase I. Since there were three zones (severe, lateral migration and long-term) delineated, there is some confusion on which zone should be used to regulate development. To reduce this confusion, the Flood Control District of Maricopa County (FCDMC) developed a new draft lateral erosion hazard zone guideline (FCDMC, 2011). In Phase II of the Watercourse Master Plan, the new guideline will be implemented.

Overview of New Guideline

The new guideline is divided into two main procedures. The first one is applicable when historical aerial photographs are available, while the second category is used when historical photographs are not available. For the Hassayampa River, historical photographs are available. Therefore, the main channel lateral erosion distance [ft], L, is calculated with

$$L = L_H + 3(D + Z_t) \quad (1)$$

where L_H is the largest lateral erosion distance that occurs in a single event [ft], D is the channel depth [ft], and Z_t is the total scour depth [ft]. The largest lateral erosion distance that occurs in a single event is estimated from measured bank movement that can be seen in historical photographs, and the total scour depth is calculated with the methodology that is given in FCDMC (2010).

If there are bends in the river, the lateral erosion hazard zone needs to be delineated to encompass these bends. The main channel lateral erosion distance, L, is still calculated with Equation 1, but only at the outer portion of the bend. The zone is then drawn to capture the maximum limits of the bends (see Figure 1).

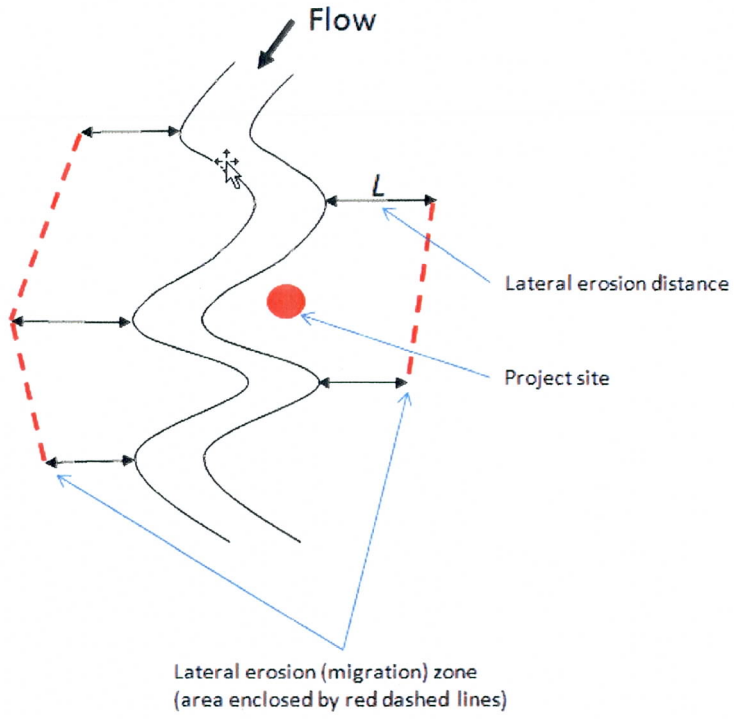

Figure 1. Lateral erosion hazard zone at a curved channel (adapted from FCDMC 2011).

Data Collection

As a part of the delineation, the Phase I River Behavior Report (JEF, 2006) and the Final Hydraulics Report (WEST, 2006) were reviewed, and it was decided that much of the data from Phase I could be used in Phase II. The following is a list of the Phase I data that was used in Phase II:

- the D_{50} gradation along the Hassayampa River,
- the designation of the Lower Hassayampa into five similar reaches,
- the long-term scour from the HEC-6 results,
- the cross-section shapefile from the Final Hydraulics Report, and
- the maximum single event lateral change from the River Behavior Report (shown in Table 1).

However, all data that was used in the Phase II analysis was not collected from the Phase I Master Plan. The effective floodplain shapefile was taken from the FCDMC's GIS database. Here, the effective floodplain is defined as those floodplains that have been approved by the Federal Emergency Management Agency (FEMA) as of November 2010, which was the date the Phase II delineation was started. The effective FEMA floodway for the Hassayampa River was delineated by Cella Barr Associates, Inc. in 1988. The effective floodway line was extracted from the floodplain shapefile, and the floodway was dissolved to make one continuous polygon. The final Hassayampa floodway shapefile (named ExstHassFEMAFlood_Dissolve.shp) is shown in Figure 2. The cross-sections shapefile (named CrossSections.shp) was taken from the LHWCMP Phase I Final Hydraulics Report (WEST, 2006). As a note, the hydraulic cross-section locations from Phase I were compared with those from the Phase II update of the HEC-RAS model by Stantec, and it was found that the locations were identical. The Phase I cross-sections shapefile was used in the current lateral erosion analysis because the Phase II shapefile was not readily available at the beginning of the study, and the cross-section locations from both Phases are in the same location. However, the Phase II HEC-RAS model was used to obtain all hydraulic variables. All digital files that were used in this analysis will be included in the Appendix.

Table 1. Maximum single event channel change from Phase I (JEF, 2006).

Reach	Aerial Photo Set	Max Lateral Change (ft)	River Station	Bank
5	1964-1972	478	25.72	Right
4	1964-1972	511	21.27	Left
3	1988-1992	540	13.32	Right
2	1949-1953	1,329	10.12	Left
1	1949-1953	665	between 1.91 and 2	Left

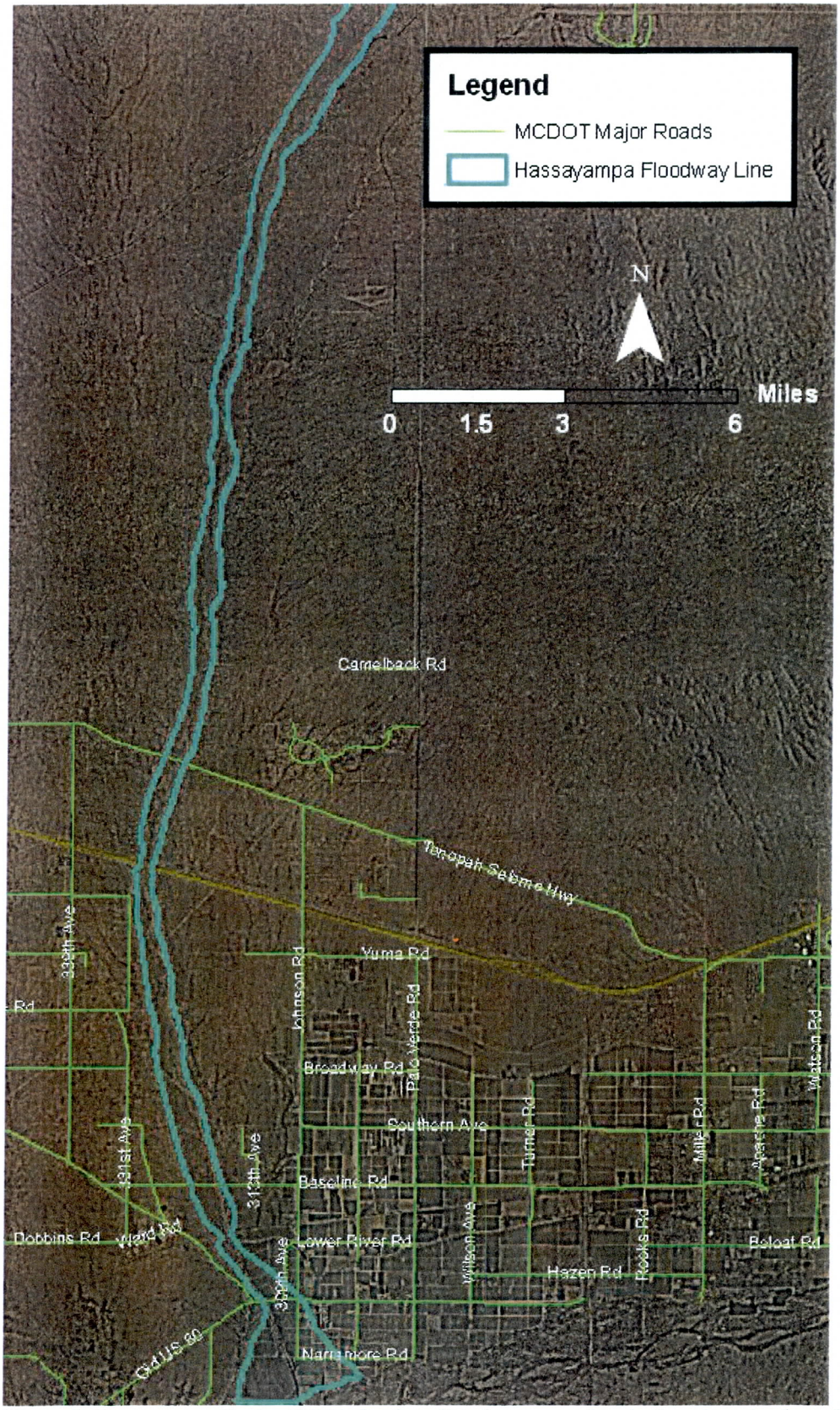

Figure 2. Hassayampa effective FEMA floodway line that was used in the lateral erosion hazard delineation. The background aerial photograph was taken in May 2009.

Assumptions Made in the Analysis

When delineating the lateral erosion hazard zone, various assumptions had to be made. The purpose of this section is to document and to provide justification for those assumptions.

Use of Maximum Single Event Change from Phase I

In Phase I of the Lower Hassayampa WCMP, JE Fuller (JEF) reviewed of the historical aerial photographs. From that analysis, the maximum single event change was measured. These changes are shown in Table 1 (JEF, 2006). However, the latest date of the photographs that were reviewed was 2004. Thus, a larger change may have occurred between 2004 and 2011.

In Figure 3, the peak flows for all events that were registered by the Flood Control District of Maricopa County (FCDMC) gage at Interstate 10 (I-10) on the Hassayampa River are shown. Between January 2004 and December 2010, the largest event occurred in January 2010. From this event, it was documented that 230 feet of lateral erosion occurred at one location of the Hassayampa River. From a comparison with Table 1, the maximum single event changes that were previously documented in Phase I remain the maximum values.

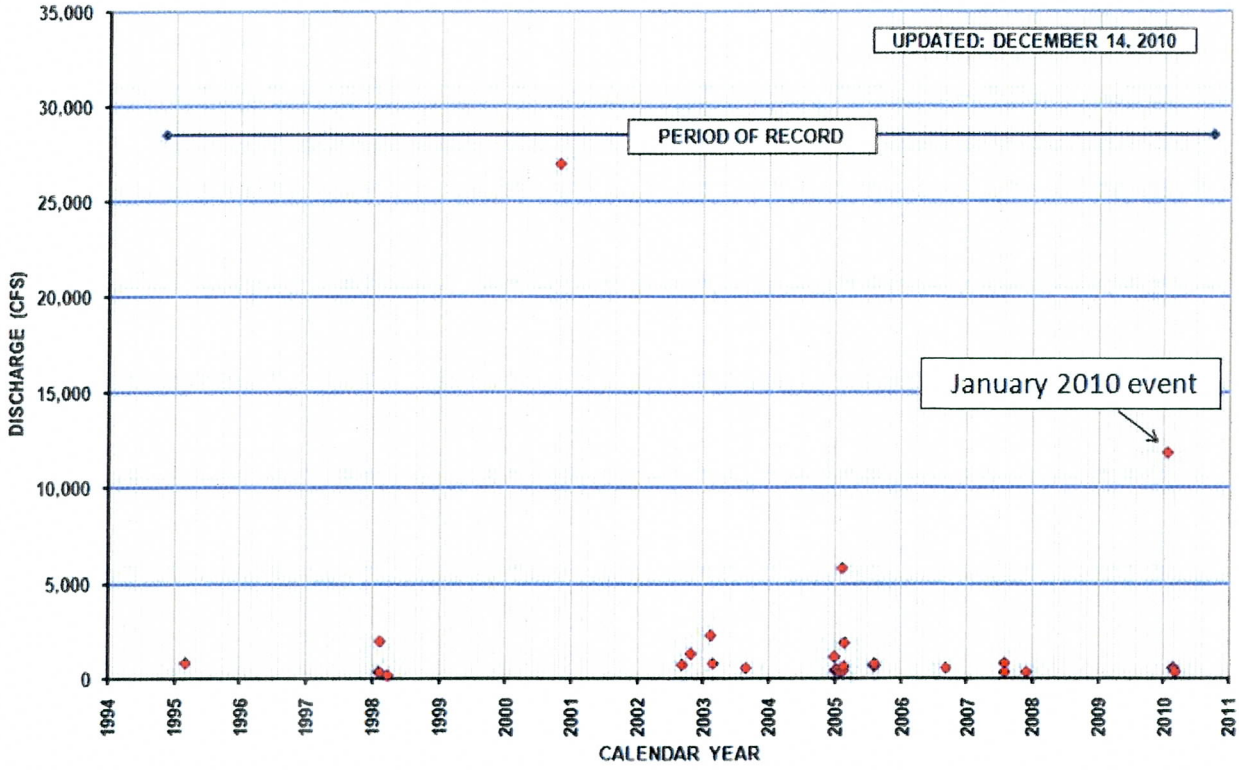

Figure 3. Peak flow data from the FCDMC gage at I-10 (number 5283) with the January 2010 event indicated.

Flow Rates and Main Channel

The flow rates that were used in both the Phase I and Phase II HEC-RAS models were taken from the HEC-2 model files from the 1988 Flood Insurance Study (FIS) by Cella Barr Associates (Cella Barr Associates, 1988). In the current lateral erosion hazard zone re-delineation, the Phase II HEC-RAS model was used. However, the full flow rate was not always used in the total scour analysis. For the area of the river that is downstream of (and including) cross-section 3.81 to the confluence with the Gila River, the Hassayampa River was not modeled as one river in HEC-RAS. Rather, it was split into three rivers, one for the main channel, one for the left overbank and one for the right overbank. This modeling procedure was used because in this area the main channel of the Hassayampa River is confined by agricultural levees (or berms), which partially contain the flow. However, since flow does overtop these berms, the left and right overbanks were added to the HEC-RAS model and connected to the main channel by multiple lateral structures (or weirs). The flow rates in each river were then automatically computed by the HEC-RAS program. Because most channel scour occurs in the main channel and the overbanks are generally depositional areas, only the main channel flow rare and hydraulic variables were used in the total scour calculation that was used in the lateral erosion hazard zone re-delineation. These flow rates are shown in Table 2. More information concerning the details the details of the hydraulic modeling procedure can be found in the Phase I Final Hydraulics Report (WEST, 2006).

Table 2. Flow rates from the main channel of the Phase II HEC-RAS model. These flows were used in the total scour calculations. The flow rates determined by lateral structures (or weirs) are highlighted.

Cross-section	Flow Rate (cfs)
27.89	57854
25.06	57230
21.93	56604
18.81	55980
15.49	76120
15.21	75574
12.94	75164
10.87	74970
9.93	74572
7.94	73966
4.91	73500
3.81	71897.67
3.72	68040.41
3.63	64937.53
3.53	65867.02
3.34	59514.22
3.25	59174.72
3.06	58869.94
2.96	58780.38
2.87	58780.25
2.78	58696.19
2.57	57563.91
2.48	56221.52
2.38	55224.11
2.29	51920.14
2.19	47451.22
2.10	45594.25
2.00	44026.8
1.91	42603.51
1.81	41139.45
1.72	40273.9
1.58	40027.3
1.49	38813.71
1.30	38292.1
1.20	36887.9
1.11	36794.01
1.01	38430.07
0.92	35558.82

Cross Section Lineage and Development

As indicated previously, the lateral erosion cross sections were derived from the Final Hydraulics Report (West, 2006) of the Lower Hassayampa River Watercourse Master Plan, Phase I. The cross sections developed by WEST were represented in an ESRI shapefile, "CrossSections.shp" (see Figure 4). These cross section graphics were redacted to facilitate the delineation of the lateral erosion zone along the lower Hassayampa River.

Graphics editing was accomplished in ArcMap (v.9.3.1), a geographic information system software package from ESRI. The final lateral erosion cross sections (shown in Figure 5) were produced via the following geoprocessing operations:

First, the source cross sections were "clipped" to the limits of the effective Hassayampa River floodway (see Figure 2). This was a preparatory step to the inclusion of lateral erosion distances along the main channel at each cross section location.

Second, a dBase table of lateral erosion distances was "joined" to the attribute table of the clipped cross sections shapefile, "HassXsec.shp." The join operation used stationing values to link the table of lateral distances with the cross section features.

Third, the length of each cross section feature was "extended" by a corresponding lateral erosion distance. The extension distance was applied to both end-points of a cross section. These operations were performed with the "2-Point Line" tool on the COGO menu within the ArcMap Editor environment. With this tool, the length of a linear graphics entity can be extended to a precise distance; but more important, the bearing of the source graphic is honored. The lateral erosion cross sections, therefore, preserve the orientation of the source graphics relative to the floodway boundary and incorporate exact, lateral erosion distances (see Figure 5).

The final lateral erosion cross sections do *not* include every cross section from the Phase I, Final Hydraulics Report. For example, cross sections stationed from 0.35 to 0.92 were omitted. A majority of these features were completely outside the floodway boundary (see Figure 4, Detail). Other cross sections were excluded because they crossed only a portion of the floodway area. Often the angle of placement was such that if these features were extended to the floodway edge, the result would have been intersecting cross sections within the area of flow, e.g., see CrossSections.shp at stations 1.03 and 1.07. Finally, several cross sections in the vicinities of Interstate 10 and Old US 80 were removed. The number of closely spaced cross sections in these areas exceeded what was necessary to delineate the meander belt, e.g., see CrossSections.shp around stations 10.99 and 11.0.

The lateral erosion cross sections were used to define the extents of the lateral erosion zone for the lower Hassayampa River. The left and right limits of the zone were digitized in the ArcMap Editor environment and represented in the shapefile "LatMig00.shp." These features were created by drawing a line graphic through the end-points of each cross section (shown in "HassXsec.shp") on both sides of the floodway. The erosion zone boundaries were "snapped" to the cross section end-points thus preserving the accuracy of these distances. One example of this process is shown in Figure 6.

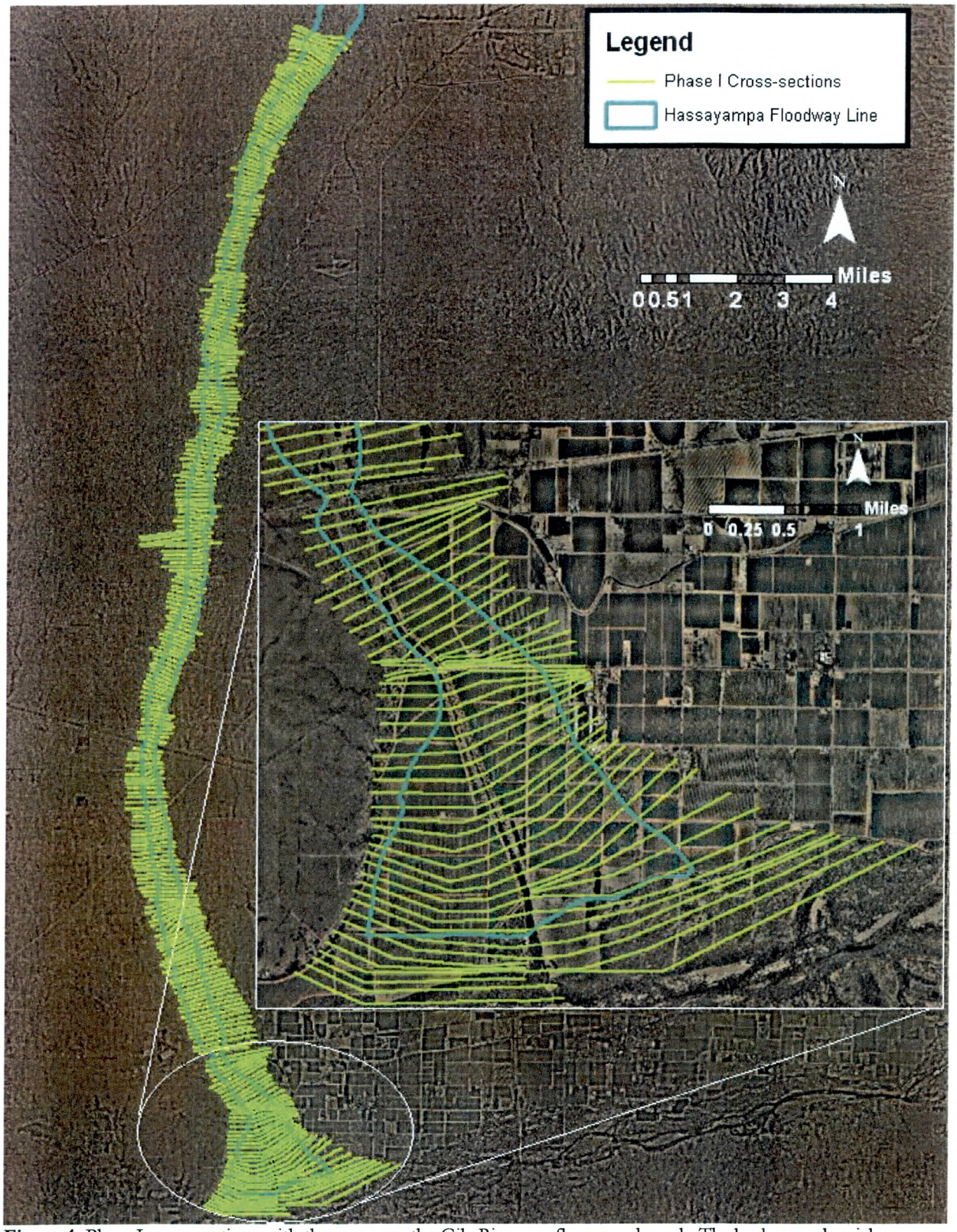

Figure 4. Phase I cross-sections with the area near the Gila River confluence enlarged. The background aerial photograph was taken in May 2009.

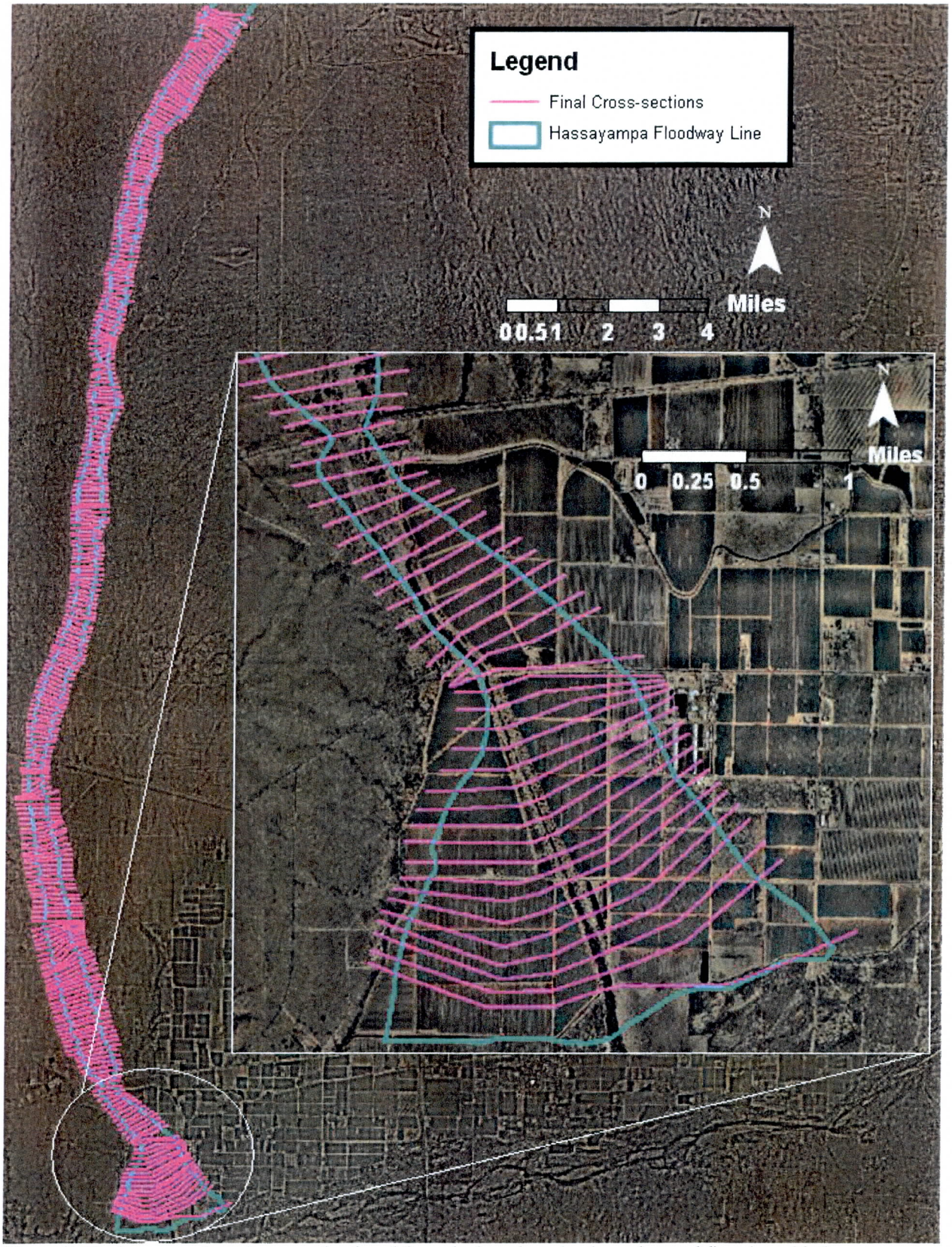

Figure 5. Final cross-sections that were developed from the lateral erosion hazard zone delineation with the area near the Gila River confluence enlarged. The background aerial photograph was taken in May 2009.

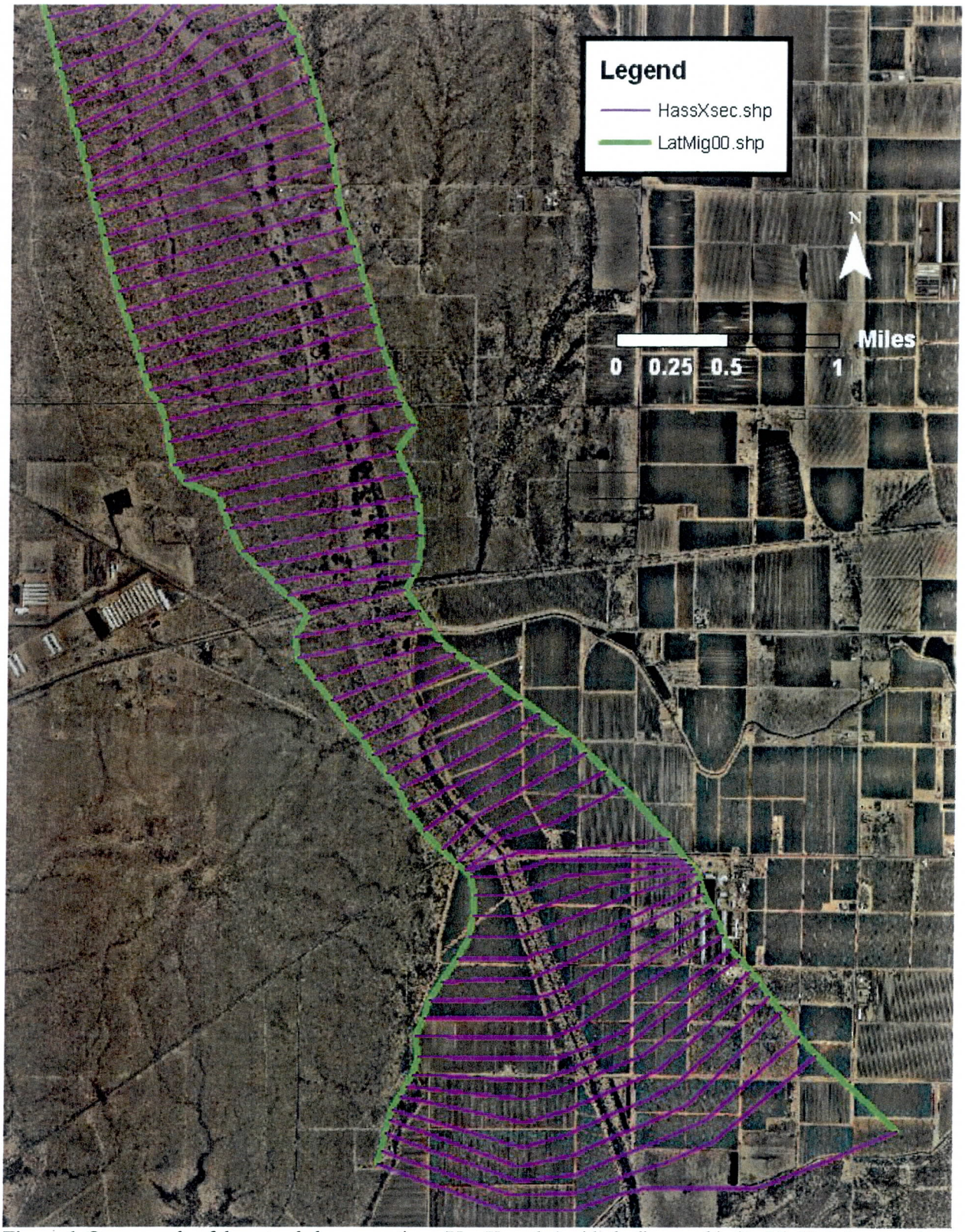

Figure 6. One example of the extended cross-sections (HassXsec.shp) with the line graphic (LatMig00.shp) snapped through the endpoints. The background aerial photograph was taken in May 2009.

Calculation of the Lateral Erosion Distance

The lateral erosion distance is a combination of the total scour, the maximum single event lateral erosion distance and the meander belt, as shown in Equation 1.

Total Scour

For each cross-section, the total scour estimate was calculated with the Flood Control District of Maricopa County (FCDMC) methodology, which is outlined in detail in the Hydraulics Manual (FCDMC, 2010). In the FCDMC methodology, the total scour estimate is based on the addition of six components plus a safety factor. The components are general scour, bedform scour, low-flow incisement, long-term scour, bend scour and local scour. In this analysis, a safety factor of 1.3 was applied to the sum of the components.

Even though the low-flow channel has meanders and bends, bend scour was not calculated in this analysis because the Hassayampa effective FEMA floodway line is generally straight. Additionally, since this analysis was a planning -level study, the details of local scour at structures, such as bridges, were not investigated. Therefore, the components of bend scour and local scour were both taken as zero in this delineation. The remaining four components are briefly discussed below.

Because the Hassayampa River is an unregulated river, the general scour was calculated with Lacey's equation. This equation has the form

$$Z_{gs} = z\left[0.47\left(\frac{Q}{1.76D_m^{1/2}}\right)\right]^{1/3} \qquad (2)$$

where Z_{gs} is the general scour [ft], Q is the design discharge [cfs], D_m is the mean grain size (taken as D_{50}) [mm], and z is the multiplying factor (0.25 for a straight reach). For this analysis, the design discharge was the 100-year flow rate (except near the confluence), and the D_{50} values were the reach-averaged value from the River Behavior Report (JEF, 2006). The flow rates that were used in the analysis are shown in Table 2, and the D_{50} values are shown in Table 3.

Table 3. Reach-averaged D_{50} values from the Phase I River Behavior Report.

Reach	Cross-section	D_{50} (mm)
5	27.89 to 21.74	0.4
4	21.65 to 15.78	0.445
3	15.68 to 10.31	0.6
2	10.21 to 4.72	0.445
1	4.63 to 0.35	0.525

Bedform scour was calculated with the following equation

$$Z_{bf} = 0.5 d_h \tag{3}$$

where Z_{bf} is the bedform scour depth [ft], and d_h is the dune or antidune height (measured from crest to trough) [ft]. When the Froude number < 0.7, the dune height equation should be used. This equation has the form

$$0.15 < \frac{d_h}{y_h} < 0.3 \tag{4}$$

where y_h is hydraulic depth of flow [ft]. Assuming a maximum value of 0.3, Equation 4 can rearranged to give the following dune height equation

$$d_h = 0.3 y_h \tag{5}$$

where the variables are the same as mentioned above. When the Froude number is in the range, 1.0 ≥ Froude number ≥ 0.7, the higher value between the dune height equation and the anti-dune height equation should be used. Finally, when the Froude number is greater than 1.0, the anti-dune height equation should be used. The anti-dune height equation has the form

$$d_h = 0.027 V_a^2 \tag{6}$$

where V_a is the average channel velocity [ft/s]. Therefore, in the total scour calculations, bedform scour was calculated with Equation 4, and Equation 5 or Equation 6 was chosen depending on the value of the Froude number.

Low-flow incisement is the depth of the small channel that is formed by smaller, more frequent flow events (e.g., a 2-year event). For this study, low-flow incisement was taken as 1.0 feet.

Long-term scour was calculated in the Phase I River Behavior Report with a long-term HEC-6 model (JEF, 2006). Therefore, the results of this model at each cross-section were used as the long-term scour estimate.

Once the total scour was calculated at each cross-section, the scour estimate was added to the depth. This result was then multiplied by three, as shown in Equation 1. The maximum value of this calculation was selected for each of the five reaches.

Maximum Single Event Erosion Distance

As indicated before, the maximum single event distance was taken from the Phase I River Behavior Report (JEF, 2006). In Phase I, the Lower Hassayampa River was divided into five reaches with each reach having similar characteristics. The maximum erosion distances in each reach were measured from historical aerial photographs. The single event erosion distances that were used in this analysis are shown in Table 1. These distances were then added to the maximum result (for each reach) from the total scour analysis, per Equation 1.

In the Hassayampa River, the low-flow channel has significant bends in it. However, the floodway line does not make significant bends. Therefore, it was assumed for this analysis that the Hassayampa effective FEMA floodway line encompasses the major bends of the low-flow channel, and the calculated lateral erosion distance was measured from the floodway line. One example of the interaction between the low-flow channel and the floodway line is shown in Figure 7.

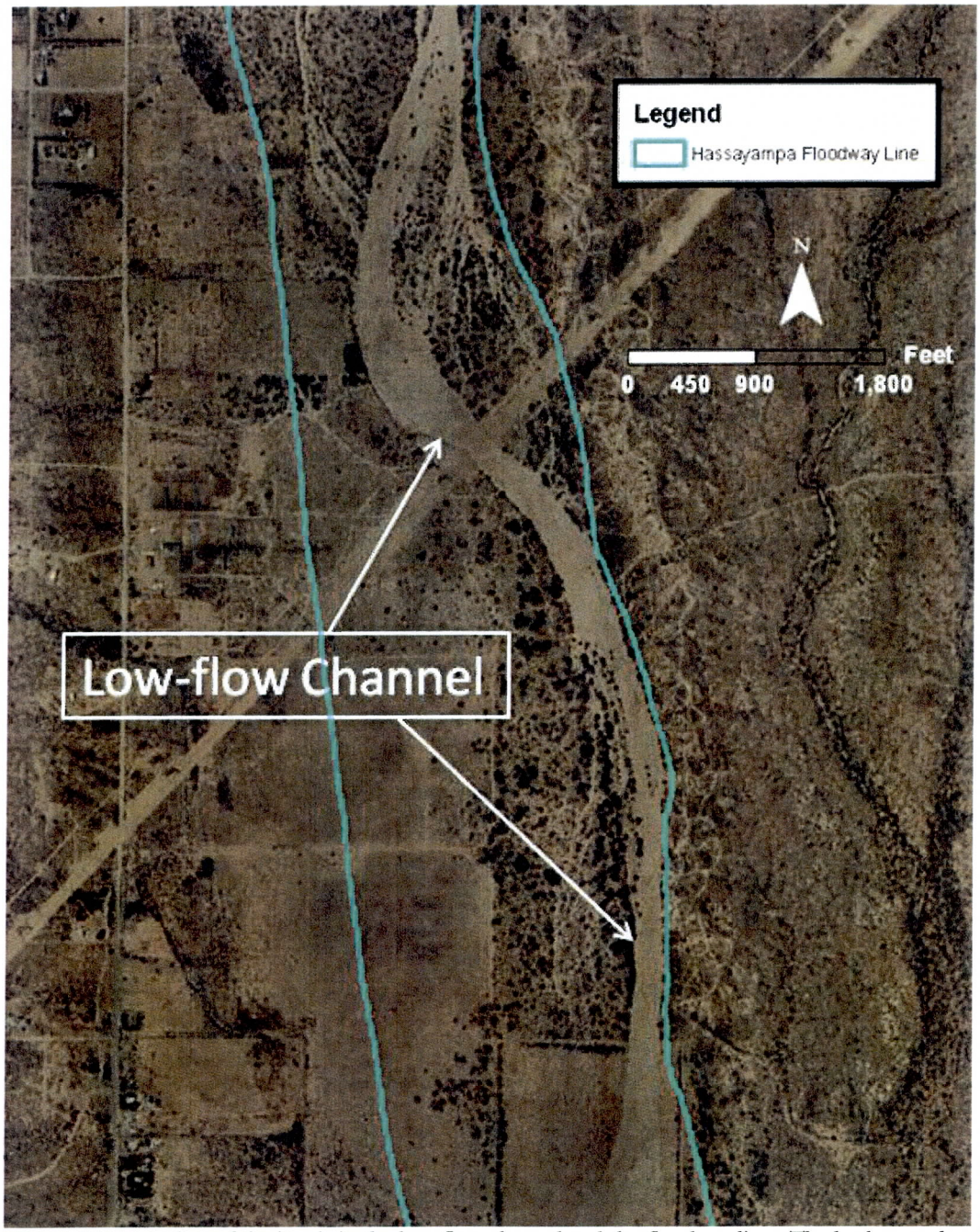

Figure 7. Interaction of the bends in the low-flow channel and the floodway line. The background aerial photograph was taken in May 2009.

Results

The final lateral erosion distances for each reach are shown in Table 4. To delineate the hazard zone, these distances were measured along the direction of the cross-section line from the floodway line. In a comparison of Table 1 and Table 4, it can be seen that the maximum single event distance is the largest component of the lateral erosion distance. The Phase II lateral erosion hazard zone is compared with the Phase I hazard zones in Figure 8 through Figure 10. From these figures, it appears that the new methodology calculates a reasonable lateral erosion hazard zone. The full Phase II lateral erosion hazard zone shapefile is included on the CD, which is attached as the Appendix.

Field Verification

On April 13, 2011, a field trip was taken in order to verify that the calculated lateral erosion hazard zone was reasonable. Photographs were taken at three main locations, the Old US 80 Bridge, the Baseline Road at-grade crossing and the Tonopah-Salome Highway at-grade crossing. The detailed locations of the photographs are shown in Figure 11, and the photographs are included on the CD, which is attached as the Appendix.

At the Old US 80 Bridge (located in Reach 1 at cross-section 2.65), the Hassayampa River is channelized by agricultural (i.e., not certified by FEMA) levees and surrounded by agricultural fields on both the east and west sides (JEF, 2006). A southern view of this reach is shown in Figure 12. At the bridge, the channelized section has a flow capacity just above 58,000 cfs (shown in Table 2) with highly erosive velocities of 15 ft/s. Therefore, in the event of a 100-year flood (currently defined as 73,500 cfs), much erosion and possible lateral migration can be expected. For example, in January 2010, a flow event of only 5880 cfs occurred at the Old US 80 Bridge (USGS, 2011). During this event, the low-flow channel shifted 75 feet, and erosion occurred at the toe of the vegetated bank. An aerial pre- and post-flood comparison is shown in Figure 12, while a detailed view of the erosion of the east bank is shown in Figure 14.

Table 4. The calculated lateral erosion distance for each reach.

Reach	Cross-section	Lateral Erosion Distance (ft)
5	27.89 to 21.74	604
4	21.65 to 15.78	597
3	15.68 to 10.31	699
2	10.21 to 4.72	1402
1	4.63 to 0.35	769

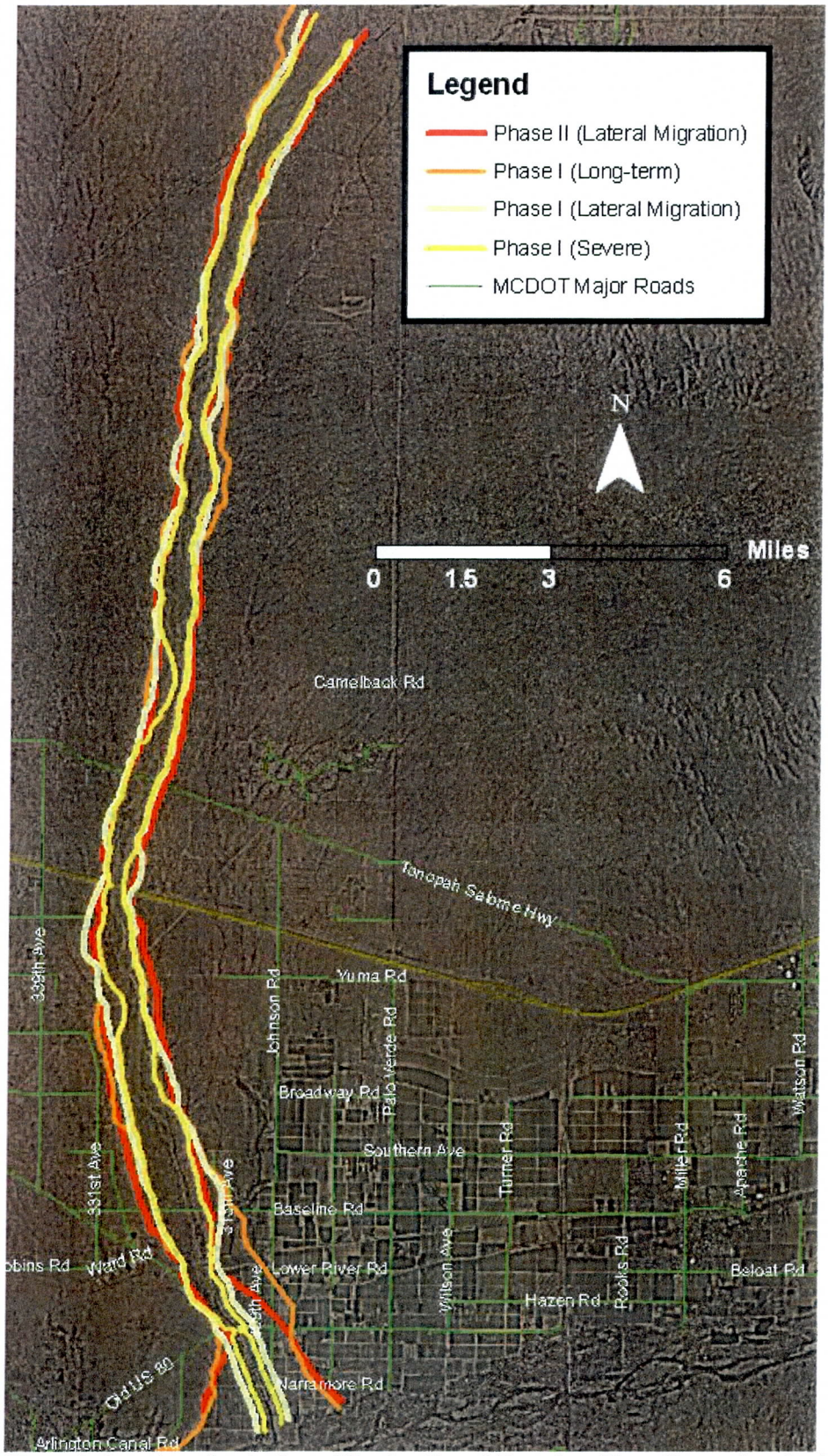

Figure 8. Overview of entire Lateral Erosion Hazard Zone from Phase II, as well as the three Lateral Erosion Hazard Zones from Phase I. The background aerial photograph was taken in May 2009.

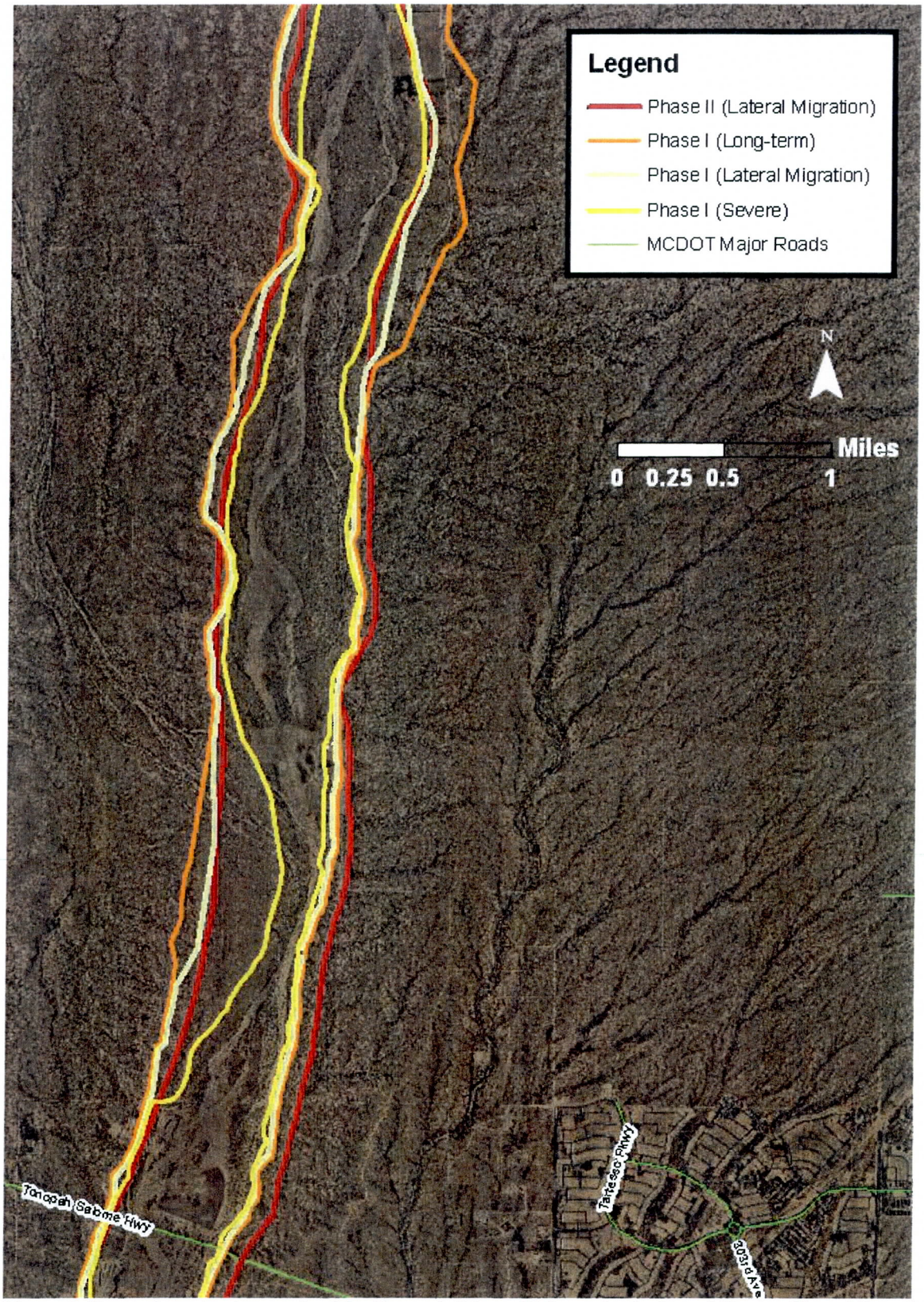

Figure 9. Zoomed portion just north of the Tonopah-Salome Highway for the Lateral Erosion Hazard Zone from Phase II, as well as the three Lateral Erosion Hazard Zones from Phase I. The background aerial photograph was taken in May 2009.

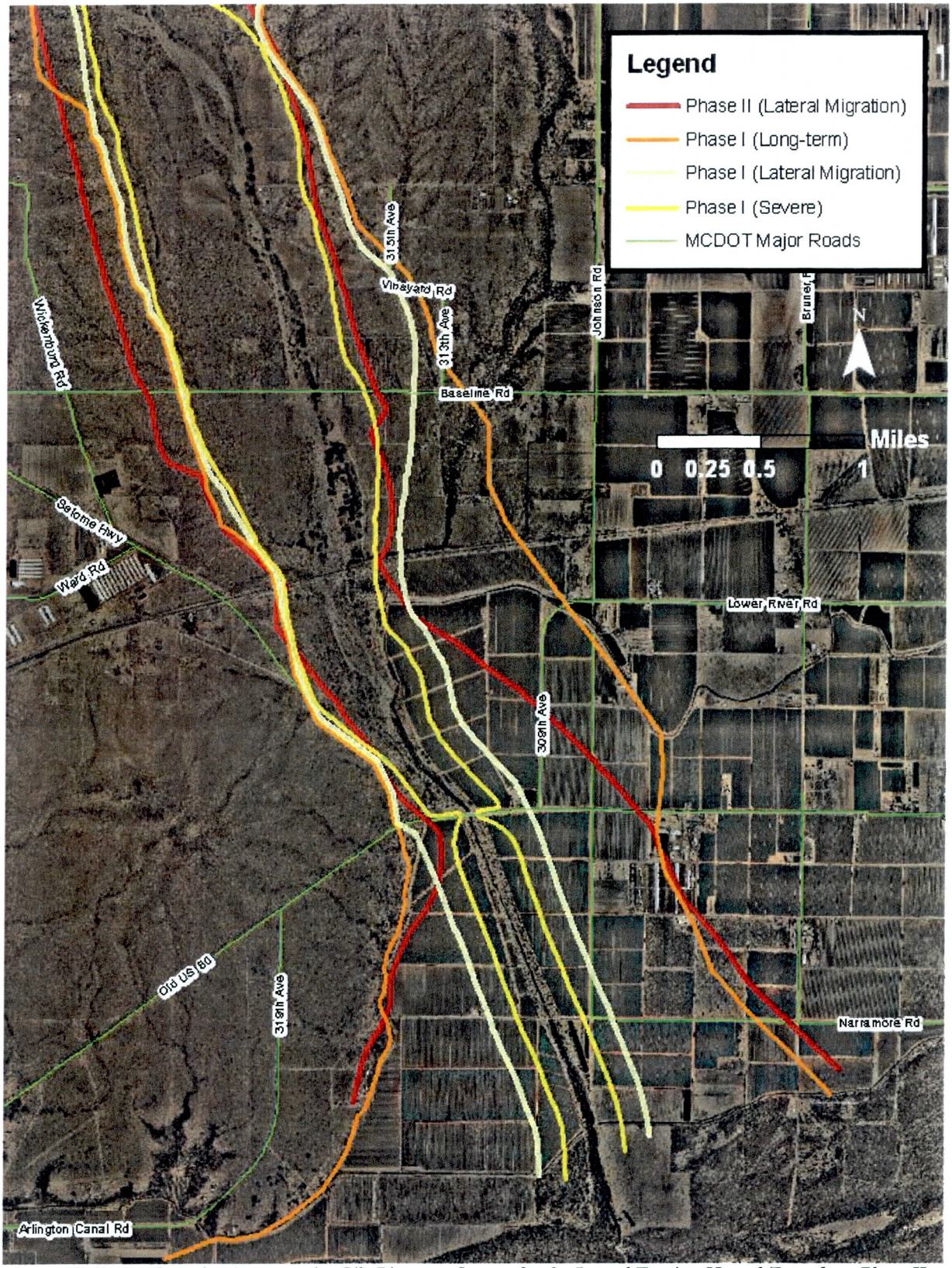

Figure 10. Zoomed portion just near the Gila River confluence for the Lateral Erosion Hazard Zone from Phase II, as well as the three Lateral Erosion Hazard Zones from Phase I. The background aerial photograph was taken in May 2009.

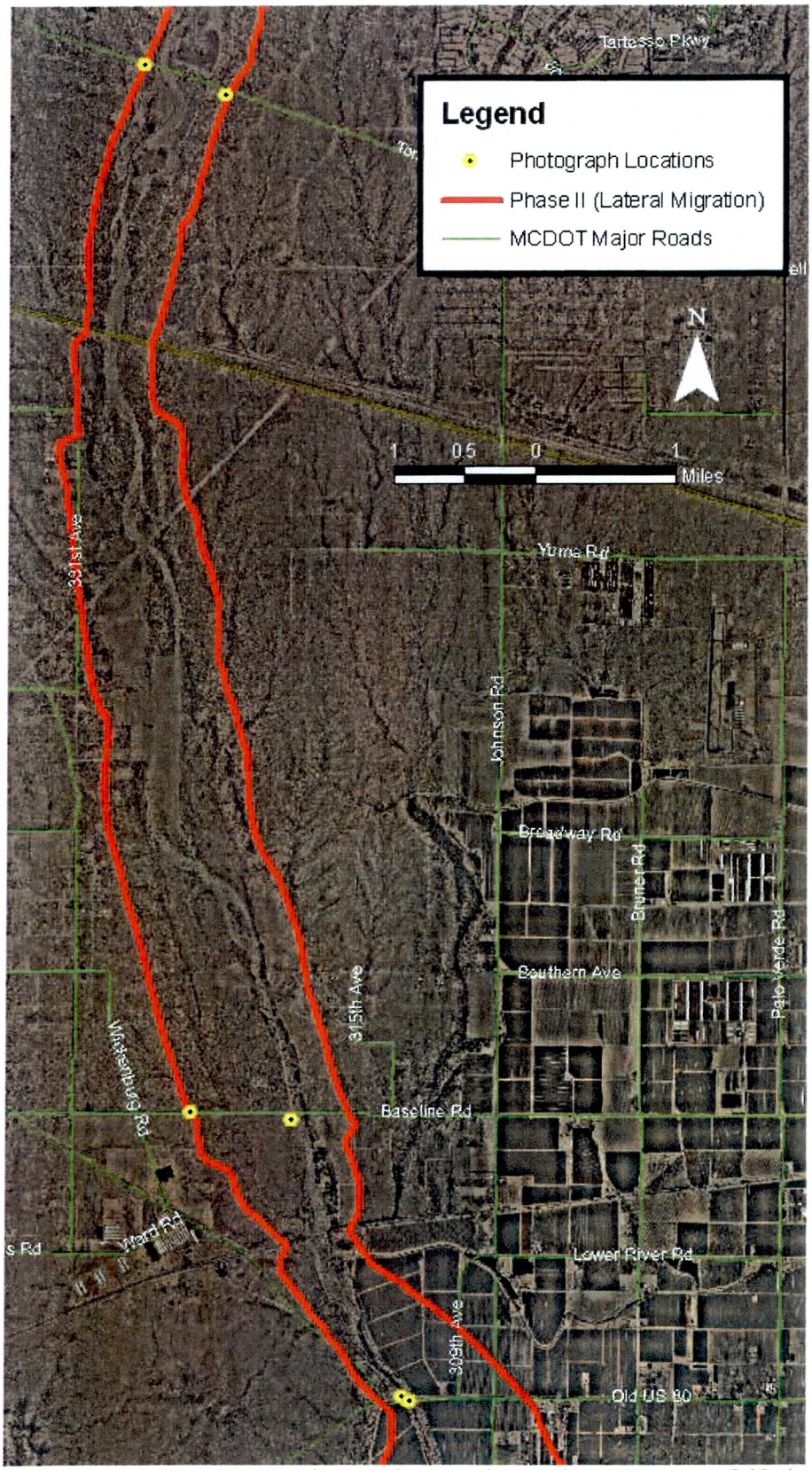

Figure 11. Locations where the photographs were taken on the April 13, 2011 field trip. The background aerial photograph was taken in May 2009.

Figure 12. View looking south at the channelized reach of the Hassayampa River that is downstream of the Old US 80 Bridge. Note the eroded section of the bank at left.

At the Baseline Road at-grade crossing, the channel is very wide and does not show much definition (see Figure 15). Agricultural fields are on the east side of the river, while open land is on the west side. The west side is significantly higher than the main channel, but the east side is about the same height as the main channel. A view from the edge of the lateral erosion hazard zone on the west side of the channel is shown in Figure 16. A view from the east edge of the main channel towards the edge of the lateral erosion hazard zone is shown in Figure 17. In this area, it can be expected that the east side of the river is more susceptible to lateral migration.

At the Tonopah-Salome Highway at-grade crossing, the main channel is again very wide and generally does not show much definition. However, the low-flow channel does show definition due to the tailcut from the upstream (of the at-grade crossing) sand and gravel mine and the headcut from the downstream sand and gravel mine merging. Therefore, this section of the river is more susceptible to erosion (or downcutting) rather than lateral erosion due to the ongoing in-stream sand and gravel mines. A view that looks east towards the main channel from the lateral erosion hazard zone line is shown in Figure 18, while a view that looks northwest towards the main channel from the lateral erosion hazard zone line is shown in Figure 19. The sand and gravel mine that was filled with sediment in the January 2010 flood event is marked in Figure 19.

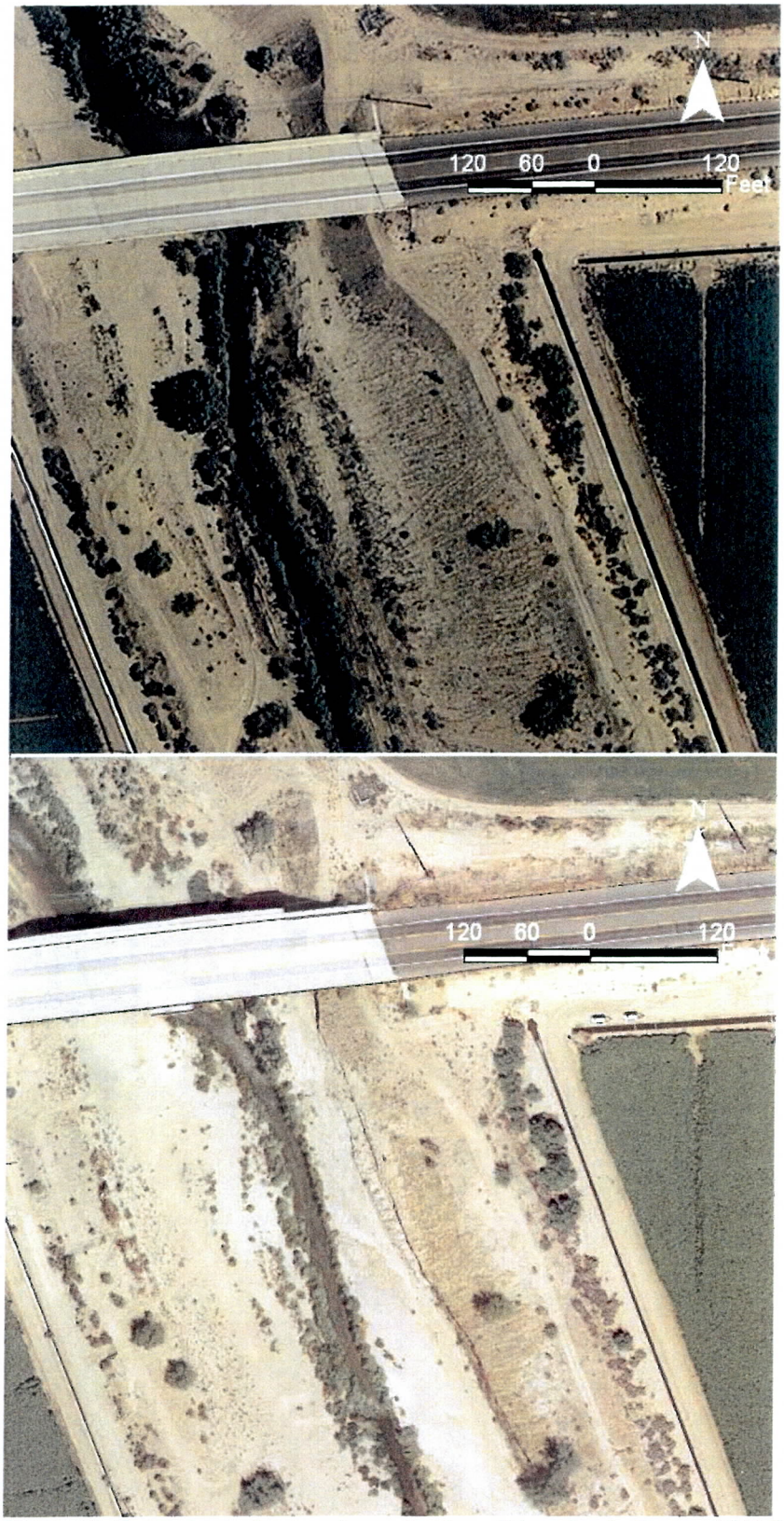

Figure 13. Comparison of pre- and post-flood conditions for the January 2010 flood event. The pre-flood condition is shown in the upper picture (dated May 2009). The post-flood condition is shown in the lower picture (dated September 2010).

Figure 14. Eroded section of the east bank of the Hassayampa River that is located downstream of the Old US 80 Bridge. This section is annotated in Figure 12.

Figure 15. View south (downstream) of the main channel of the Hassayampa River at the Baseline Road at-grade crossing.

Figure 16. View looking east towards the main channel from the west edge of the lateral erosion hazard zone on Baseline Road. The cars mark the approximate location of the main channel.

Figure 17. View looking northeast from the east edge of the main channel towards the lateral erosion hazard zone line at Baseline Road.

Figure 18. View looking east towards the main channel from the west edge of the lateral erosion hazard zone at the Tonopah-Salome Highway at-grade crossing.

Figure 19. View looking west towards the main channel from the east edge of the lateral erosion hazard zone at the Tonopah-Salome Highway at-grade crossing. The sand and gravel mine is noted at right.

Conclusions

In Phase II of the Lower Hassayampa Watercourse Master Plan, a new method was used to re-delineate the lateral erosion hazard zone for the Hassayampa River. The new method was developed to simplify hazard zone delineation process and to base this process on repeatable engineering procedures.

From this study, it is shown that the methodology is easy to apply while also being repeatable. The methodology also appears to produce reasonable results. From Figure 8 through Figure 10 and the discussion in the field visit section, it can be seen that the results appear reasonable. However, since this was a planning-level study, some areas of the erosion hazard zone may need refinement. Overall, though, the method is easy to apply and produces reasonable results.

Recommendations

The Phase II lateral erosion hazard zone delineation was a planning-level study, i.e., a large portion (about 27 miles) of the Hassayampa River was studied. Therefore, every location could not be studied in detail. Thus, some areas that may not be erodible are shown in the lateral erosion hazard zone. One example is shown in Figure 20. In this figure, the Central Arizona Project (CAP) canal is shown within the lateral erosion hazard zone, but the canal is protected with soil cement erosion protection and may not be susceptible to lateral erosion. However, since the details of every structure (bridge, bank protection, etc.) could not be adequately studied to completely eliminate the hazard zone, the zone was drawn exactly as the methodology specified. Thus, in some areas, the zone may be over-estimated. However, in the future, if a local, more detailed study is done and better information is obtained, the lateral erosion hazard zone can be modified in the area of the local study; but final approval and revision of the zone always rests with the Flood Control District of Maricopa County.

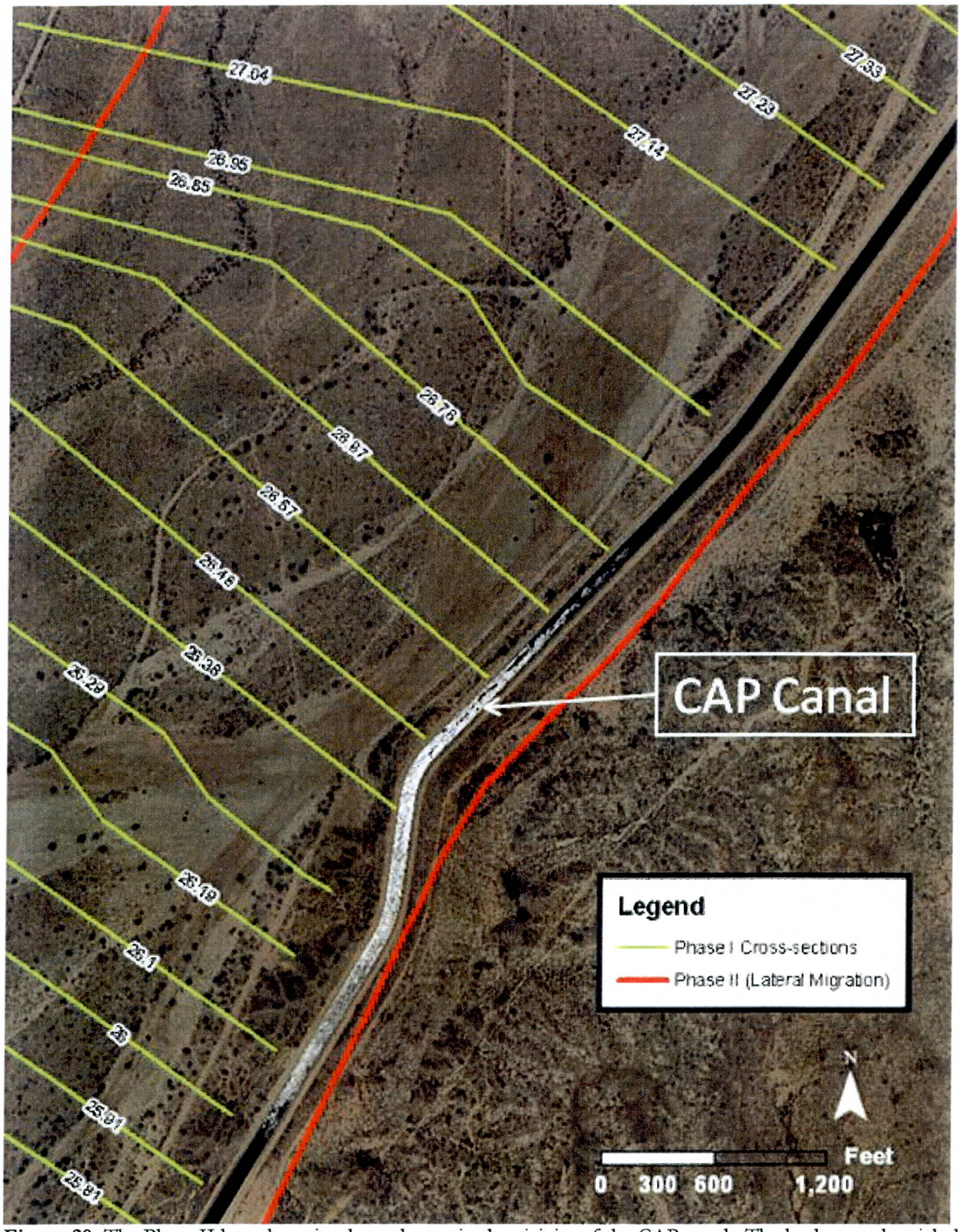

Figure 20. The Phase II lateral erosion hazard zone in the vicinity of the CAP canal. The background aerial photograph was taken in May 2009. The cross-section locations have been shown as reference.

References

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Appendix

CD of digital files that were used in the delineation