# KOZLOWSKI
# FPAP LOMR – PHASE 01

***FINAL REPORT** – April 2011*

***Prepared For:***

**FLOOD CONTROL DISTRICT OF MARICOPA COUNTY**
2801 West Durango Street
Phoenix, AZ 85009-6399

***Prepared By:***

WEST
CONSULTANTS, INC.

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Registered Professional Engineer (Civil)
CERTIFICATE NO.
41980
BRIAN THOMAS
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Date Signed 04-22-2011
ARIZONA, U.S.A.
Expires 3/31/2014

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# TABLE OF CONTENTS


LIST OF TABLES ........ ii

LIST OF FIGURES ........ ii

1. INTRODUCTION ........ 1

1.1. Study Overview ........ 1

1.2. Study Purpose and Scope ........ 1

1.3. Data Collection & Review ........ 1

2. FLO-2D HYDRAULIC MODEL DEVELOPMENT ........ 5

2.1. General Model Characteristics ........ 5

2.2. Hydraulic Model Data & Assumptions ........ 7

2.2.1. Topography and Grid Development ........ 7

2.2.2. Discharge ........ 7

2.2.3. Manning's *n* Values ........ 7

2.2.4. Computational Time Step and Grid Element Size ........ 12

2.2.5. Boundary Conditions ........ 12

2.2.6. Flow Obstruction ........ 12

2.2.7. Froude Number ........ 12

3. HYDRAULIC MODEL RESULTS ........ 15

3.1. 25-foot Grid 100 Year Event ........ 15

3.2. 10-foot Grid 100 Year Event ........ 15

3.3. Discussion of Results ........ 16

4. HEC-RAS Evaluation and Recommendations ........ 25

4.1. Revisions ........ 25

4.2. Results ........ 25

4.3. Recommendations ........ 26

5. REFERENCES ........ 27


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# LIST OF TABLES

Table 2-1. Manning's *n* values 8

Table 3-1. 25-foot grid results 15

Table 3-2. 10-foot grid results 16

# LIST OF FIGURES

Figure 1-1. Kozlowski study area 2

Figure 1-2. Regulatory FEMA floodway (Zone FW) for Wash T4N-R3W-S08W and assumed flow path in relation to the Kozlowski residence 3

Figure 1-3. Half-foot and 2-foot contours 4

Figure 2-1. FLO-2D physical processes (O'Brien, 2009) 6

Figure 2-2. Channelized portion and overbanks of Wash T4N-R3W-S08W (Floodplain Category) 8

Figure 2-3. Example of higher roughness north of Patton Road (Vegetated Channel Category) 9

Figure 2-4. Channelized portion of Wash T4N-R3W-S08W (Floodplain Category) 9

Figure 2-5. 25-foot FLO-2D elevation grid 10

Figure 2-6. 25-foot FLO-2D elevation grid with a close up on the Kozlowski Residence 11

Figure 2-7. 25-foot FLO-2D grid flow obstructions 13

Figure 2-8. 25-foot FLO-2D grid flow obstructions close up 14

Figure 3-1. 25-foot FLO-2D grid flow depths 17

Figure 3-2. 25-foot FLO-2D grid flow depths with a close up 18

Figure 3-3. 25-foot FLO-2D grid velocity vectors 19

Figure 3-4. 25-foot FLO-2D grid velocity vectors with a close up 20

Figure 3-5. 10-foot FLO-2D grid flow depths ... 21

Figure 3-6. 10-foot FLO-2D grid flow depths with a close up ... 22

Figure 3-7. 10-foot FLO-2D grid velocity vectors ... 23

Figure 3-8. 25-foot FLO-2D grid velocity vectors with a close up ... 24

# 1. INTRODUCTION

## 1.1. Study Overview

WEST Consultants Inc. (WEST) was retained by the Flood Control District of Maricopa County (District) to determine the current hydraulic conditions near the Kozlowski residence in northeastern Maricopa County. This work was performed under Work Assignment Number 3 of Contract Number FCD 2010C027. The WEST project number was FCDM001003. The District project manager was Mr. John Hathaway, P.E., and the District technical supervisor was Mr. Tom Loomis, P.E. The WEST project manager was Dr. Brian Wahlin, P.E., D.WRE. Additionally, Mr. Chuck Davis, CFM, and Mr. Cameron Jenkins assisted with data collection and hydraulic modeling. Quality assurance was provided by Mr. David S. Smith, P.E., CFM, D.WRE.

## 1.2. Study Purpose and Scope

The Kozlowski residence is located in the Wittmann, AZ area near Wash T4N-R3W-S08W (see Figure 1-1). This wash was studied and delineated as part of the Wittmann Phase 2 Zone AE Floodplain Delineation Study in 2006 (DEA, 2006). During the construction of the Kozlowski residence prior to the effective FEMA delineation, Wash T4N-R3W-S08W was re-graded to flow around the houses in the area. However, the floodplain and floodway developed for Wash T4N-R3W-S08W does not reflect this new channel realignment. Thus, the Kozlowski residence is located in the middle of a regulatory floodway (see Figure 1-2 below). The Kozlowski family has applied to the Floodprone Properties Assistance Program (FPAP) in an effort to have their house removed from the regulatory floodway.

The purpose of this work assignment is to develop a more detailed hydraulic model of Wash T4N-R3W-S08W in the area of the Kozlowski residence using FLO-2D. This model used newly flown (2010 flight date) 0.5-foot topography and well as existing 2-foot topography. WEST developed a new hydraulic model of the area to determine the actual flow path and flooding extents since the re-grading of the channel. Steady-state hydrology from the Wittmann Phase 2 Zone AE Floodplain Delineation Study (DEA, 2006) was used for this task.

Although a floodway analysis was not part of the scope of work, WEST also conducted a cursory HEC-RAS analysis using the effective FEMA model (i.e., the model developed as part of the Wittmann Phase 2 Zone AE Floodplain Delineation Study) to evaluate whether the floodway can be modified in the project reach.

## 1.3. Data Collection & Review

Digital half-foot and 2-foot contour interval topography of the site was provided by the District (Figure 1-3). A detailed field reconnaissance of the study area was conducted by Dr. Brian Wahlin, Mr. Chuck Davis, and Mr. John Hathaway on February 23, 2011, to document field conditions and estimate model parameters. For the hydraulic modeling effort, floodplain roughness values were estimated and expected flow characteristics were observed.

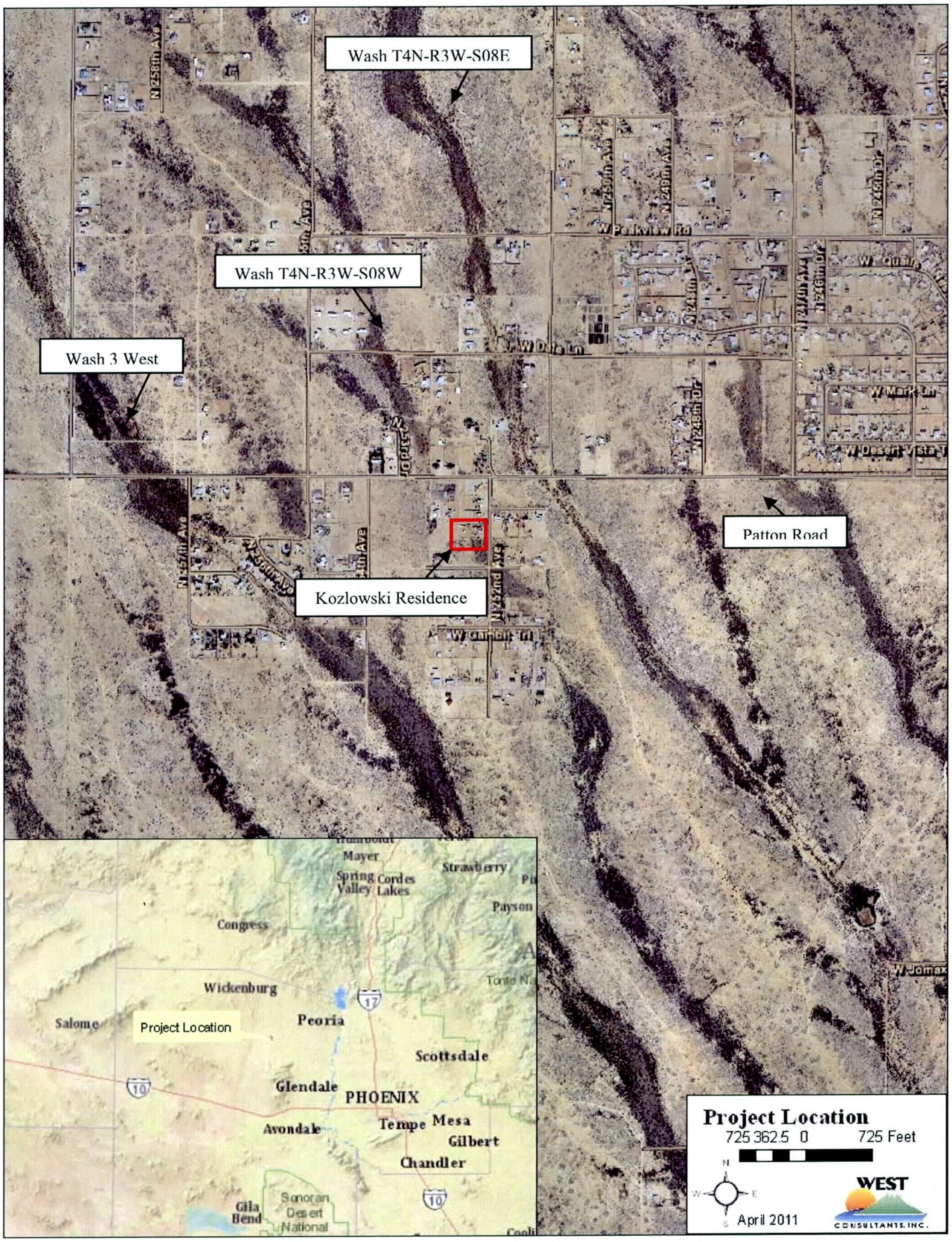


Figure 1-1. Kozlowski study area

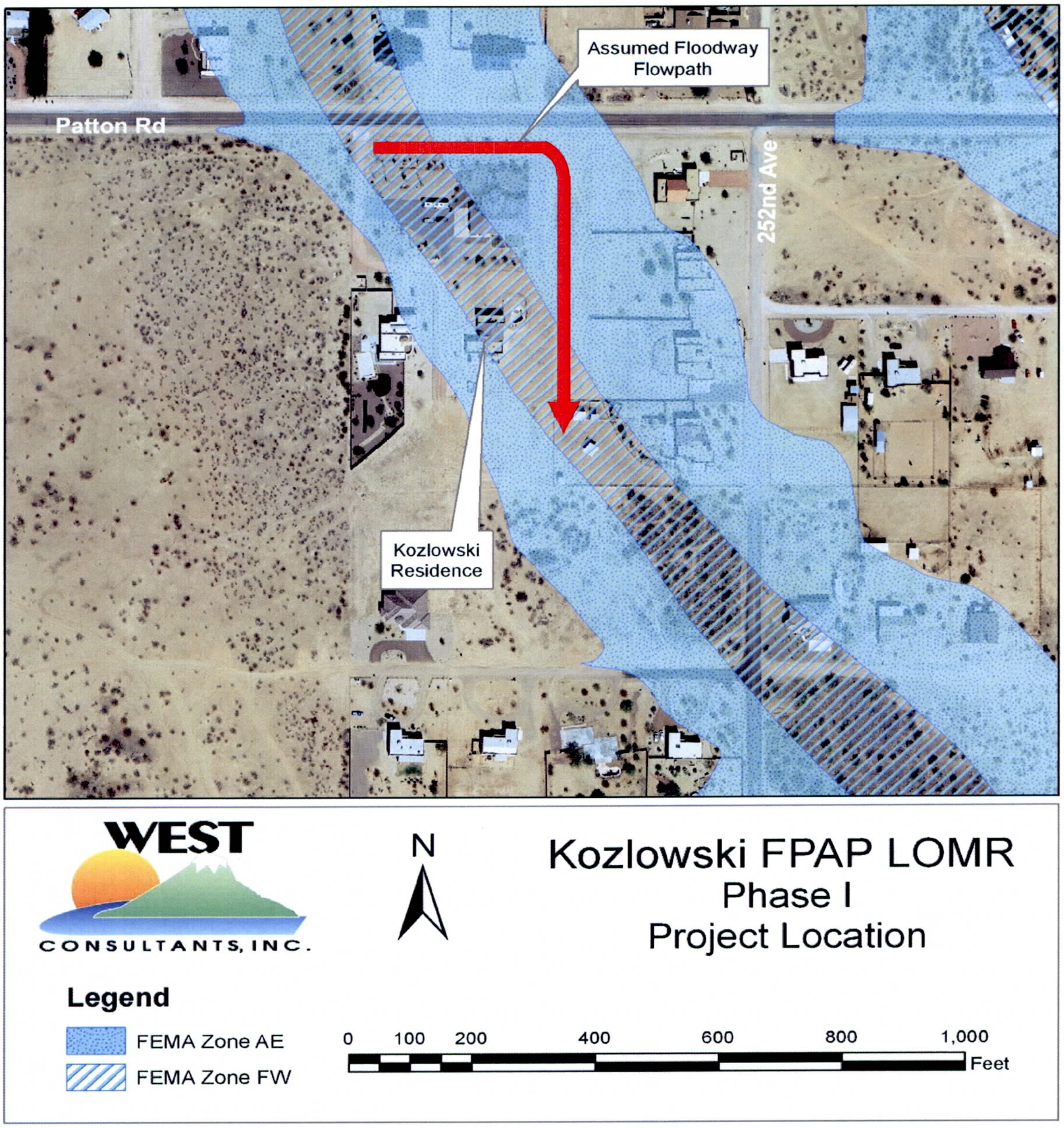


Figure 1-2. Regulatory FEMA floodway (Zone FW) for Wash T4N-R3W-S08W and assumed flow path in relation to the Kozlowski residence

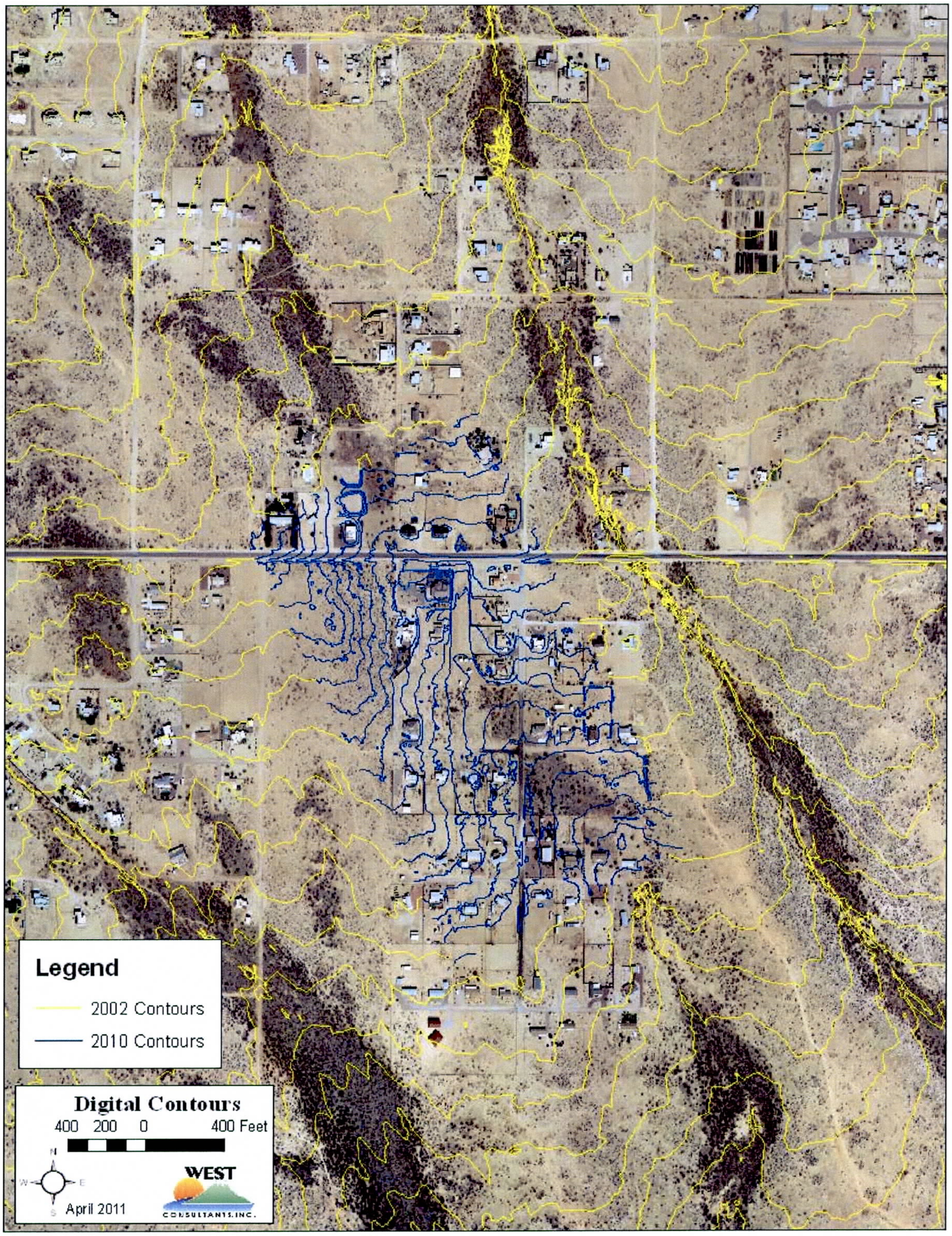


Figure 1-3. Half-foot and 2-foot contours

# 2. FLO-2D HYDRAULIC MODEL DEVELOPMENT

A two-dimensional hydraulic model using the FLO-2D 2009.06 software was constructed for the project site to study the flow from the north of the project and its effects at the project site. The studied area encompasses approximately 250 acres.

## 2.1. General Model Characteristics

FLO-2D is a two-dimensional (horizontal) flood routing (volume conservation) model developed by Dr. Jim O'Brien. It numerically routes a flood hydrograph over a computational domain while predicting the area of inundation and simulating floodwave attenuation.

FLO-2D routes rainfall-runoff and flood hydrographs over unconfined flow surfaces or in channels using either a diffusive or dynamic wave approximation to the momentum equation. The model has a number of components to simulate spatially variable rainfall and infiltration, sediment transport and mobile bed, street flow, buildings/obstructions, floodways and other flooding details. Physical processes that can be simulated by the model are illustrated in Figure 2-1.

FLO-2D is a volume conservation model. It moves the flood volume from upstream to downstream on a series of computational cells. Flood routing in two dimensions is accomplished through an explicit numerical integration of the equations of motion and the conservation of fluid volume. The model can solve either the diffusive wave equation (neglecting the acceleration terms in the momentum equations) suitable for simple overland flow on a mild slope, or the full dynamic wave equation for simulating complex flow hydraulics.

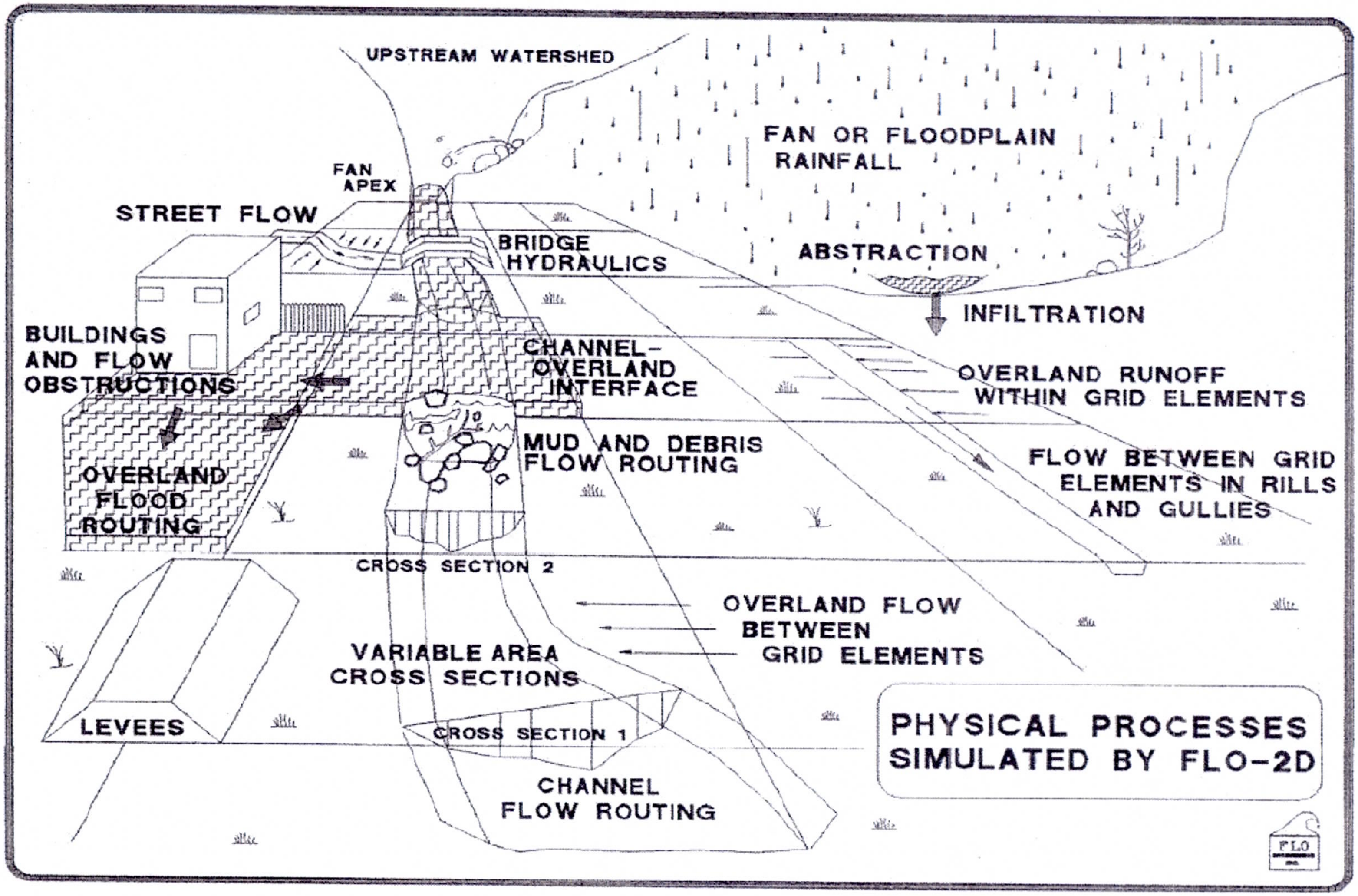


Figure 2-1. FLO-2D physical processes (O'Brien, 2009)

## 2.2. Hydraulic Model Data & Assumptions

### 2.2.1. Topography and Grid Development

Half-foot and two-foot contour interval digital topographic data (NAVD 88 datum) for the site were obtained from the District. The combined data were used to create a five-foot raster within the ArcView Geographic Information System (GIS) program. The study area was divided in to 17,000 square elements (25 by 25 feet) within the FLO-2D grid developer system (GDS) and the raster was imported in the background. A 10 by 10 foot grid in the GDS program was also developed at the request of the District. This grid divided the study area into 110,900 square elements. The purpose of making the two grids was to compare the results and make sure buildings and elevation data was adequately captured for the grid size chosen.

Each grid element (center of the computational cell) was assigned a representative ground elevation from the raster based on the sophisticated interpolation algorithm embedded in the FLO-2D interface. The two-dimensional grid with interpolated ground elevations is shown in Figure 2-5 for the 25 by 25 foot grid.

### 2.2.2. Discharge

The FEMA HEC-RAS model was provided by the District and was used to obtain the inflow boundary condition for the 100 year flood event. The inflow value of 880 cfs was taken from cross-section 2.769 and used in the FLO-2D model. Since FLO-2D is an unsteady model, the steady state flow value of 880 cfs was used as a constant flow hydrograph for input into the FLO-2D models.

### 2.2.3. Manning's *n* Values

The assignment of overland flow resistance must account for vegetation, surface irregularity, flow depth, and flow path redirection. Overland roughness values can be two or three times those used for conventional open channel flow. Therefore, Manning's roughness values were carefully selected based on field observations, District comments, and engineering judgment, with guidance from the FLO-2D manual (2009). Table 2-1 provides a summary of the roughness *n* values used for this study. The most recent imagery show less vegetation in the channel than what was used in the DEA study (2006). Examples of project site roughness values are shown in Figure 2-2 to Figure 2-4. The channelized portion of the wash shown in Figure 2-4 has an *n* value of 0.06.

Table 2-1. Manning's *n* values

| Type of channel or overland area | Manning's *n* value |
|---|---|
| Vegetated Channels | 0.072 |
| Floodplain | 0.06 |
| Dirt Road | 0.04 |
| Shallow overland flow (depth < 0.2 feet) | 0.15 |
| Paved Road | 0.035 |

Figure 2-2. Channelized portion and overbanks of Wash T4N-R3W-S08W (Floodplain Category)

Figure 2-3. Example of higher roughness north of Patton Road (Vegetated Channel Category)

Figure 2-4. Channelized portion of Wash T4N-R3W-S08W (Floodplain Category)

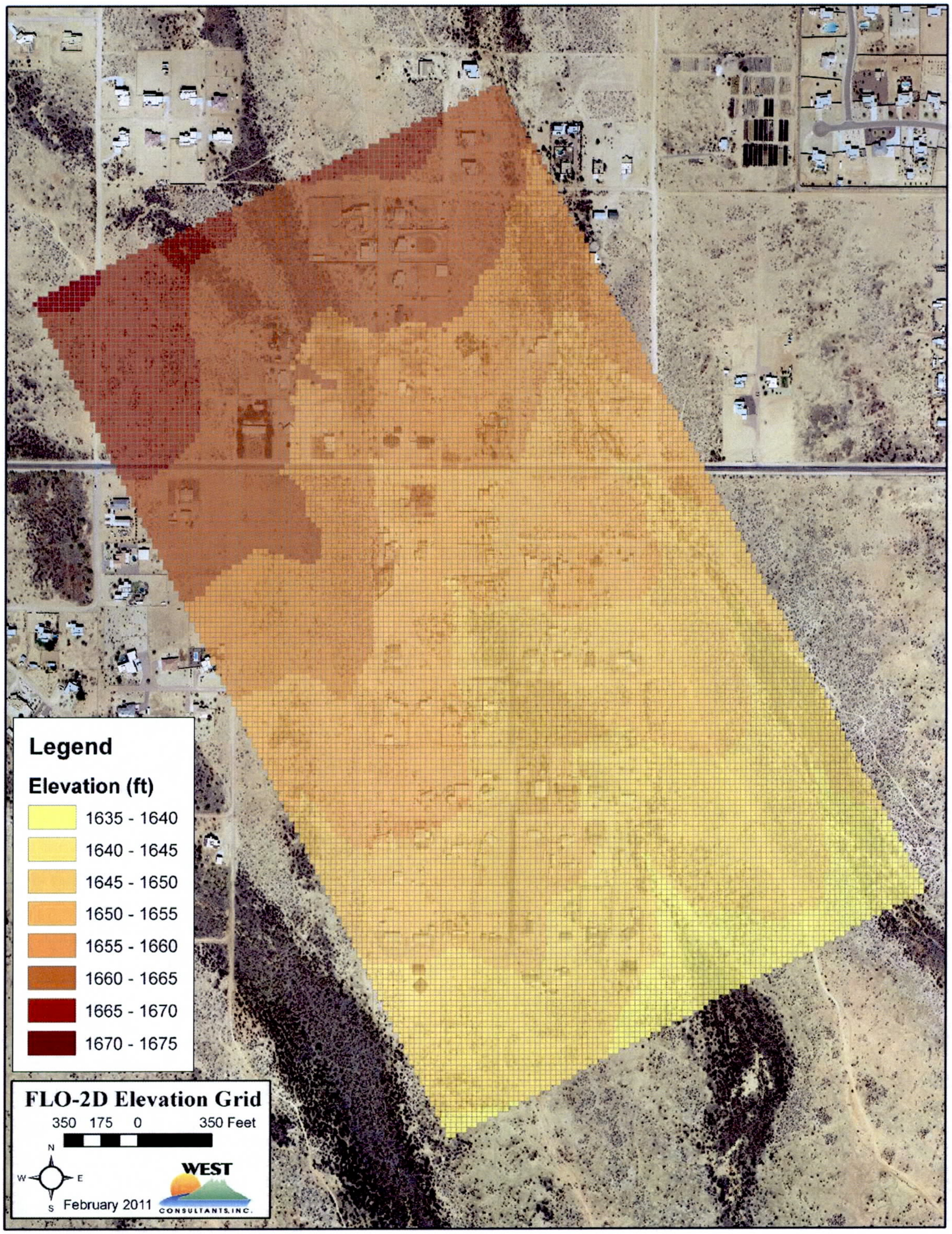


Figure 2-5. 25-foot FLO-2D elevation grid

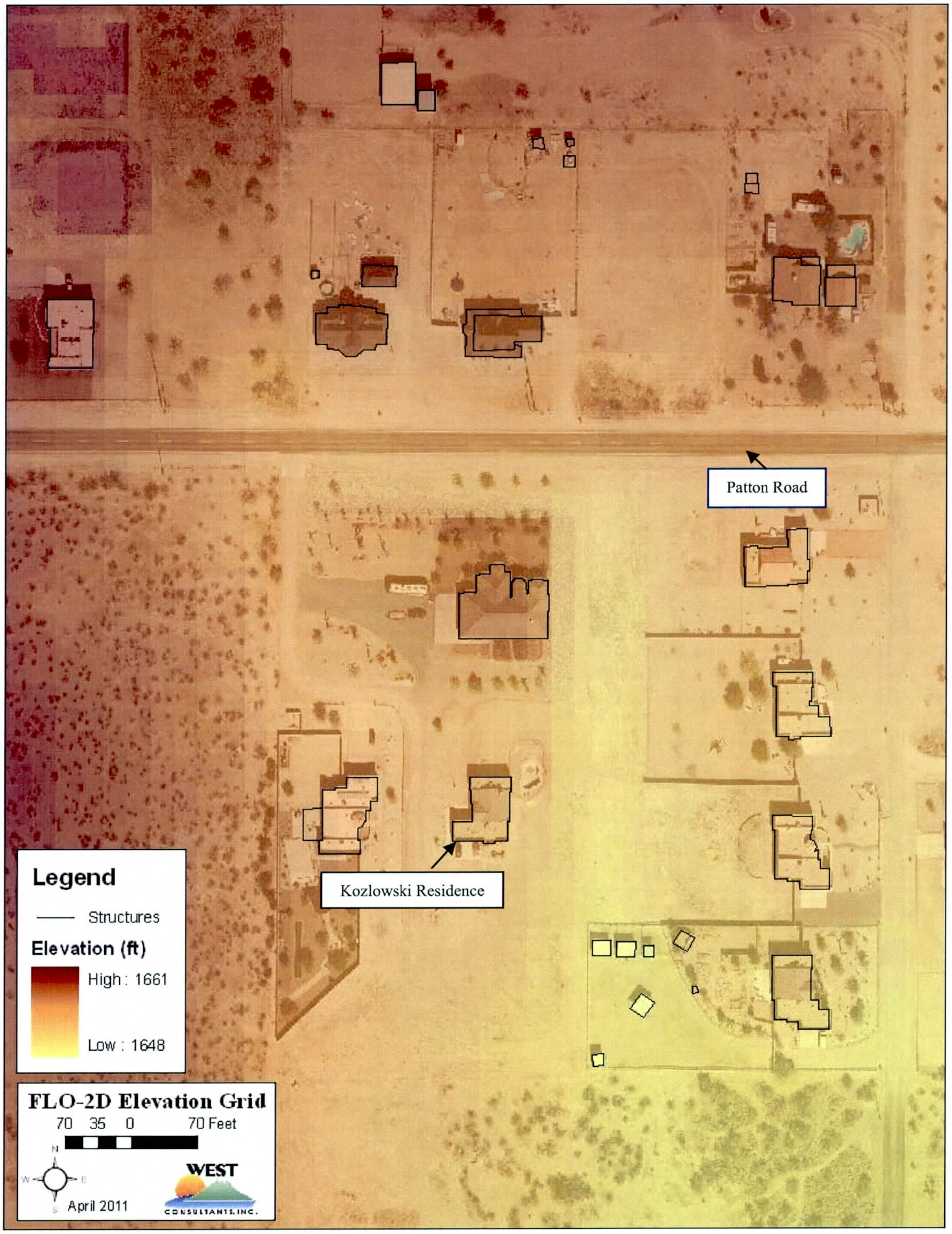


Figure 2-6. 25-foot FLO-2D elevation grid with a close up on the Kozlowski Residence

### 2.2.4. Computational Time Step and Grid Element Size

FLO-2D is an explicit finite difference model that requires careful selection of the computational time step to maintain numerical stability. This selection process is accomplished internally by the program based on the Courant stability criterion which ties the computational time step to the grid element size. In order to prevent the model from running exceedingly slow, it is recommended to select the grid element surface area $A$ such that $Q/A < 1.0$ cfs/ft$^2$ ($Q$ is the peak discharge in the grid element).

For the 25-foot grid model, the inflow of 880 cfs was split up along five grid cell elements with 176 cfs for each one to meet this criterion. For the 10-foot grid model, the inflow was split up along 10 grid cell elements with 88 cfs for each one to meet this criterion.

The DEPTHTOL and WAVEMAX which control the time step were set to zero based on comments from the District.

### 2.2.5. Boundary Conditions

FLO-2D requires that an inflow hydrograph be specified at the upstream end of the computational domain and an outflow condition at its downstream end. The upstream (north) boundary in this study was conveniently selected to be near cross-section 2.769 from the HEC-RAS model, while the downstream (south) boundary is near cross-section 1.803. The upstream hydrograph was a constant hydrograph of 880 cfs, which was taken from DEA (2006). The downstream outflow condition of "normal depth with a friction slope equal to a surface gradient" was used for both the 25-foot and 10-foot grid models.

### 2.2.6. Flow Obstruction

One of the unique features of the FLO-2D model is its ability to simulate flow around obstructions. Area reduction factors (ARF's) and width reduction factors (WRF's) are coefficients used to modify the individual grid element surface area storage and flow width. These factors greatly enhance the detail of the flood simulation through an urbanized area. ARF's were used in this study to reduce the flood volume storage on grid elements due to lots (Figure 2-7). WRF's were assigned to particular flow directions in a grid element to refine the flow around the lots and down the streets.

### 2.2.7. Froude Number

Establishing a limiting Froude number in a flood routing model helps sustain the numerical stability by forcing the model to have a reasonable representation of physical reality. In general, supercritical flow on washes is suppressed by high rates of sediment transport, hence high velocities and shallow depths on washes will dissipate energy with sediment entrainment (supercritical flow is more prevalent on bedrock or other hard surfaces). Therefore, a limiting Froude number of 0.5 to 0.9 is recommended for an analysis on washes. In this study, a limiting Froude number of 0.6 was found to provide stable numerical results.

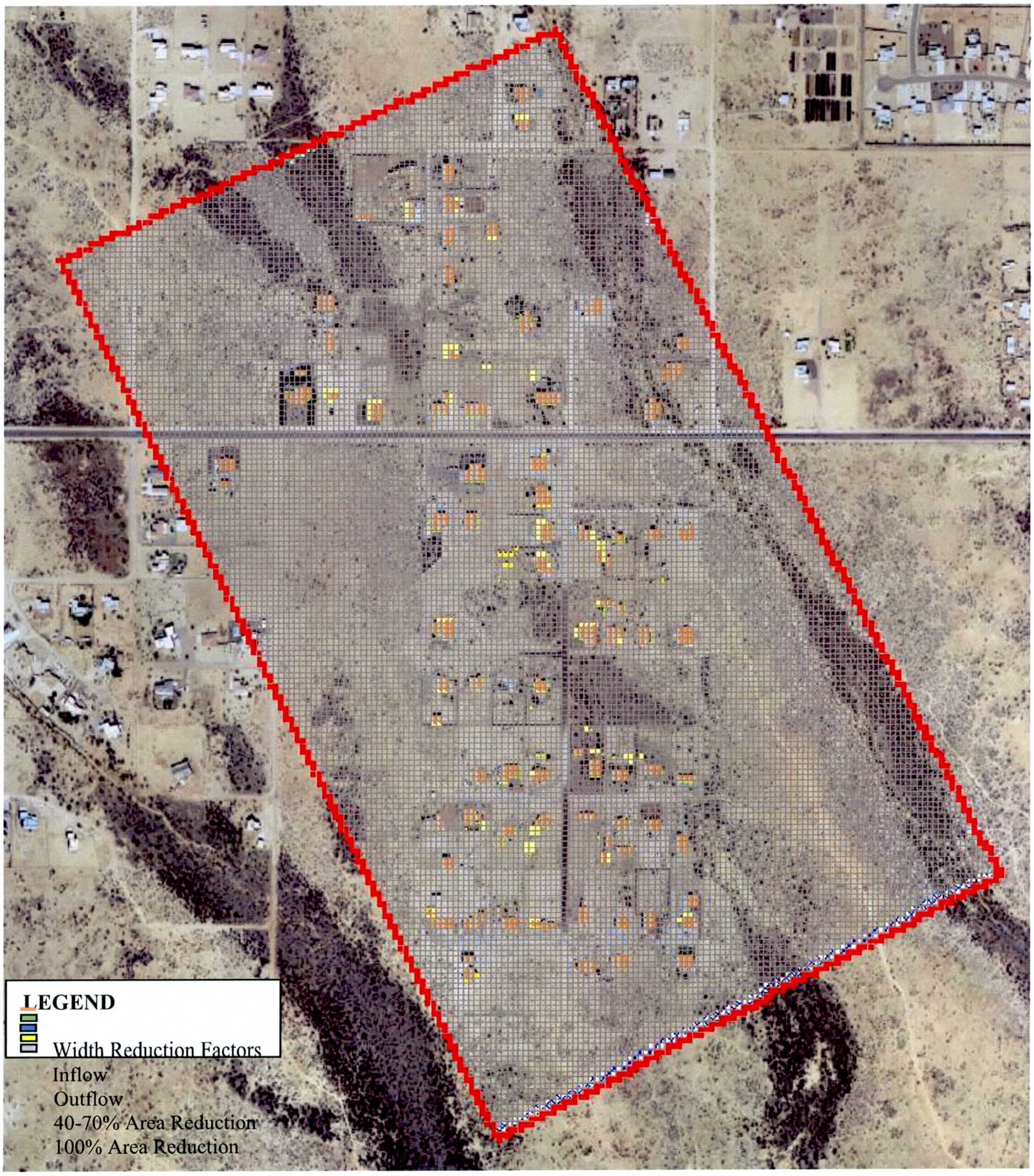


Figure 2-7. 25-foot FLO-2D grid flow obstructions

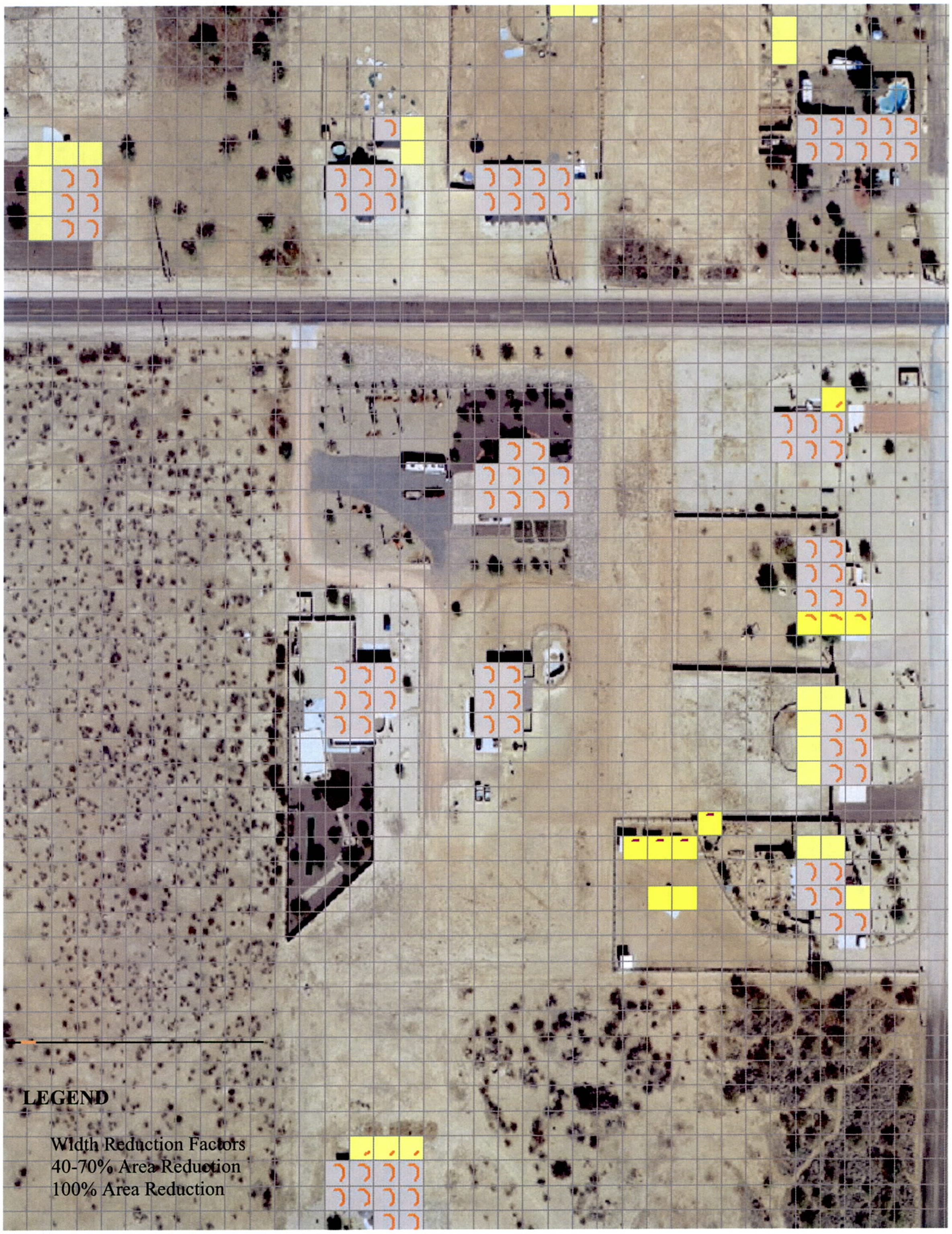


Figure 2-8. 25-foot FLO-2D grid flow obstructions close up

# 3. HYDRAULIC MODEL RESULTS

## 3.1. 25-FOOT GRID 100 YEAR EVENT

The flood scenario described above was simulated for six hours of constant inflow hydrograph (880 cfs), which was sufficient to develop steady-state conditions (i.e., no discernible change in depth and flow velocity thereafter) on the floodplain. The simulation results in terms of floodplain depths and flow velocities are discussed below.

Maximum floodplain depths for the 25-foot model are shown in Figure 3-1 and Figure 3-2. The majority of grid elements have the flow depth less than 1.0 foot (an average depth is 0.68 feet), except in the main channels of the wash (the maximum depth is 3.18 feet). The maximum flow depths within 75 feet of the Kozlowski residence are shown in Table 3-1.

Maximum floodplain velocities are shown in Figure 3-3 and Figure 3-4. The majority of floodplain velocities are less than 0.31 ft/s. The maximum velocities within 75 feet of the Kozlowski residence are shown in Table 3-1.

The flow is mainly directed south-east in the T4N-R3W-S08W wash, splitting into two distinctive flow paths: 1) down Wash T4N-R3W-S08W and 2) down Patton Road to the adjacent Wash T4N-R3W-S08E. Once the flow reaches Patton Road, the flow begins to go toward and eventually flow down Wash T4N-R3W-S08E. The maximum flow and velocity for the split flow is shown in Table 3-1.

Table 3-1. 25-foot grid results

| Location | | MAX Velocity (ft/s) | MAX Depth (ft) |
|---|---|---|---|
| Near Kozlowski Residence | North | 2.58 | 1.4 |
| | East | 2.85 | 2.29 |
| | South | 1.49 | 0.77 |
| | West | 1.61 | 0.82 |
| Wash T4N-R3W-S08E | | 1.3 | 1.08 |
| Model Max | | 4.65 | 3.18 |
| Model Average | | 0.31 | 0.68 |

## 3.2. 10-FOOT GRID 100 YEAR EVENT

The results for the 10-foot grid are similar to those of the 25-foot grid with slightly higher velocities and depth of flow. Maximum floodplain depths for are shown in Figure 3-5 and Figure 3-6. The majority of grid elements have the flow depth less than 1.0 foot (an average depth is 0.72 feet), except in the main channels of the wash (the maximum depth is 3.56 feet). The maximum flow depths within 75 feet of the Kozlowski residence are shown in Table 3-2.

Maximum floodplain velocities are shown in Figure 3-7 and Figure 3-8. The majority of floodplain velocities are less than 0.30 ft/s. The maximum velocities within 75 feet of the Kozlowski residence are shown in Table 3-2.

The flow is mainly directed south-east in the T4N-R3W-S08W wash, splitting into two distinctive flow paths: 1) down Wash T4N-R3W-S08W and 2) down Patton Road to the adjacent Wash T4N-R3W-S08E. Once the flow reaches Patton Road, the flow begins to go toward and eventually flow down Wash T4N-R3W-S08E. The maximum flow and velocity for the split flow is shown in Table 3-2.

Table 3-2. 10-foot grid results

| Location | | MAX Velocity (ft/s) | MAX Depth (ft) |
|---|---|---|---|
| Near Kozlowski Residence | North | 2.44 | 1.28 |
| | East | 3.02 | 2.15 |
| | South | 1.81 | 0.87 |
| | West | 1.95 | 0.94 |
| Wash T4N-R3W-S08E | | 2.25 | 1.61 |
| Model Max | | 5.16 | 3.56 |
| Model Average | | 0.3 | 0.72 |

### 3.3. DISCUSSION OF RESULTS

The FLO-2D results for both the 10 and 25-foot grid model show that the updated topography has a large effect on the flow path near the Kozlowski residence by causing the majority of the flow to pass around the property in the designed channel. The velocities and depths near the Kozlowski residence are lower than the upstream (effective HEC-RAS model XS 2.375) and downstream (effective HEC-RAS model XS 2.77) cross-section in the DEA's HEC-RAS model except on the east side where the channel is located.

The FLO-2D results indicate potential split flows in two locations towards the east while the DEA study (2006) did not. The first potential split is located at Patton Road and the second is near the downstream boundary. In addition, the FLO-2D model shows more flooding upstream than the DEA (2006) study and adds houses to the floodplain. The reason for the split flow and the increased flooding extents are likely a combination of revised topography, increased obstructions due to housing construction, differences in model input parameters (such as Manning's roughness), and differences in model solution techniques.

Based on this result, it appears that it may be possible to modify the floodway in the area using HEC-RAS to remove the Kozlowski residence from the floodway. WEST recommends that the modification of the floodway be done with HEC-RAS instead of FLO-2D.

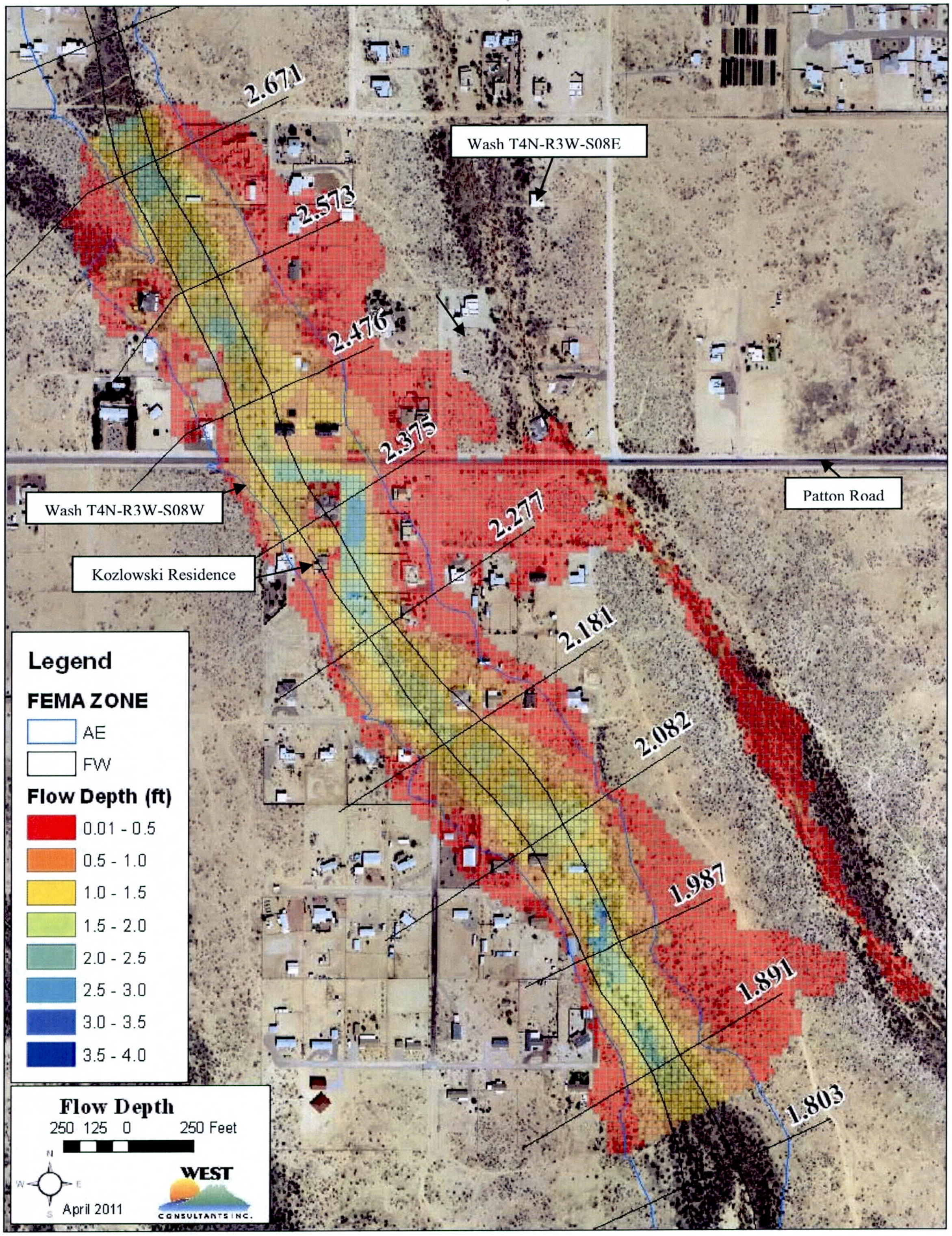


Figure 3-1. 25-foot FLO-2D grid flow depths

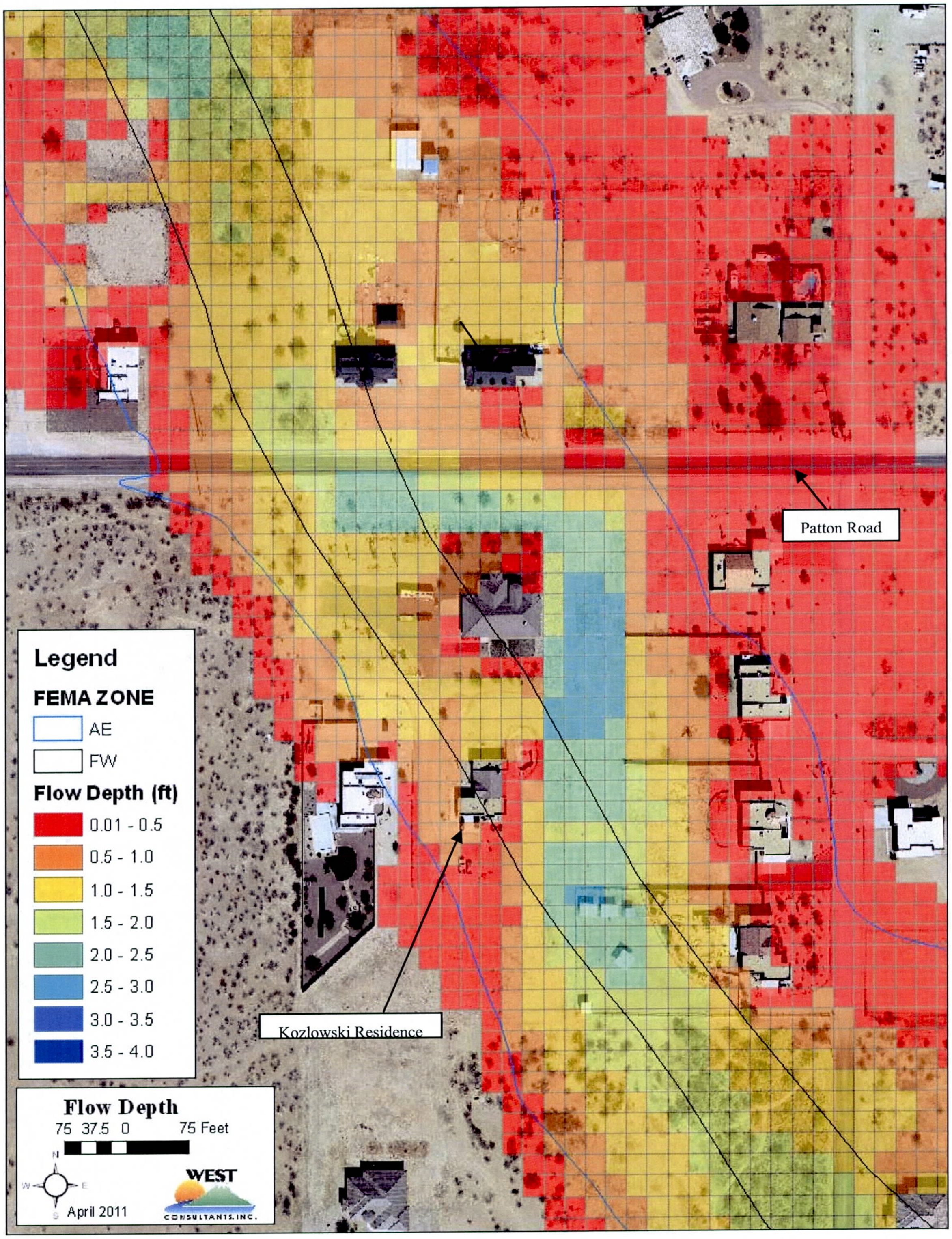


Figure 3-2. 25-foot FLO-2D grid flow depths with a close up

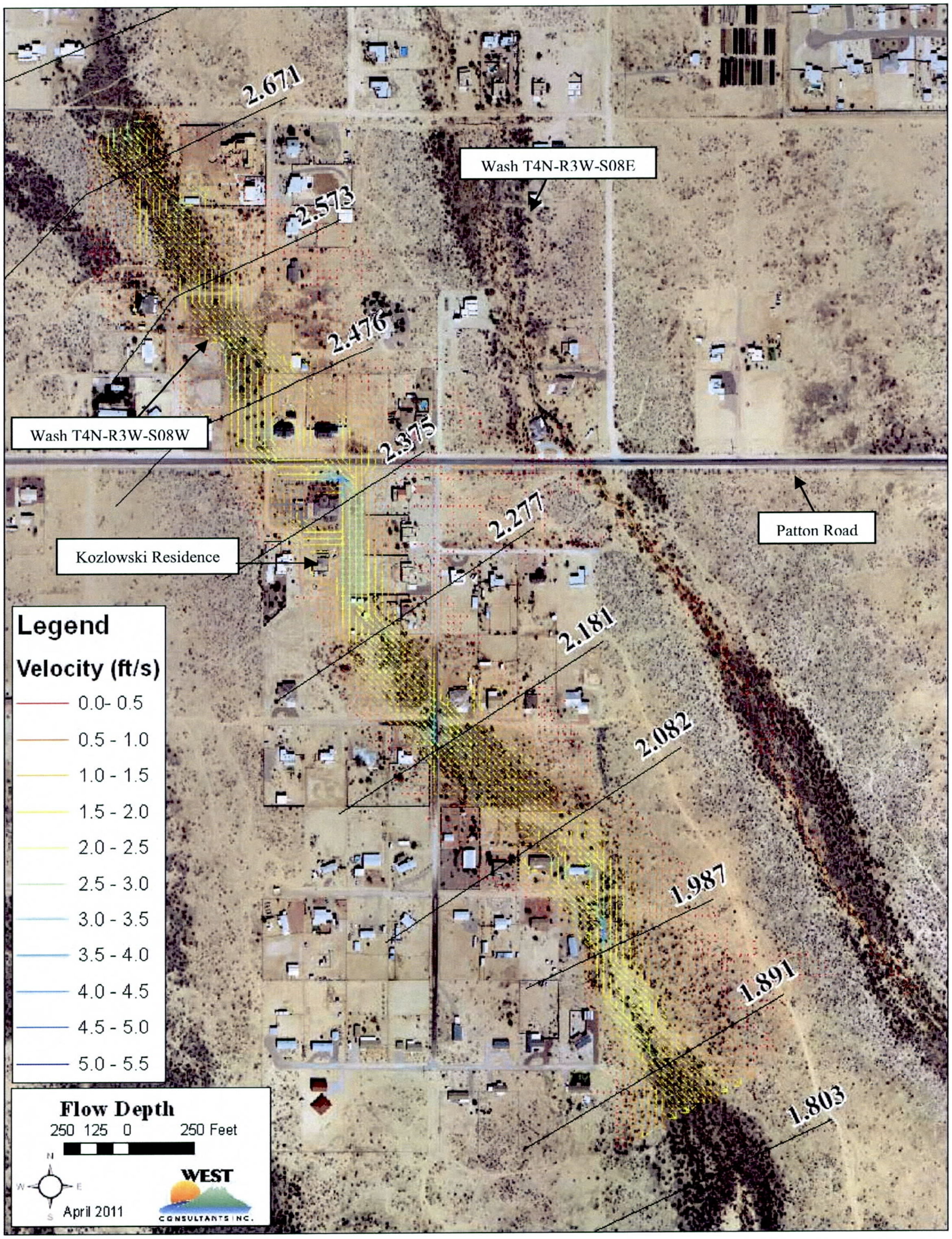


Figure 3-3. 25-foot FLO-2D grid velocity vectors

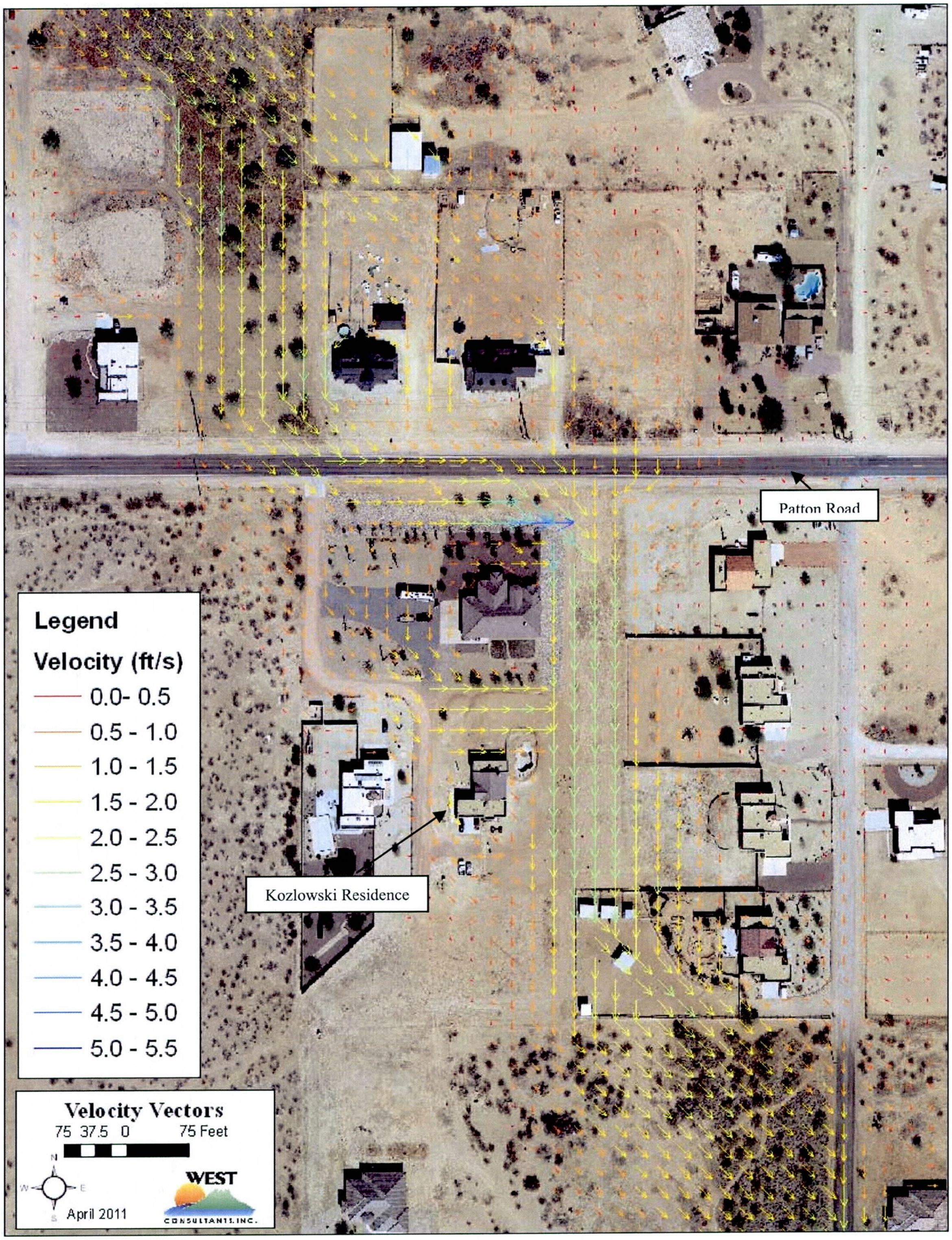


Figure 3-4. 25-foot FLO-2D grid velocity vectors with a close up

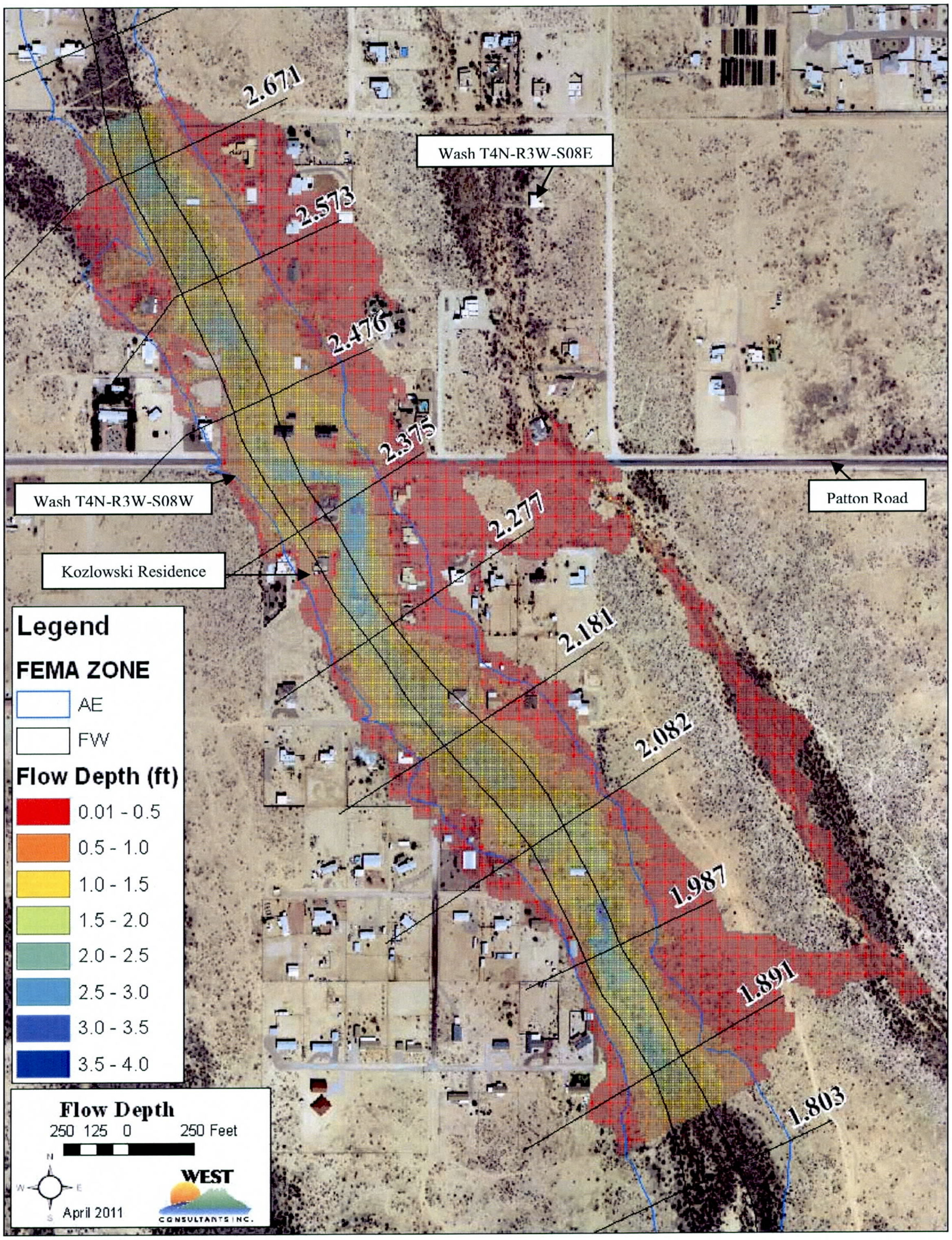


Figure 3-5. 10-foot FLO-2D grid flow depths

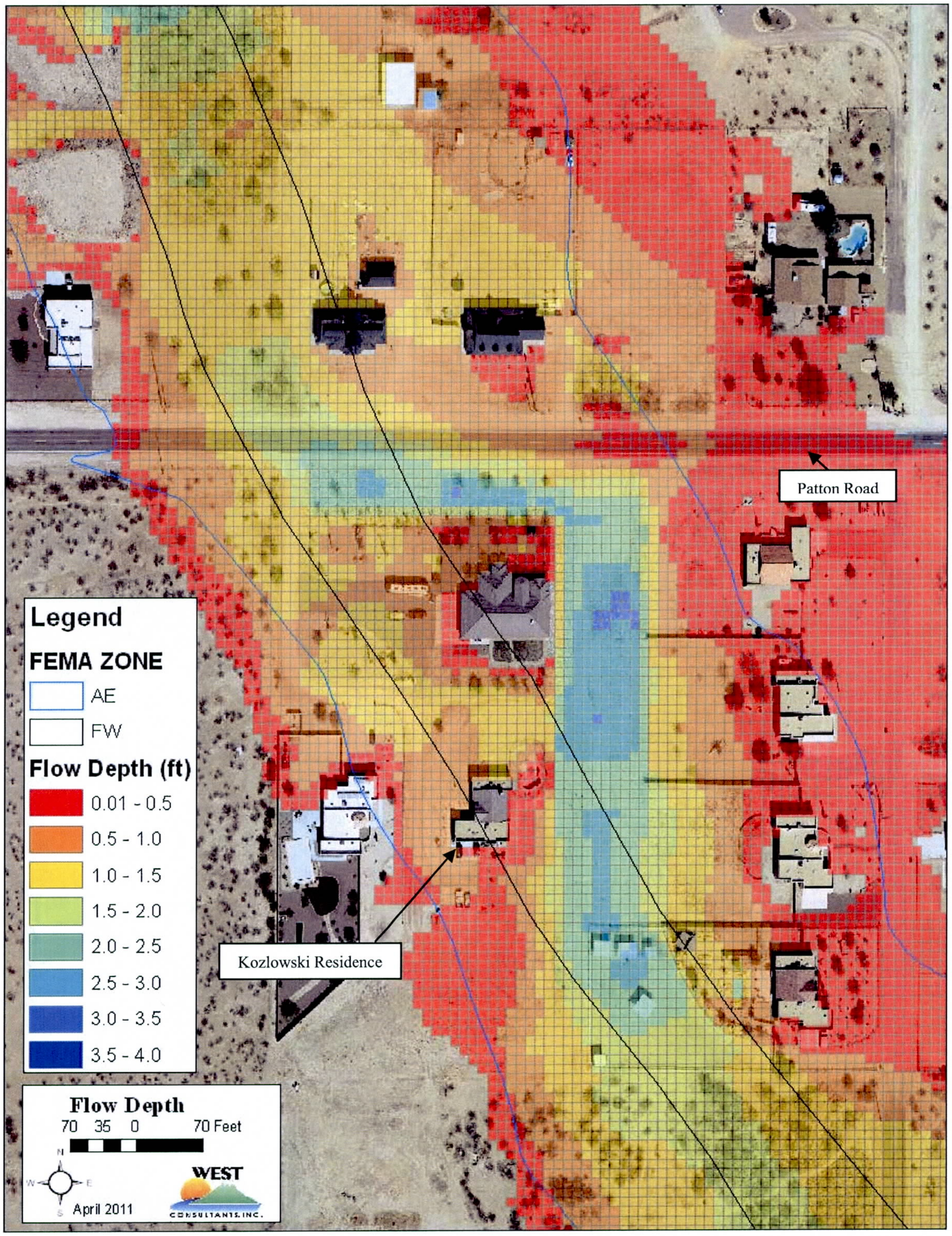


Figure 3-6. 10-foot FLO-2D grid flow depths with a close up

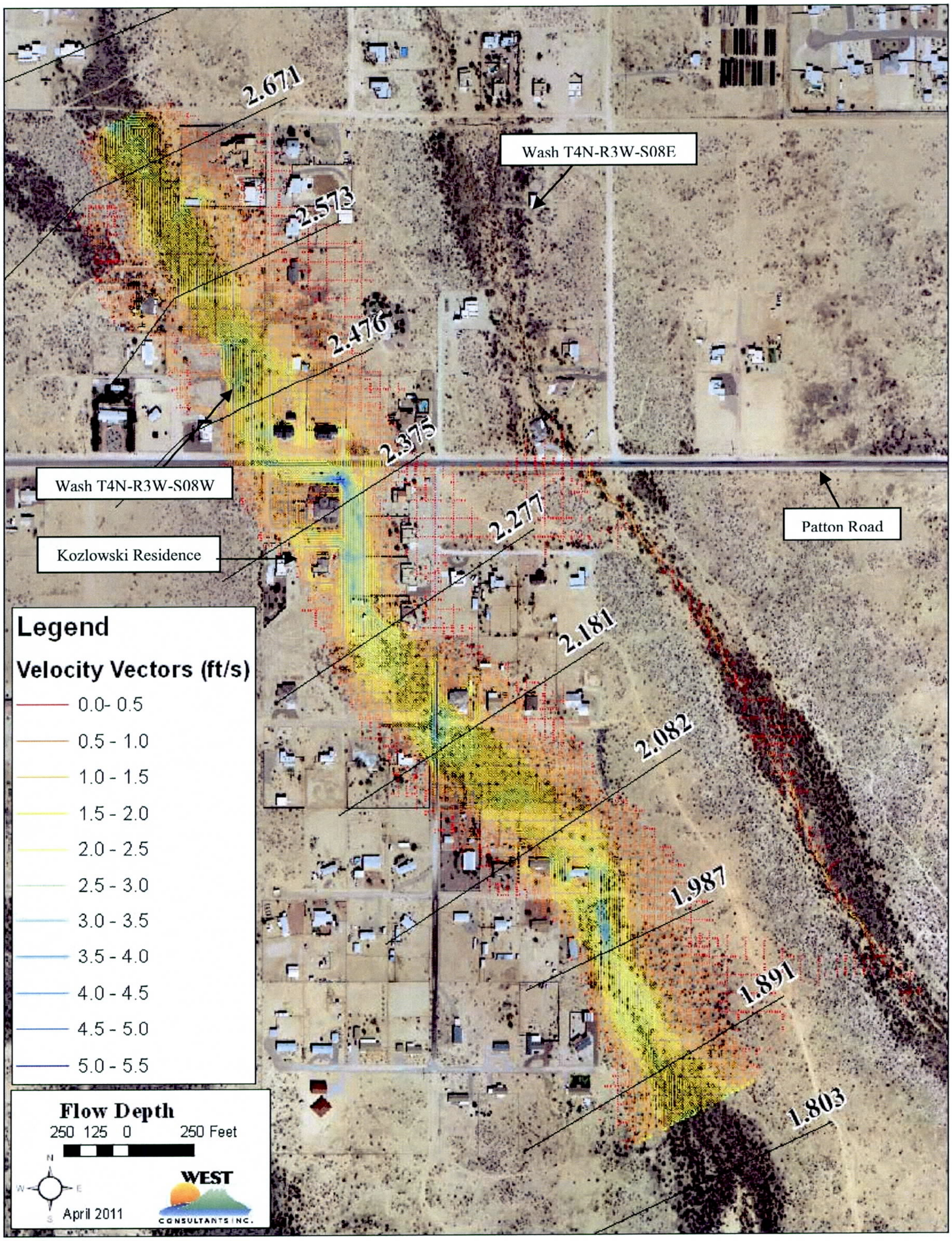


Figure 3-7. 10-foot FLO-2D grid velocity vectors

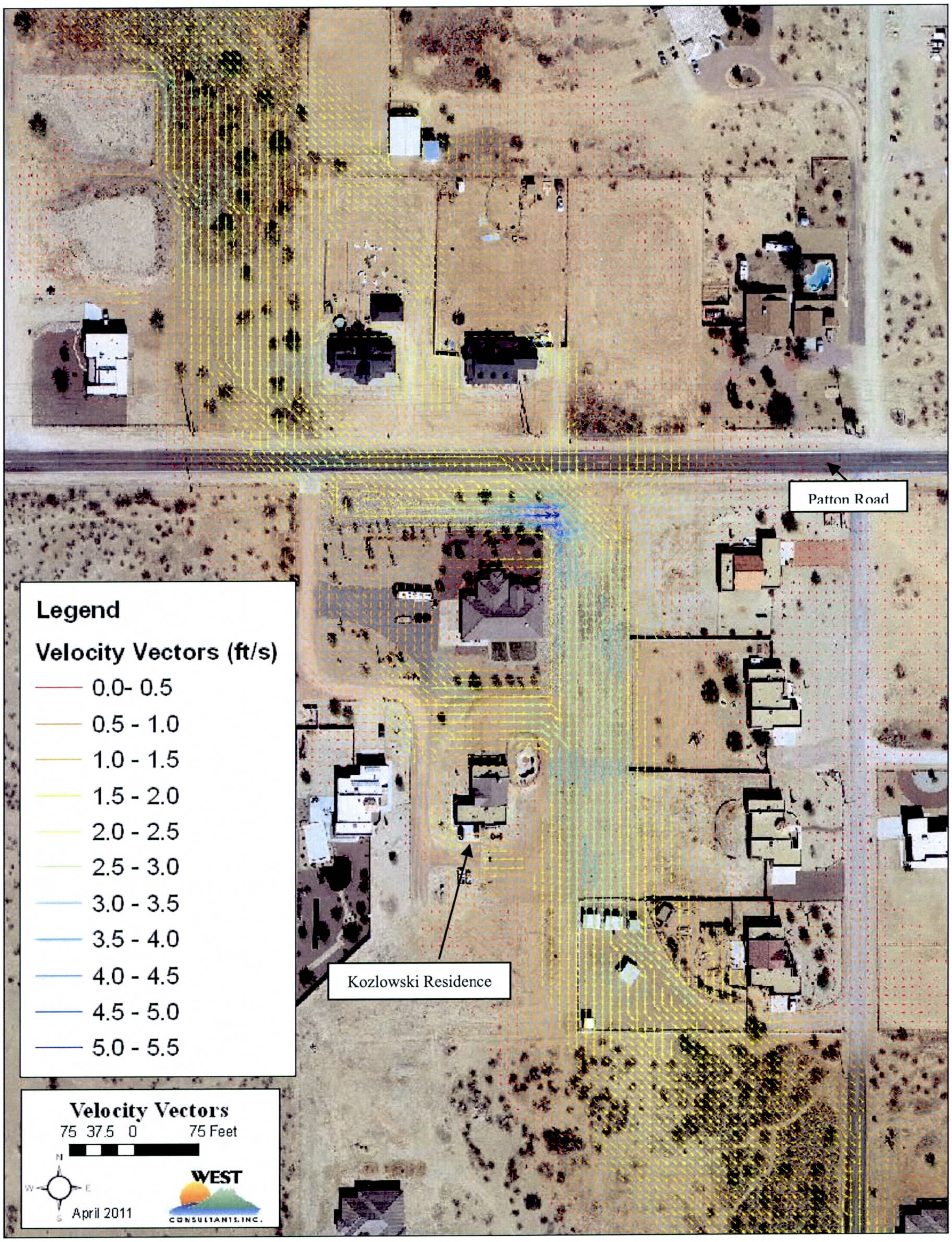


Figure 3-8. 25-foot FLO-2D grid velocity vectors with a close up

# 4. HEC-RAS EVALUATION AND RECOMMENDATIONS

Although not requested in the scope of work, WEST modified the effective FEMA HEC-RAS model (DEA, 2006) in a cursory manner to determine whether modifying the floodway around the Kozlowski residence would be feasible. A brief description of the model revisions and results are provided below. Model results are not provided in this report due to the preliminary nature of the calculations.

## 4.1. REVISIONS

The effective FEMA HEC-RAS model was modified to include the channelization in the vicinity of the Kozlowski residence and the 2010 topography. In general, the 2010 topography was not significantly different than the geometry in the effective FEMA model. Several cross-sections were added to the model and several others were modified to more accurately represent the flow direction trends indicated by the FLO-2D model. Added cross-sections include 2.044 near the downstream end of the 2010 topography, and cross-sections 2.519 and 2.552 near the upstream end of the topography.

The hydraulic effect of houses was modeled using blocked obstructions, which is the method used in the effective FEMA model. WEST added additional blocked obstructions to account for recent home construction in the vicinity of the channel based on aerial photography.

Bank stations were selected in a similar fashion as the effective FEMA model. However, the Manning's *n* values in the channel of approximately 0.043 to 0.047 did not seem appropriate for some reaches of the main channel due to a lack of established vegetation. Therefore, the channel *n* values were reduced to 0.033 in some locations to account for the clear channel conditions. The channel bend upstream of the Kozlowski residence was modeled with increased Manning's *n* values based on a meander factor of 1.3 to represent a severe meander (Chow, 1959).

## 4.2. RESULTS

Our cursory HEC-RAS analysis suggests that a Letter of Map Revision (LOMR) request to modify the floodway in the reach between cross-sections 1.987 and 2.671, including the Kozlowski residence reach, is hydraulically feasible. The water surface elevations are expected to increase slightly in some portions of the modeled reach, but the downstream portion of the model will tie into the FEMA model at cross-section 1.987 and the water surface elevation at the upstream end (cross-section 2.671) will be slightly less than the current base flood elevation. In addition, the floodway can be revised to a reasonable width without exceeding the maximum allowable surcharge of 1 foot and all houses in the modeled reach can be removed from the floodway.

Near the downstream end of the modeled reach, there are two houses in the lowest part of the channel between cross-sections 2.082 and 2.044. Both of these structures are currently within the floodway. There is a possibility that the floodway can be modified to miss one of these structures, but removing both structures from the floodway does not appear to be feasible without aligning the floodway to pass between the houses. The resulting constriction in the floodway width may result in a surcharge greater than 1 foot, but this has not yet been confirmed in the model. If necessary, the downstream limit of the revision could be moved upstream to cross-section 2.181 without impacting the results in the Kozlowski reach.

## 4.3. Recommendations

Based on the above preliminary findings, WEST recommends finalizing the HEC-RAS modeling and proceeding with the LOMR request to remove the Kozlowski property from the floodway. Although the FLO-2D results are likely more accurate and reveal higher water surface elevations than HEC-RAS and potential split flows, further analysis with FLO-2D is not recommended.

# 5. REFERENCES

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